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ІМЕНІ ІВАНА ПУЛЮЯ

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ТЕХНОЛОГІЇ ВИРОБНИЦТВА ЗАГОТОВОК ЛИТТЯМ

Навчальний посібник

для здобувачів вищої освіти
галузі знань 13 «Механічна інженерія»

Тернопіль
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У навчальному посібнику «Технології виробництва заготовок литтям» розглянуто еволюцію ливарного виробництва, сучасні методи одержання литих заготовок, класифікацію способів виробництва заготовок литтям, їх переваги та недоліки.

Подано фундаментальні основи сучасного виробництва литих заготовок, раціональні варіанти їх виготовлення; обладнання, інструменти та технологічне оснащення для різних технологічних режимів і умов. Для перевірки отриманих знань запропоновано тестові завдання з кожного розділу посібника.

Начальний посібник рекомендовано для здобувачів вищої освіти галузі знань 13 «Механічна інженерія», а також для інженерно-технічних працівників ливарної промисловості.

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TECHNOLOGIES OF WORKPIECES MANUFACTURING BY CASTING

Manual

for Higher Education Seekers
in 13 «Mechanical Engineering» Major

Ternopil
2023

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The manual «Technologies of Workpieces Manufacturing by Castings» provides knowledge regarding different foundry processes and their industrial importance. It is considered the modern techniques of processing raw materials by casting as an important stage of solving the tasks of designing technological processes for manufacturing the parts.

The manual includes fundamentals of metal casting, the evolution of the foundry industry, basic casting techniques, the metal casting operations, methods of manufacturing the cast blanks; the most rational variants of their manufacturing; equipment, tools and machining attachments for making workpieces of machine elements and parts in different process specifications and conditions. Also focused on efficient design of casting runner, riser and gating system with minimal casting defects and solidification process. Multiple choice questions from each section of the manual are offered to test the acquired knowledge.

Recommended for higher education seekers in 13 «Mechanical Engineering» majors, and can also be useful for engineering and technical specialists of foundry technologies in the mechanical engineering industry.

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INTRODUCTION

Metal casting has been serving the manufacturing industry for years. It is used for manufacturing a range of products from simple to exceptionally intricate. The challenges associated with the process have led to many advancements in metal casting technologies over time. During this period, different cast materials and casting processes have evolved making it possible to design and manufacture almost any product with high quality. It is important to analyze the progress of metal casting in the past, trends in the field at present, and envisage the future of these technologies for continuous improvement.

Casting technology encompasses many branches of science and engineering including physics, metallurgy, mechanical engineering, chemical engineering, and computational modeling. Chemical reactions involved in the melting of metals and treating of liquid metals, formation of crystal structures, thermodynamic principles as applied to the determination of phase diagrams, design of gating and risering systems, and principles behind grain refinement and heat treatment all deal with some branch of science and engineering. Although there is still a lot of craft involved in the casting process, a good understanding of casting technology for the foundry engineer and technologist, mold maker, and pattern maker, would be useful to produce premium quality castings by minimizing casting defects. Application of solidification modeling in the design of gating and risering systems would eliminate the guesswork and contribute to the production of sound castings.

The engineer who designs a casting must have accurate information about the properties of the cast metals to be used. The manual may not be useful in the design of components that would lead to low mechanical properties. To provide a foundation for foundry work, coursework in the principles of metal casting finds a place in the educational preparation of student engineers. In addition, training offered by casting institutes or societies must incorporate developments in all aspects of metal casting such as alloy development, melting, melt treatment, sand, mold design, and gating and risering design.

This manual is addressed by explaining various types of casting defects along with their possible causes and remedies. The underlying idea behind this study is to let the readers ingrain the fundamental knowledge of metal casting technologies in all the above-mentioned areas so that the integrity and quality of castings can be enhanced.

1. EVOLUTION OF THE METAL CASTING INDUSTRY

Metal casting is one of the primitive manufacturing processes which was developed based on fire-using technologies (or pyrotechnologies). Initially, pyrotechnologies have been used to improve the workability of stone, make plaster by burning lime and produce ceramics by firing the clay.

Metalworking, however, started 10,000 years ago when the earliest metal objects are found to be wrought rather than cast [5, 36]. Evidence of such metal objects is found in the form of decorative pendants and beads which were formed by hammering native copper. Table 1 summarizes the advancements in metalworking over these 10,000 years.

Today, metal casting is a complex and intricate process that requires exact chemistry and flawless execution. While current methods may be relatively new when compared to the history of human civilization, the first casting of metals can actually be traced all the way back to around 4000 B.C. In those times, gold was the first metal to be cast because of its malleability, and back then, metal from tools and decoration was reused because of the complications of obtaining pure ore.

Metal casting, on the other hand, dates back to 5000 and 3000 B.C., which refers to the Chalcolithic period during which metals were melted for castings together with the experimentation of smelting copper. Initial molds were made from smooth textured stones as shown in Fig. 1, resulting in fine cast products which could be witnessed in the museums and archeological exhibitions. Both single and multifaceted (carved on both sides of a rectangular piece of stone) molds were developed from stones to produce castings that are not necessarily flat. However, multifaceted molds were more popular for being portable and economical in terms of utilizing a suitable piece of stone [5].

Some historians believe that iron casting began in ancient China as early as 6000 B.C. while others believe that only copper and bronze castings were being made at this time. However, evidence provided by archeologists contradicts both beliefs. Discovered by archeologists in what was then known as Mesopotamia, the earliest uncovered example of a cast component is a copper frog that dates to 3200 B.C. Although iron and other metals had been discovered, it was not until centuries later that they could be melted and poured into a mold, such as a casting.

Archeologists believe that iron was discovered by the Hittites of ancient Egypt somewhere between 5000 and 3000 B.C. During this time, they hammered or pounded the metal to create tools and weapons. They found and extracted it from meteorites and used the ore to make spearheads, tools, and other trinkets. Between 2000 B.C. and 1200 B.C., the Hittites developed a process for smelting the iron – heating its ore to purify it – expanding its usability. For centuries, the production of iron remained a closely-held secret of the Hittite people until roughly 1000 B.C. when Chinese metallurgists discovered the superiority and workability of iron.

Followed the by Chalcolithic period, the Bronze Age started in Near East around 3000 B.C. during which alloying elements were added to copper. The first bronze alloy reported was a mix of copper (Cu) with 4–12 percent of arsenic (As), thus forming a silvery appearance of the cast surface as a result of inverse segregation of the arsenic-rich low-melting phase to the surface. Next, 5–10% of tin (Sn) was added to copper which was advantageous to lower the melting point, improving strength, deoxidizing the melt, and producing a fine and easily polished cast surface capable of reproducing the features of the mold with exceptional fidelity, often desirable for art castings.

The Bronze Age lasted for 1500 years during which mankind had its first exposure to elemental ores such as tin, copper and silver. Also, lost wax castings of small parts of bronze and silver, are reported during this age between 3000 and 2500 B.C. in the Near East region.

The earliest known casting in existence is a copper frog as shown in Fig. 2, probably cast in 3200 B.C. in the Mesopotamia region [6]. The intricate design and three-dimensional characteristics suggest that it was created using a sand casting process instead of using a permanent stone mold [36]. The beginning of the Bronze Age in the Far East was about 2000 B.C., a millennium after its emergence in the Near East region.

Some of the earliest examples of iron casting in ancient China are the four statues that stand outside of the Zhongyue Temple in Dengfeng. These statues were cast in approximately 1024 B.C. Before this, Chinese metallurgists worked with bronze and copper to create cast components, which were largely used in the country’s agricultural industry. It was revolutionized when the iron plow was invented. It made turning over the soil much easier for farmers.

One of the biggest impacts that China had on the evolution of iron casting occurred in 645 B.C. when Chinese metallurgists began using sand molding. In this process, sand is tightly packed around an object, creating a mold. Then molten metal is poured into the mold to create a metal casting. The advantage of this process is the large variety of shapes and sizes that can be easily molded.

Table 1 – Development in use of materials and metal casting [5, 37]

Date	Development	Location
1	2	3
9000 B.C.	Earliest metal objects of wrought native copper	Near East
6500 B.C.	Earliest life-size statues, of plaster	Jordan
5000–3000 B.C.	Chalcolithic period: melting of copper; experimentation with smelting	Near East
3200 B.C.	A copper frog, the oldest known casting in existence, is made in Mesopotamia. Copper was a popular material for metalworking due to its high ductility (stretch)	Near East
3000–1500 B.C.	Bronze age: arsenical copper and tin bronze alloys. Bronze alloys are used in casting, offering key benefits such as low weight and a low melting point. Bronze tools and weapons are cast in permanent stone molds	Near East
3000–2500 B.C	Early use of investment (lost wax) casting for ornaments and jewelry. The lost wax casting of small objects	Near East
2000 B.C.	Bronze age	Far East
600 B.C.	Cast iron	China
233 B.C.	Iron ploughshares are cast	
500 A.D.	Cast crucible steel is produced	India
1200–1450 A.D.	Introduction of cast iron	Europe
1313	Development of the first bronze cannon in Ghent	China
1500s	Sand introduced as the mold material	France
1709 A.D.	Cast iron produced with coke as fuel, Coalbrookdale	England
1735 A.D.	The great bell of the Kremlin cast	Russia
1740 A.D.	Cast steel developed by Benjamin Huntsman	England
1779 A.D.	Cast iron used as an architectural material, Ironbridge Gorge	England
1809 A.D.	Development of centrifugal casting	England
1818 A.D.	Production of cast steel by crucible process	U.S.
1837 A.D.	Development of first molding machine	U.S.

Continue Table 1

1	2	3
1849	Development of a die casting machine	-
1863	Metallography of casting surfaces	England
1870	Development of sandblasting for large castings	U.S.
1876	Aluminum started to use as cast material	U.S.
1887	Development of oven for core drying	-
1898	Mold development with bonded sand	England
1899	Electric Arc Furnace for commercial production of castings	France
1900	Low pressure permanent mold casting	England
1907	Heat treatment and artificial aging to improve cast aluminum alloys	Germany
1910	Match plates and Jolt Squeezing machines	-
1925	X-ray radiography for casting quality control	U.S.
1940	Chvorinov's Rule	-
1944	First heat-reactive, chemically-cured binder	Germany
1948	Ductile Iron castings in industrial applications	U.S.
1950s	High pressure molding	-
Mid 1950s	Squeeze casting process	Russia
1960	Development of Furan as a core binder	-
1968	Cold box process for mass production of cores	-
1971	Vacuum forming or the V-process method	Japan
1974	In-mold process for ductile iron treatment by Fiat	U.S.
1948	Ductile Iron castings in industrial applications	U.S.
1980s	Development and commercialization of a solidification software	-
1988	Rapid prototyping and CAD/CAM technologies	-
1993	Plasma ladle refining (melting and refining in one vessel)	U.S.
Mid 1990s	Microstructure simulations	-
1996	Cast Metal Matrix Composites in automobile applications	England
End 1990s	Stress and distortion simulation of castings	-
2001	Software development by NASA and Department of Energy/OIT	U.S.
2016	Casting simulations coupled to mechanical performance simulations	-

The disadvantages are the unavoidability of defects and the fact that this process is quite labor-intensive. This is the earliest known use of this process and represents China's significant contribution to the history of iron casting. Casting was the main forming process in China with little evidence of other metalworking operations before 500 B.C. The complexity of antique cast bronze ritual vessels suggested that they must have been produced using the lost wax casting method.

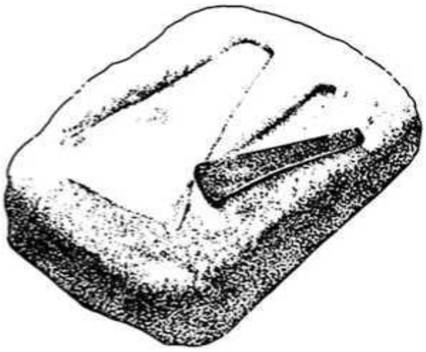


Figure1 – Mold prepared by smooth textured stone with an axe [5]

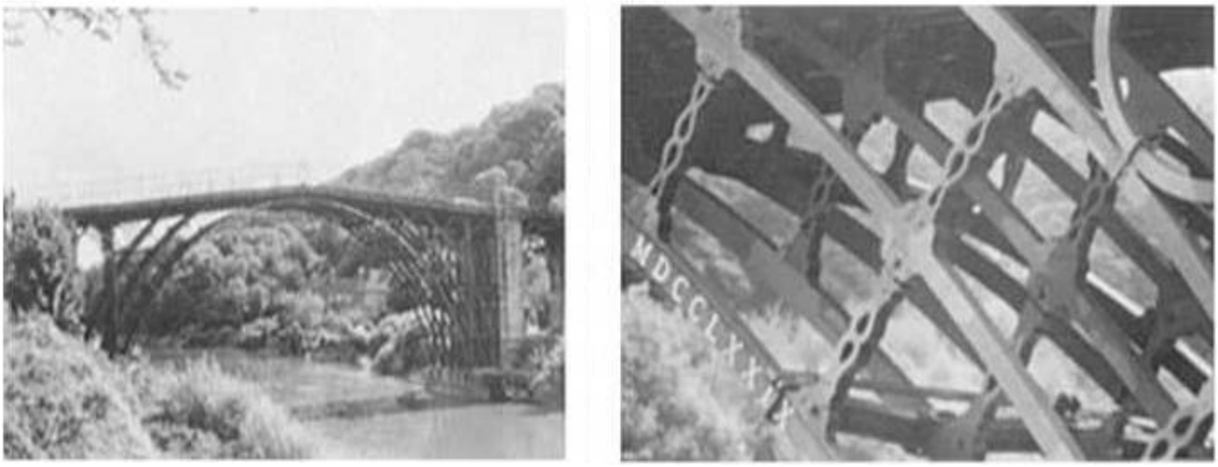
Figure 2 – The earliest known casting in existence «A Copper Frog», cast in 3200 B.C. [66]

In Europe, cast iron was introduced as a casting alloy between 1200 and 1450 A.D. The earliest evidence of cast products in Europe is a cast iron pipe used to transport water at the Dillenberg Castle in Germany. It was cast in 1455. Soon after this, in Burgundy, France, and England, cast iron was also used to make cannons during the Reformation of the 16th century.

In 1619, the first ironworks were established in North America by the Virginia Company of London. It was named Falling Creek Ironworks and was located near the James River. The colonists chose this location not only because of nearby ore deposits but also because it provided easy access to water for power and shipping-related needs. The surviving written records indicate that this facility was able to produce some iron. But historians believe that full production was never achieved.

In 1642, Saugus Iron Works, America's first iron foundry, was established near Lynn, Massachusetts. This was also the location where the first American iron casting, the Saugus pot, was made. Saugus Iron Works is now a national historic site, because of its landmark contribution to the manufacturing industry and the American industrial revolution.

Between the 15th and 18th centuries, some other important developments in the casting industry include where ut not limited to the introduction of sand as mold material in the 16th century, the production of cast iron with coke as fuel at Coalbrookdale (1709), the casting of the Great Bell of the Kremlin (1735), and the development of cast steel by Benjamin Huntsman (1740). The cast iron produced at Coalbrookdale was first used as an important structural material in building the famous iron bridge as shown in Fig. 3 and other architectural applications during that period.



a) b)

Figure 3 – The Iron Bridge (a) across the Severn River at Ironbridge Gorge (b) detail of the Iron Bridge showing the date, 1779 [1]

Iron’s great impact on Britain can be attributed to a flurry of innovations that were introduced during the 1700s. The first of these occurred in 1709 when Abraham Darby became the first man to smelt iron with coke instead of charcoal in a coke-fired furnace. Coke is a solid fuel that is created by heating coal in the absence of air and is a key element in the history of iron casting. Coke was much cheaper and more efficient than charcoal. With the introduction of coke, it became possible and lucrative to use larger furnaces, which enabled large-scale production. Charcoal was too weak to support a heavy charge of iron in large quantities, but coke was much stronger. Although the challenge of brittle iron had not yet been solved, Darby’s innovation had a big impact on the industry and inspired many other advancements.

The next innovation in iron casting history was the steam engine. It was invented in 1712 by an Englishman named Thomas Newcomen. At this time, the steam engine was primarily used to pump water out of coal mines. Coal was a key part of the iron casting process, so this invention was integral to the industry and the industrialization of England.

Between 1700 and 1750, Britain relied heavily on cast iron imports from Sweden, because it could not expand its capacity fast enough to meet the growing demand for cast iron. This was prior to Britain's industrial revolution. At that time, the iron manufacturing industry consisted of small, localized production facilities that had to be located close to the resources they needed, such as water, limestone and charcoal. That's because there were limited resources for transporting raw materials and finished goods.

At this time, furnaces were small, which meant that their production capacity was very limited. Although Britain had abundant iron ore reserves, the iron that could be produced from it was brittle pig iron of low quality with many impurities, which were caused by charcoal-fueled blast furnaces.

As a result, cast iron's usability was very limited. Most of the demand was for wrought iron, which was pig iron after its impurities were hammered out. But this took a long time to do, and imported wrought iron was less expensive. As a result, British iron at this time was only used for cheap items such as nails. However, iron would soon become the cornerstone of industrialization for the British economy, and by 1800, its leading export.

Between 1770 and 1790, Scottish inventor James Watt improved on Thomas Newcomen's work, making the steam engine capable of powering machinery, locomotives and ships. This further advanced the industry's speed and ability to transport raw materials and finished goods.

James Watt's breakthrough happened when he realized that the design of the steam engine wasted a great deal of energy because it repeatedly cooled and re-heated the cylinder. Watt introduced a design enhancement, the separate condenser, which avoided this waste of energy and radically improved the power, efficiency and cost-effectiveness of steam engines.

Eventually, Watt adapted his engine to revolutionize transportation, which had been a major limiting factor for growth within the iron manufacturing industry. Material transportation was finally made efficient and more economical than ever.

In 1783, Henry Cort developed two methods for extracting impurities from iron, turning it from pig iron to wrought iron, and allowing large-scale production of non-brittle iron. Pig iron is a term used to describe the crude and brittle iron that comes directly from the blast furnace. In 1783, Cort patented grooved rollers that allowed iron bars to be made more quickly with a more economical process he called the rolling technique. Previously used methods consisted of hammering or cutting strips from a rolled plate. In 1784, Cort patented the puddling process, which consisted of stirring molten pig iron on the bed of a furnace in which fire and hot gases swirling above the metal provide heat. This prevented the metal from coming in contact with the fuel.

As the iron was decarbonized by air, it became thicker and balls of «puddled» iron could be removed from the more liquid impurities that remained in the furnace. The puddled iron, like the wrought iron, was tougher and more malleable than the pig iron and could be hammered and finished with the grooved rollers that Cort had invented. The rollers helped to squeeze out impurities. Additionally, by forming the iron into bars, the metal became easier to use for the creation of finished goods. Cort's contributions to the industry allowed large-scale production of cast iron products because it no longer took so much time and manpower to rid the pig iron of its impurities.

Between 1793 and 1815, due to increased demand from the military, British iron production quadrupled. The sizes of blast furnaces increased, and Britain finally had production capabilities that could meet demand.

Cast materials and casting technologies progressed substantially from the 19th century onwards. A new method of centrifugal casting was developed in 1809 in England. However, in 1815, the War of 1812 ended, ushering in a period of peace. With the war's end came the decline of both the price and demand for iron. However, Britain had become the largest producer of ironworks in all of Europe. In addition, its economy and way of life were reshaped and revolutionized by innovations in iron casting.

In 1818 first U.S. cast steel was produced by the crucible process at Valley Forge Foundry. The extraction of aluminum from aluminum chloride is also reported during the same century. The first molding machine was developed by S. J. Adams Co. in Pittsburgh and was available by 1837.

The urge to further develop the casting process led to the development of a die casting machine to supply rapidly cast lead type for newspapers in 1849. Examination of castings was started by the development of metallography in 1863 which enabled foundry men to polish, etch and physically analyze the castings through optical microscopy. Next, sand blasting was developed for large castings in 1870. By 1876 aluminum was started to use as cast material and its first architectural application was reported in 1884 when a cast aluminum pyramid was mounted on the tip of Washington Monument. Some other developments during the 19th century are the oven for core drying (1887), non-art application of lost wax casting method to produce dental inlays (1897), mold with bonded sand for salt-water piping system (1898), and electric arc furnace for commercial production of castings (1899).

In the early 1900s, the first patent for low pressure permanent mold casting was issued in England. American Foundry Association (AFS) produced rail wheels by centrifugal casting process for the first time. The advancement in the field continued with a die casting machine patented by H.H. Doehler patents in 1905. Heat treatment and artificial aging were proposed in 1907 to improve the properties of cast aluminum alloys. In 1910, jolt squeezing machining became possible through the development of match plates. Another important development in 1915 was the experimentation on bentonite clay due to its exceptional high green and dry strength. In addition to that furnaces for non-ferrous melting were also developed during the 1910s.

The quality of casting was first examined through X-ray radiography in 1925 after which all military aircraft castings had to pass X-ray inspection for acceptance by 1940. The development of mathematical relationships between casting geometry and solidification time was established by Chvorinov in 1940. Also, statistical process control was started to use for casting quality control and assurance in 1940s in the United States. The research on binders resulted in the first heat-reactive, chemically-cured binder in Germany in 1944 for the rapid production of mortar and artillery shells during World War II. By 1948, ductile iron was not just limited to laboratory castings and started to use as a cast material in industrial applications.

To increase mold hardness (density), high pressure molding was experimented in the 1950s. A hotbox system to prepare and cure the cores simultaneously was introduced in 1953 thereby eliminating the need for dielectric drying ovens. In the mid 1950s, the squeeze casting process originated in Russia. In addition to that a full mold process was developed in 1958, known as lost foam casting, where the pattern and gating systems were carved from expanded polystyrene (EPS) and placed into a green sand mold.

During the 1960s, Furan was developed as a binder to be used in core production. Also, shell flake resin was introduced in 1963 and it eliminated the need for different solvents. In 1968, a new method called the “cold box process” was developed for the mass production of cores in foundries. The late 20th century i.e. 1970–1999 brought more advancements to metal casting such as the development of vacuum forming or the V-process method in 1971 to produce molds using unbonded sand by using vacuum. In 1974, Fiat developed an in-mold process for ductile iron treatment.

During the 1980s, it was started to investigate the casting processes computationally an example of which is the development and commercialization of solidification software. In the late 1980s, casting solidification software gained acceptance in foundries resulting in the optimization of quality and cost of the casting process in virtual reality. An important development during this period was 3D visualization techniques followed by rapid prototyping and CAD/CAM technologies in 1988 which significantly reduced the time of tool development.

Plasma ladle refining (melting and refining in one vessel) was introduced for the first time in 1993 at Maynard Steel Casting Company in Milwaukee, WI. In order to cast large components through lost foam castings, low-expansion synthetic mullite sand is patented by Brunswick Corp. in 1994. Microstructure simulations in the mid 1990s enabled designers to analyze the effects of metallurgy and predict and control the mechanical properties of cast components.

Cast metal matrix composites (MMCs) were used in automobile applications such as brake rotors for the first time in 1996. In the same year, General Motors Corp. developed a non-toxic and recyclable, water-soluble biopolymer-based core sand binder. Casting simulation developed further towards the end of the 1990s by stress and distortion simulation. As a result, the generation and distribution of residual stresses in the cast component could be well understood which allowed to control casting distortion, reduce residual stresses, minimize defects such as hot tears and cracking, minimize mold distortion and improve mold life.

In 2001, a physics-based software was developed by NASA and the Department of Energy/OIT capable of predicting the filling of EPS patterns and sand cores when process variables are changed.

In 2016, a new approach was developed which emphasized developing an accept/reject criteria for castings by integrating simulation with mechanical performance simulations. Integrated simulations are currently being researched with an aim to improve integrity and quality, which eventually result in the reliable operation of cast parts in service.

Today, nearly every mechanical device we use, from automobiles to washing machines are manufactured using metal parts that were created using the casting process. The difference between today’s cast metal products and those that were manufactured even 100 years ago is the precision and tolerances that can be achieved through the computerized automated design process, and modern methods for producing detailed cores and molds. Modern-day metal casting represents innovation at work.

Throughout the centuries, various combinations of raw materials have been developed to produce various metal types. Some cast products are used in engines that require a high tolerance for heat and cold. Cast iron pipes must resist corrosion and high pressures. Other cast parts must be lightweight but durable. In many applications, parts are designed to allow for precise tolerance between expansion and contraction.

Multiple Choice Questions

1.1. In which country, according to historians, did cast iron begins in 6000 B.C.?

1) ancient Rome;
2) ancient China;
3) ancient Greece;
4) Kyivan Rus;
5) Middle East.

1.2. What chemical element was discovered by the Hittites of ancient Egypt somewhere between 5000 and 3000 B.C.?

1) steel;
2) iron;
3) copper;
4) nickel;
5) aluminum.

1.3. What age began following bythe chalcolithic period in the Near East around 3000 B.C.?

1) Wooden Age;
2) Stone Age;
3) Copper Age;
4) Bronze Age;
5) Diamond Age.

1.4. One of the biggest impacts that China had on the evolution of iron casting occurred in 645 B.C. when Chinese metallurgists began using:

1) shell molding;
2) machine forming;
3) sand molding;
4) centrifugal casting;
5) injection molding;
6) ceramic mold casting.

1.5. When cast iron was introduced as a casting alloy in Europe?

1) before 6000 B.C.;
2) between 5000 and 3000 B.C.;
3) between 5000 and 3000 B.C.;

4) between 1200 and 1450 A.D.;
5) later 1500 A.D.

1.6. The earliest evidence of cast products in Europe is:
1) four statues near the temple in Denfeng;
2) copper frog casting;
3) iron ploughshares;
4) bronze cannon;
5) cast iron pipe.

1.7. Where the first ironworks were established?
1) in North America;
2) in South America;
3) in Eastern Europe;
4) in Western Europe;
5) in India.

1.8. In the 16th century, the production of cast iron with coke as:
1) charcoal;
2) brown coal;
3) hard coal;
4) fuel;
5) anthracite.

1.9. Who developed two methods for extracting impurities from iron, turning it from pig iron to wrought iron?
1) Chvorinov;
2) Benjamin Huntsman;
3) Henry Cort;
4) James Watt;
5) Thomas Newcomen.

1.10. When a new centrifugal casting method was developed in England?
1) in 1793;
2) in 1809;
3) in 1815;
4) in 1818;
5) in 1837.

1.11. In which country was the first cast steel produced by the crucible process in 1818?

1) in the U.S.;
2) in Canada;
3) in Britain;
4) in England;
5) in Europe.

1.12. In 1849 to supply rapidly cast lead type for a newspaper was developed:

1) centrifugal casting device;
2) molding machine;
3) die casting machine;
4) sand pattern;
5) crucible furnace.

1.13. In 1863 examination of castings was started by the:

1) invention of electron microscopes;
2) invention of X-ray radiography;
3) invention of X-ray;
4) appearance of defectoscopy;
5) development of metallography.

1.14. Sand blasting was developed in 1870 for:

1) small castings;
2) large castings;
3) castings of complex shape;
4) hollow castings;
5) cast iron and steel castings.

1.15. When aluminum was started to use as cast material?

1) in 1812;
2) in 1835;
3) in 1870;
4) in 1876;
5) in 1905.

1.16. Heat treatment and artificial aging was proposed in 1907 to:

1) improve the properties of cast aluminum alloys;
2) ensure plasticity of copper castings;

3) increase the strength of steel castings;
4) reduce of brittleness of iron castings;
5) production of responsible parts from cast iron and steel.

1.17. During 1910s were also developed furnaces for:
1) heat treatment of iron castings;
2) heat treatment of steel castings;
3) melting non-ferrous metals;
4) melting non-colored alloys;
5) melting metals and alloys.

1.18. In 1925 the quality of casting was first examined through:
1) microstructure simulations;
2) stress and distortion simulation;
3) electronic metal analyzers;
4) X-ray radiography;
5) X-rays.

1.19. The development of mathematical relationships between casting geometry and solidification time was established in 1940 by:
1) Chvorinov;
2) Henry Cort;
3) Abraham Darby;
4) Benjamin Huntsman;
5) Isaac Newton.

1.20. Squeeze casting process was originated:
1) in 1988;
2) in 1974;
3) in 1970–1980s;
4) during the 1960s;
5) in the middle of 1950s.

1.21. What new achievements in metal casting occurred in 1970–1999?
1) development of high pressure molding;
2) development of squeeze casting;
3) development of vacuum forming;
4) development of continuous casting;
5) development of simulation casting.

2. METAL CASTING AS A MANUFACTURING PROCESS

Metal casting is the manufacturing process of forming metallic objects by melting metal, pouring it into the shaped cavity of a mold and allowing it to solidify. The process of casting involves the basic operations of pattern making, sand preparation, molding, melting of metal, pouring in molds, cooling, shake-out, fettling, heat-treatment finishing and inspection, performed on foundries. What can be found in today's foundry that creates castings? Similar to a factory's production line, the manufacturing chain is composed of nine primary sections:

1. First, foundries melt metal to extremely hot temperatures. This requires heating raw metal and/or alloying elements into the molten form so it can be poured into molds. In order to achieve these temperatures, specialized furnaces are used. Foundries may house different furnaces based on the type of material or casting process involved.

2. Some metals discharge quantities of hydrogen during cooling. Hydrogen bubbles escape to the top of the surface at the moment of cooling and solidification. This will create porosity on the object's surface and lead to mechanical and chemical deterioration of the object over time. To combat this, a foundry will employ various types of «degassing» equipment to measure and regulate the amount of hydrogen present in the object.

3. To create a casting from an original design, foundries require mold and pattern making equipment. Depending on the casting process involved, a foundry may offer several types of mold making systems. For example, sand casting requires specialized resin-bonded sand molds. Investment casting requires the creation of wax patterns and ceramic molds. Die casting involves machining metals into molds using various alloys containing zinc, copper, lead, pewter, and more.

4. In foundry operations molten metal is transported, contained, or poured. Crucibles, robotic arms, and gravity-induced pouring machines are used to move molten metal from one location to another. Metal workers will also pour molten metal by hand using ladles.

5. Once a mold solidifies, equipment is used to eject the final object from the mold. This requires the use of specialized cutting torches, saw blades, sledge hammers, or even knockout machinery to eject the casting from the mold.

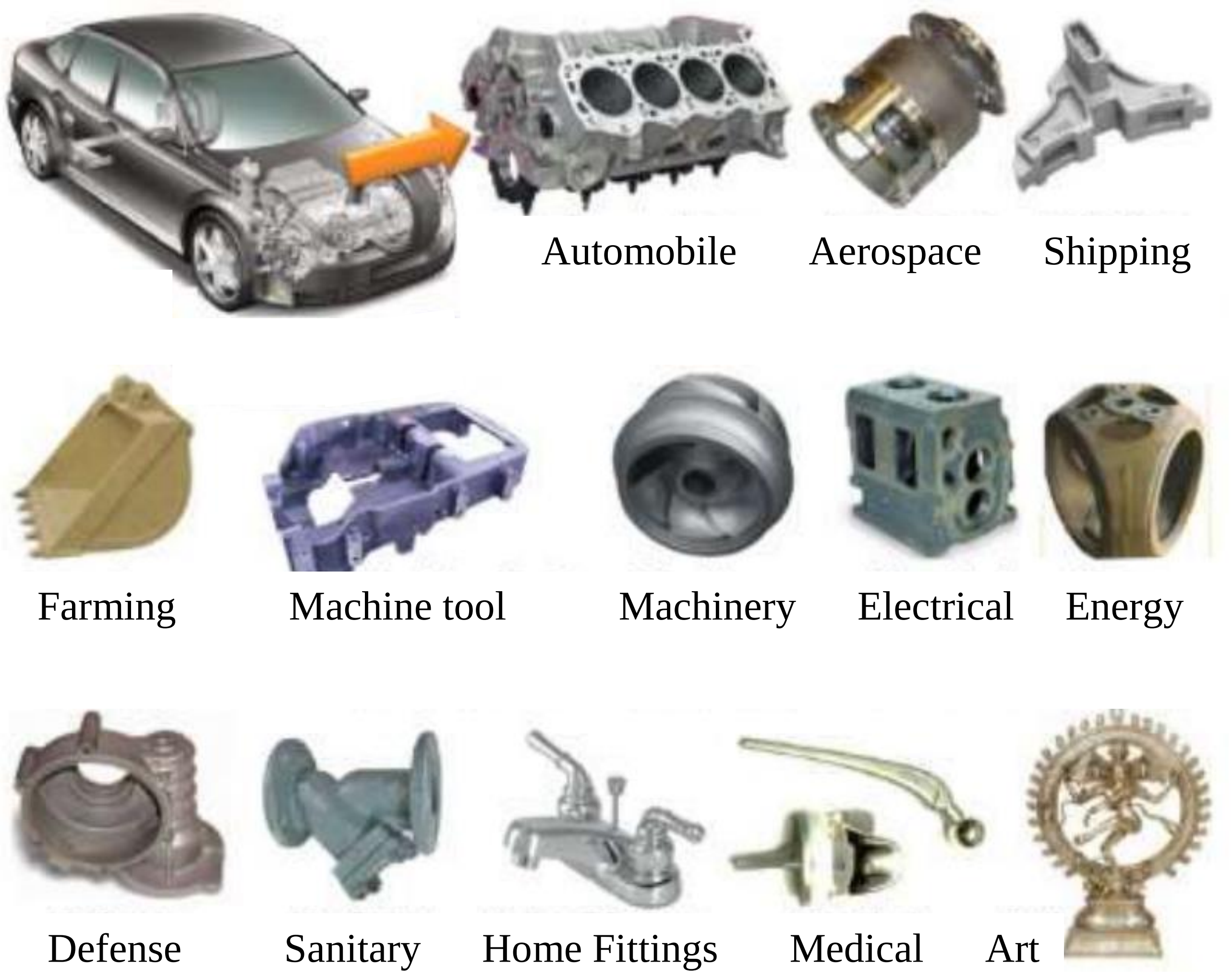
6. Foundries also employ equipment used to heat treat metals in order to alter their physical properties. Using specific techniques in heating and

cooling, a metal’s properties are manipulated through annealing, case hardening, tempering, and quenching.

7. Once the casting is ready, its surface properties still require treatment. Excess mold media such as sand or metal particulate need to be removed. In this case, various surface treatments are used. This can include high powered compressed air or surface blasting with beads, metals, or other media.

8. Now that the casting is clean, the final finishing takes place. The finishing process involves equipment for grinding, sanding, machining, painting, and welding to achieve whatever is requested by the customer.

Foundries are simply factories that provide steel casting services. Castings are the end product created by foundries (Fig. 4). The tools, techniques, and processes used to make castings were berthed under the roof of the foundry. To this day, the pillars of our industry depend on foundries to create castings of all sizes and for every sector of our society.



Automobile Aerospace Shipping

Farming Machine tool Machinery Electrical Energy

Defense Sanitary Home Fittings Medical Art

Figure 4 – Typical metal cast parts

Certain advantages are inherent in the metal casting processes. These may form the basis for choosing casting as a process to be preferred over other shaping processes. Some of the reasons for the success of the casting process are as follows [13, 18].

The most intricate of shapes, both external and internal, may be cast. As a result, many other manufacturing operations such as machining, forging, and welding may be minimized or eliminated.

Because of their metallurgical nature, some metals can only be cast to shape since they cannot be hot-worked into bars, rods, plates, or other shapes from ingot form as a preliminary to other processing. A good example of casting is the family of cast irons which are low-cost, extremely useful, and exceed the total of other metals in tonnage cast.

Casting is a simplified manufacturing process. An object cast as a single piece often would otherwise require multiple manufacturing steps (stamping and welding, for example) to be produced any other way.

Casting can be a low-cost, high-volume production process, where large numbers of a given component may be produced rapidly. Typical examples are plumbing parts and automotive components such as engine blocks, manifolds, brake calipers, steering knuckles, and control arms.

Extremely large, heavy metal objects such as pump housings, valves, and hydroelectric plant parts which could weigh up to 200 tons may be cast. These components would be difficult or economically impossible to produce otherwise. Some engineering properties such as machinability, bearing, and strength are obtained more favorably in cast metals. In addition, more uniform properties from a directional standpoint can be expected, which is not generally true for wrought products.

Casting technology has progressed significantly, allowing products to be cast with very thin cross sections, often referred to as «thin-wall-casting»; such capabilities allow designers to reduce the casting weight that is often assumed necessary for production.

One has to consider the economic advantages of the casting process. In the aerospace industry, some components are still being machined out of forged or rolled pieces despite the fact such pieces can be cast more economically to meet the design criteria, especially concerning strength and toughness.

In some cases, the casting process may give way to other methods of metal processing. For example, machining produces smooth surfaces and dimensional accuracy not obtainable in any other way; forging aids in developing the ultimate tensile strength and toughness in steel; welding provides a convenient method of joining or fabricating wrought or cast parts into more complex structures; and stamping produces lightweight steel metal parts. Thus, the engineer may select from several metal-processing methods, singularly or in combination, which is most suited to the needs of his or her work.

In comparison to other manufacturing processes like rolling, forging, welding, powder metallurgy, machining, pressing, etc., the casting process has the following advantages:

1. There is no restriction on the type of metal or alloy for casting operation. In other processes like forging only a few ductile materials can be formed whereas a brittle metal like cast iron cannot be manufactured. For example, high alloy steels of high-melting temperature to low-melting aluminum alloys.

2. There is no restriction on the size of the component for casting. Items from a few grams to many tons weight are produced by the casting process. There are severe problems in manufacturing larger parts by processes like powder metallurgy, forging, etc. For example, watch cases of a few grams to rolling mill housings and kiln-tyres of 50 tons each.

Extremely large, heavy metal objects such as pump housings, valves, and hydroelectric plant parts which could weigh up to 200 tons may be cast. These components would be difficult or economically impossible to produce otherwise.

3. The most intricate external and internal shapes can be formed by the casting process, by suitable molding and core-making techniques. No such possibility exists in the other forming methods as rolling. For example, automobile cylinder blocks, carburetors and valve bodies.

4. Casting technology has progressed significantly, allowing products to be cast with very thin cross sections, often referred to as «thin-wall-casting»; such capabilities allow designers to reduce the casting weight that is often assumed necessary for production.

5. Because of their metallurgical nature, some metals can only be cast to shape since they cannot be hot-worked into bars, rods, plates, or other shapes from ingot form as a preliminary to other processing. A good example of casting is the family of cast irons which are low-cost, extremely useful, and exceed the total of other metals in tonnage cast.

6. Some engineering properties such as machinability, bearing, and strength are obtained more favorably in cast metals. In addition, more uniform properties from a directional standpoint can be expected, which is not generally true for wrought products.

7. Casting is a simplified manufacturing process. An object cast as a single piece often would otherwise require multiple manufacturing steps (stamping and welding, for example) to be produced any other way.

8. A wide range of properties can be obtained in cast parts by suitable choice of alloy and heat treatment. Special properties like corrosion resistance, heat resistance, damping capacity, high strength, etc., are possible.

9. Casting can be a low-cost, high-volume production process, where large numbers of a given component may be produced rapidly. Typical examples are plumbing parts and automotive components such as engine blocks, manifolds, brake calipers, steering knuckles, and control arms.

10. The casting process is economically suitable for both small-quantity jobbing production as well as mass production by automatic machines. In the other process like rolling or forging, it is difficult to have flexibility in production-run without increasing cost. In the aerospace industry, some components are still being machined out of forged or rolled pieces despite the fact such pieces can be cast more economically to meet the design criteria, especially concerning strength and toughness.

11. The casting process is still the cheapest available technique for forming many components from raw materials to the final usable stage. So it remains the fundamental manufacturing process inspired by many developments in other fields.

In some cases, the casting process may give way to other methods of metal processing. For example, machining produces smooth surfaces and dimensional accuracy not obtainable in any other way; forging aids in developing the ultimate tensile strength and toughness in steel; welding provides a convenient method of joining or fabricating wrought or cast parts into more complex structures; and stamping produces lightweight steel metal parts. Thus, the engineer may select from several metal-processing methods, singularly or in combination, which is most suited to the needs of his or her work.

The casting process has the following disadvantages:

1. Metal casting involves the melting of metal, which is a highly energy-consuming process. Due to the growing cost of energy, many restrictions are being imposed on the energy-intensive metal casting units in several countries. For example, about 2000 kWh of power is required to produce a ton of finished steel castings.

2. Metal casting is still highly labor-intensive compared to other processes. The productivity is thereby less than in other automatic processes like rolling.

3. The quantum of raw materials required for producing a ton of castings is quite high, needing exhaustive buildings, handling systems, large space and inventory costs. For example, for producing each ton of steel castings about 2.2 tons of metallics, 0.3 tons of refractories, 1.2 tons of facing sand and 4 tons of backing sand are needed apart from many other minor materials.
4. The time required for the process of making castings starting from receipt of drawing is quite long compared to other processes like machining. On average, a medium-size ferrous casting takes 2 to 4 months for the first casting. Thus the entire cycle of order execution for castings can take between 3 months to one-and-a-half years depending on size, intricacy, composition, quantity to be cast, etc.
5. The working condition in foundries, due to heat, dust, fumes, heaps of scrap, castings, and, slag, etc. at different stages, is quite bad compared to other process industries. Environmental pollution is high in metal casting industries. This is leading to the closure of foundries in advanced countries like Germany, Switzerland, etc., both by governmental legislation and by unpopularity as a profession.

Despite this, casting production is considered of the main factors influencing the development of the world economy. The actual capacity of the world's casting production, which is higher than 91 million metric tons per year (2020), is strongly diversified.

The last decade brought significant changes in the Word map of the greatest casting producers. Globalization and transformation of economic systems are reflected by variations of foundry production in different countries, moreover, the globalization of the economy is regarded not only as a chance but also as a menace for the European foundries [24].

The most important research directions leading to the further development of the foundry industry:

1. Development of new technologies and casting alloys.
2. Melting and liquid metal preparation.
3. Manufacturing of molds and cores.
4. Preparation of casting materials and composites.
5. Pouring. solidifying and cooling of casting.
6. Technological waste management.
7. New production systems and quality control.
8. Sustainable development of the foundry industry.
9. Energy and material efficient technologies.

European metal casting industry, just like most European and USA manufacturing, suffered greatly from arly in this decade. Moreover, substantial dynamics in the global economy, especially off-shore sourcing of cast metal components as well as the off-shore manufacturing of durable goods that require castings continue to profoundly reshape the European metal casting industry. The effects of the recession were magnified by the influx of low-priced castings from off-shore sources including Brazil, India and particularly China.

Nowadays it is becoming clear that economic trends and technological advances are creating an inflection point in the growth rate for cast metal components. The growth in the world economy demand for casting related to transportation and an industrialized infrastructure. Metal casters need to invest in technology and people. Meaningful improvements in casting design, modeling, prototyping and production will be of the highest importance if foundries want to achieve increasing capabilities and lower costs.

Finally, foundries need to invest in people. The knowledge and skills needed to keep pace are changing even faster than technology. Over the next 50 years, new skills will need to be developed every three to five years. Ongoing training and education will be a must for successful foundries.

These five trends are important for foundries in the future.

Aluminum is displacing classic steel, the shortage of skilled workers is to be compensated for by progressive automation, and environmental protection is increasingly becoming a priority - this is only a small part of the topics that will dominate the foundry industry this year and in the years to come.

1. Aluminum instead of steel.

Ever more products are produced with the material aluminum. There are numerous reasons for this: The automotive industry is just as pleased as the avionics sector when it comes to lighter components. However, the stability of aluminum is also a major factor. In mechanical engineering, this material is also used for mechanically demanding tasks.

In the last decade, the world has produced about six percent more aluminum than in the previous 10 years. The higher price of the material becomes an ever smaller argument against this metal: the price of the finished product decreases due to advanced manufacturing methods and state-of-the-art machinery. Raw material prices have been comparatively high for years, but they are not affected by as many fluctuations as metal.

2. Automation due to lack of skilled workers.

Fewer and fewer people are working in the foundry industry. Harsh working conditions and falling training figures suggest further declines. In order to remain competitive, companies rely on semi-automated or completely autonomous systems to maintain or even increase their production.

By no means does this lead to further job cuts? Quite the opposite: employees can invest more time in designing or testing instead of pressing buttons on machines, transporting raw materials, or filling molten metal at high risk. At the same time, this increases the interest of younger generations to get involved in the design or the development of the foundry industry.

3. Digitization and Industry 4.0.

The terms Industry 4.0 and the Fourth Industry Revolution have been around at least since 2014, but the revolution is ongoing with fresh new implementations continuing to enter industries worldwide.

The metal casting industry is going through its version of a fourth revolution, and a growing number of suppliers, foundries and end-users are creating new ways to use the Internet of Things to do their jobs more efficiently.

Sensors, linked machines and smart controls have no fear for the foundry either: numerous production sites are already centrally connected. Not only foundries, but also customers and potential clients benefit from the data. Processes can be optimized with big data and possible bottlenecks and errors in the system can be detected at an early stage. Manual adjustments in the operating procedure are less necessary.

Employing Industry 4.0 technologies in the casting and foundry industry does not fully spell success, or guarantee it for that matter. However, companies can reap the benefits of implementing Industry 4.0 by taking the time to decide on the tech implementation part, choosing the goalposts, and offering employees ample time to familiarize themselves with the new process set in place.

New technologies like virtual reality help companies present themselves to the outside world. Thus, a virtual tour of the production halls becomes possible for everyone. Safety concerns are no longer necessary – furthermore, a presentation of the company is possible everywhere. Thanks to augmented reality, technicians can easily adjust or repair machines with a superimposed virtual image. Also, virtual learning becomes easier with the new technologies. Meanwhile, numerous CAD programmers can also be used by way of 3D glasses to make prototyping more efficient.

4. Environmental protection and eco metals.

Foundries are considered to be amongst the most energy-hungry industries in Germany. A study by the Federal Environment Agency proves that the majority of foundries could get their energy requirements from renewable energies. For this, however, energy storage devices are necessary that can meet the enormous requirements for continuous day-night operation.

Through the use of more efficient casting molds, fewer raw materials are required, which also do not need to be transported. The energy requirement can be further reduced by using more efficient furnaces to make the entire production process more environmentally friendly.

5. Additive manufacturing.

Particularly for smaller cast products, things could change soon: More and more 3D printers are managing to deal with metals. Selective laser sintering (SLS) applies metal layer by layer in order to produce small components cost-effectively, quickly and more accurately than with conventional processes. Depending on the individual application, additive manufacturing offers various sizes ranging from half a cubic meter to entire warehouses that can be converted.

Innovative technology is already being used in projects that require only a small quantity of the final product. Structures, which would not be possible in normal casting, pose no problem for additive manufacturing either. For large quantities and parts with larger dimensions, not much will change for the time being.

The structure of the modern foundry industry is complex. Directly related to the traditional industry are the jobbing foundries with their capacity for undertaking work involving a wide range of sizes and designs. Quantity requirements are usually small and there is still some dependence on manual operations even though much of the heavy labor is removed by mechanical aids. At the opposite end of the scale are the specialized foundries, with their emphasis either on the mass production of a limited range of articles or on the use of a single special casting process. Many such foundries are captive to engineering organizations that incorporate castings in their finished products.

The jobbing foundry is constantly presented with new problems in the molding of individual design features and in the determination of casting methods that will ensure a sound product at the first attempt. Whilst some minor design variations can be accommodated by recourse to the skill of the molder, the casting method must either be systematically evolved from an understanding of the underlying principles or must incorporate wide margins of safety at the risk of uneconomic production.

This is where the introduction of computer simulation can save both costs and time by validating the intended casting method before any molten metal is poured.

In the mass production foundry, by contrast, the emphasis is on close process control to maintain consistency in materials and procedures. Sophisticated pattern equipment eliminates the need for a high degree of skill in molding, whilst there is the opportunity for the progressive development of the casting method to reduce margins and achieve the most economic production.

This picture of the industry is necessarily simplified since many companies operate in several fields, with jobbing and mass production, conventional and highly specialized processes operating in parallel. Similarly, although most foundries base their activities on a limited range of alloys, for example, grey cast iron or steel, copper base, or die casting alloys, other firms produce several of these materials sides by side. Achieving vision goals will enable the industry to produce thinner-walled more efficient casting geometry, reduced casting rejections at all stages of production, increased delivery performance at lower in-process and finished inventory levels, and overall lower cost of production through control, automation, and elimination of administrative waste.

The task of increasing the efficiency of global foundry production and the development of metal casting processes is carried out in three interrelated areas: improved product performance, reduced production costs, and waste reduction. To the extent possible, models to achieve similar goals in other industries and other countries should be investigated. Opportunities for advanced technologies, automation, and cleaner more efficient technologies must be pursued. Areas of focus include:

1. Reduce production costs. Opportunities to reduce labor and energy content and make other efficiency improvements must be pursued. Lean manufacturing, six sigma and other concepts to improve operating efficiencies need to be pursued as do activity-based cost accounting approaches.

Revolutionary technologies and process changes also should be investigated to achieve metal casting without the use of tooling. The industry should investigate the application and blending of statistical, shop floor layout, computer numerical control, and scheduling technologies to radically change the nature of Economic Order Quantities (EOQs), production release sizes, inventory levels, and delivery performance in metal casting plants.

2. Reduce the Energy Content of Cast Products. Energy content can be reduced by improving product quality – thereby reducing scrap and melting requirements. Improvements in equipment and process efficiencies will also save energy. The industry should develop a complete understanding of the thermophysical behavior of alloys in melting, flow, and solidification as well as the ability to accurately simulate these behaviors.

3. Waste Management. Process improvements are needed to enable increased reuse of foundry sand and other by-products and/or waste streams, more environmentally sound binders, and better emission treatment. Process improvements will also help to reduce scrap and thereby waste in casting processes.

4. Reduced Labor Content of Cast Products. Current practices must be investigated to identify opportunities to reduce the number of process steps, develop and implement no-touch casting processes, and implement advanced information and control technologies.

5. High-Quality, High-Performance Engineered Cast Components. Methods to improve quality, precision and performance will result in fewer customer returns. The industry must develop an understanding of all process variation that affects the performance of castings in their applications; and develop process controls to ensure that variation is within allowable limits. Better-performing products will also open new markets for metal castings. Tools are needed to capture digital, analog, or computer vision signals from all levels of the metal casting process to provide real-time feedback about process status and to provide the ability to correct variances before they become product defects.

The future holds great promise for the metal casting industry. New advances have allowed the industry to employ materials such as aluminum, magnesium, titanium, zinc, advanced copper-based, and advanced ferrous alloys to produce thin walls, high-strength castings with higher precision castings and more complex shapes. But to remain competitive and maintain a viable domestic industry, challenges must be overcome in industry recognition, casting design, processing efficiency, and employer attractiveness.

Multiple Choice Questions

2.1. What is a factory that performs casting operations usually called?
1) casting enterprise;
2) foundry;
3) casting department;
4) casting factory.

2.2. Metal casting is:
1) technological operation for the production of metal parts by pouring metal into molds and solidifying it;
2) manufacturing process of forming metallic objects by melting metal, pouring it into the shaped cavity of a mold and allowing it to solidify;
3) manufacturing and technological process of manufacturing parts from the molten metal using special molds for casting;
4) special technological operation in mechanical engineering for the production of workpieces from liquid metal.

2.3. What are the main operations involved in the casting process?
1) pattern making;
2) workpiece forming;
3) sand preparation;
4) molding;
5) shaping.

2.4. What are the main operations involved in the casting process?
1) heating the metal form;
2) melting of metal;
3) pouring into molds;
4) cooling;
5) sandblasting of the casting.

2.5. What are the main operations involved in the casting process?
1) shake-out;
2) weighing the sand mixture;
3) fettling;
4) decoration of the casting;
5) fine jet processing of the casting.

2.6. What additional operations are necessary for the casting process?

1) heat-treatment finishing;
2) chemical-thermal strengthening;
3) thermo-mechanical processing;
4) inspection;
5) cleaning.

2.7. Which of the listed operations are included in the structure of the casting production process?

1) melting ore to speed up the smelting operation;
2) mixing, if necessary, ore with alloying elements;
3) heating raw metal and/or alloying elements into molten form so they can be poured into molds;
4) degassing to measure and regulate the amount of hydrogen present in the object.

2.8. To create a casting from an original design, foundries require:

1) mold making;
2) pattern making;
3) pattern making equipment;
4) execution of formative patterns;
5) preparation of catalysts.

2.9. What types of mold making systems are used for sand casting?

1) ground molds of open pouring of metal;
2) specialized resin-bonded sand molds;
3) ceramographic molds;
4) ceramic sand molds;
5) plastic molds.

2.10. Investment casting requires the creation of:

1) wax patterns;
2) sand-ground molds;
3) ceramic molds;
4) metallographic molds;
5) phenol formaldehyde molds.

2.11. In foundry operations molten metal is:

1) transported;

2) cooled down;
3) recrystallized;
4) contained, or poured;
5) mixed with alloying elements.

2.12. To move molten metal from one location to another are used:
1) crucibles;
2) patterns;
3) mechanical flasks;
4) robotic arms;
5) gravity-induced pouring machines.

2.13. Metal workers will also pour molten metal by:
1) crucibles;
2) hand using ladles;
3) directly from the oven;
4) robots;
5) manipulators.

2.14. Once a mold solidifies, equipment is used to:
1) open the mold;
2) eject the final object from the mold;
3) clean the mold from metal residues;
4) clean the mold from sand residues;
5) lubricate the inner cavity of the mold.

2.15. The process of removing unwanted material from the casting is called:
1) cleaning;
2) finishing;
3) blowing;
4) fettling;
5) molding.

2.16. Foundries also employ equipment used to heat treat metals to change:
1) their physical properties;
2) their mechanical characteristics;
3) the chemical composition of the metal;
4) the crystal structure of the casting.

2.17. Using specific techniques in heating and cooling, a metal's properties are manipulated through:

1) annealing;
2) tempering;
3) surface hardening;
4) quenching.

2.18. What types of mechanical processing are used to clean the surface of castings in foundry manufacturing?

1) compressed air;
2) liquid jets;
3) surface blasting with beads;
4) electro-vibration methods;
5) electro-erosion methods.

2.19. The finishing process in casting involves equipment for:

1) welding;
2) machining;
3) grinding;
4) hardening;
5) painting.

2.20. What are the end products created by foundries?

1) fluxes;
2) sand molds;
3) castings;
4) carburetors.

2.21. In the following type of foundry, a melting unit, as well as balance equipment, are installed for the casting of the particular metal is?

1) jobbing foundry;
2) ferrous foundry;
3) mass production foundry;
4) non-ferrous foundry.

2.22. What is the basis for choosing casting as a process to be preferred over other shaping processes?

1) the most intricate of shapes, both external and internal, may be cast;
2) many other manufacturing operations such as machining, forging, and welding may be minimized or eliminated;

3) high productivity;
4) high cost of products;
5) production of extremely large heavy metal objects that cannot be obtained in other ways.

2.23. What are the advantages of casting compared to other manufacturing processes?
1) there are no restrictions on the type of metal or alloy for casting operation;
2) there are no restrictions on the size of the component for casting;
3) there are no changes in the metal structure during casting;
4) the most intricate external and internal shapes can be formed by the casting process;
5) the casting process is economically suitable for both small quantity jobbing production as well as mass production.

2.24. The casting process has the following disadvantages:
1) metal casting involves the melting of metal which is a highly energy consuming process;
2) metal casting is still highly labor intensive compared to other processes, the productivity is thereby less;
3) casting is a simplified process of making products;
4) poor working conditions in foundries compared to other branches of the processing industry;
5) environmental pollution is higher in metal casting industries.

2.25. Which of the following sentences is/are correct for the casting process?
1) casting process is comparatively costly;
2) objects of large sizes cannot be produced easily by the casting process;
3) the time required for the process of making casting is quite long;
4) all of the above sentences are correct.

2.26. The productivity of the casting process is comparatively:
1) lower than the productivity of other automatic processes like rolling;
2) higher than the productivity of other automatic processes like rolling;
3) similar to the productivity of other automatic processes like rolling;
4) unpredictable.

3. METALS AND ALLOYS USED IN METAL CASTING

Different cast parts have different requirements. For example, some need to be as strong as possible, while others need to be as light as possible. The right metal for one part might not be the right metal for another, so it's important to know the options before using cast parts. To get started, here is an overview of the eight most common metals used in manufacturing today: gray iron, white iron, ductile iron, stainless steel, carbon steel, copper-dazed alloy, nickel-based alloy and aluminum alloy.

Cast iron and steel are alloys of the metallic element iron, but they differ in important ways. Cast iron contains over 2% by weight of carbon, and as a result, has a lower melting temperature and requires less refining than steel, which has a typical carbon content of 0.5%. Iron castings can therefore be produced with less costly and less specialized equipment than steel castings. Because cast iron shrinks less when solidifying than steel, it can be cast into more complex shapes; however, iron castings do not have sufficient ductility to be rolled or forged.

Iron is the most commonly cast metal in the foundry industry, being not only relatively less costly to produce than cast steel, but also easily cast, readily machinable, and suitable for a wide range of cast metal products that do not require the superior strength and malleability of steel. The iron foundry industry comprises establishments that produce both rough and machined iron castings. Metal foundries produce molten iron by melting scrap iron, pig iron, and scrap steel in a traditional coke-fired cupola furnace, or in electric-induction or electrical furnaces.

Molten iron is refined by adding alloying metals into either the furnace or a ladle. It is then moved to a pouring station for pouring into molds. Molten iron is cast by most molding processes, but is less suited for permanent molding and injection molding (die casting) because its high melting temperature increases wear on the casting surfaces of cast-iron permanent molds and steel dies. There are several important types of cast iron, each of which has physical properties that make it suitable for specific applications.

1. Gray iron is the most widely cast metal and is easier to cast and less costly to produce than other types of cast iron because it neither requires special alloy additions necessary to produce ductile iron or compacted-

graphite iron nor does it require annealing (heat treatment) of the rough castings as is necessary to produce malleable iron. The largest end use for gray iron castings is the motor vehicle industry. Gray iron is ideal for engine blocks because it can be cast into complex shapes at a relatively low cost. Gray iron also is preferred for engine blocks because of its high strength-to-weight ratio, ability to withstand high pressures and temperatures, corrosion resistance, and greater wear resistance compared to aluminum.

Gray iron is suitable for brake drums and disks because of its dimensional stability under differential heating. Also, it is suitable for internal-combustion engine cylinders because of its low level of surface-friction resistance. Gray iron is successfully used for manufacturing gear boxes, differential housings, power-transmission housings, and speed changers in both automotive and non-automotive applications because of its high vibration-dampening capability.

Other casting applications for gray iron include compressor housings for appliances and other equipment; construction castings and fittings (e.g. manhole covers, storm grates and drains, grating, fire hydrants, lamp posts, etc.); utility meter box covers; soil pipe and fittings; parts for pumps for liquids; and rolls for rolling mills, among other cast products.

Depending on the class of gray iron, different levels of machinability and strength can be achieved. Softer, more machinable gray iron can have tensile strengths as low as 20,000 psi. Tougher, less machinable iron can have tensile strengths triple that.

2. White iron is known for its excellent wear resistance. Some white irons have high levels of chromium or other alloys for increased performance of high-temperature service or corrosion resistance.

3. Ductile iron (also called «nodular iron») combines many of the engineering qualities of steel with the processing capabilities of iron. To produce ductile iron, magnesium is added to molten iron, which increases the ductility, stiffness, impact resistance, and tensile strength of the resulting castings. Ductile iron also offers flexibility in casting a wide range of sizes, with sections ranging from very thin to very thick. Ductile iron is a growth metal in the casting industry to the point of approaching gray-iron production levels.

Ductile iron is primarily used for pipes, tubes, and fittings, and for automotive parts. Pressure pipes and fittings are cast with ductile iron primarily to resist fracturing from ground movement, shocks, and soil corrosion; these products are common in municipal water and sewage systems. For the automotive industry, ductile iron is cast into camshafts and crankshafts for different internal combustion engines. Other end uses for ductile iron castings are bearing housings, machinery components, construction and utility applications, and electric and electronic equipment components.

Ductile iron also ranges in strength and has a higher level of tensile strength than gray iron. This wide range of strengths allows ductile iron to serve a wide variety of markets.

Malleable iron is cast iron with properties similar to those of ductile iron, however, malleable iron castings are produced by a method that requires a lengthy period of annealing in a special furnace to induce characteristics of increased strength, durability, and ductility; ease of machining; and high resistance to atmospheric corrosion.

The lengthy annealing period increases the relative cost of producing castings of malleable iron compared to those of gray or ductile irons. In addition, technical requirements limit the thickness of a casting that can practically be produced of malleable iron. Malleable iron use declined, particularly for automotive parts, after the widespread adoption of the ductile-iron process in the early 1970s. A major use for malleable iron is pipe fittings, particularly for applications that require resistance to shock and vibration or rapid temperature changes.

Compacted graphite iron (CGI) exhibits properties that are intermediate between those of gray and ductile iron, and results from the addition of certain rare-earth elements and titanium to molten iron. Recent growth in CGI use was made possible by the development of advanced sensors and controls for precise metallurgical additions to molten iron. CGI exhibits unique properties of medium to high strength, good thermal conductivity, low shrinkage, and medium dampening capacity while retaining much of the castability of gray iron to produce complex shapes and intricately cored passages. CGI also provides a better-machined finish than gray iron.

CGI exhibits slightly higher thermal conductivity, more dampening capacity, and better machinability than is possible with ductile iron. A drawback of CGI castings is the close metallurgical control necessary to obtain successive castings with consistent properties. The largest end use for CGI is internal combustion engine blocks for both motor vehicles and other applications1 Detailed properties of specific cast irons could be found in the appropriate industry standards and references. Just to mention some of them:

ASTM A644 – 09a. Standard Terminology Relating to Iron Castings

ASTM A48 / A48M – 03(2012). Standard Specification for Gray Iron Castings

ASTM A126 – 04(2009). Standard Specification for Gray Iron Castings for Valves, Flanges, and Pipe Fittings

ASTM A159 – 83(2011) . Standard Specification for Automotive Gray Iron Castings

ASTM A278 / A278M – 01(2011). Standard Specification for Gray Iron Castings for Pressure Containing Parts for Temperatures Up to 650°F (350°C)

ASTM A319 – 71(2011). Standard Specification for Gray Iron Castings for Elevated Temperatures for Non–Pressure Containing Parts

ASTM A436 – 84(2011). Standard Specification for Austenitic Gray Iron Castings.

4. Stainless steel is the classification of steel that contains a chromium content of 10.5% or higher. It’s best known for its corrosion resistance, but also provides a high level of toughness. Higher levels of corrosion resistance can be reached using higher levels of chromium and molybdenum. Drawbacks to stainless steel include its lower level of machinability and medium tensile strength. These properties make stainless steel a great option for parts in oxidizing or corrosive environments.

Steel castings are produced in a wide range of chemical compositions and physical properties. Steel castings are, in general, of higher strength and ductility than cast iron. Castings of alloy steel have high strength, and those of stainless steel are highly resistant to corrosion. Steel castings are used extensively in the agricultural, construction, manufacturing, power generation, processing, and transportation industries. Typical products made from steel castings include bridge and building supports, compressors, mechanical components, pumps, tools, and valves. The railway rolling-stock industry is the largest consumer of steel castings in the United States, by volume.

5. Carbon steel has virtually no alloying elements. As a result, carbon steel offers very high level of machinability and weldability, while maintaining a high level of toughness.

Alloy steel is created by adding elements to carbon steel. These elements can include: manganese, nickel, molybdenum, silicon, vanadium, chromium, boron and titanium. Alloy steels have improved tensile strength, hardness and wear resistance, but sacrifice some weldability and toughness.

6. Copper-based alloys, in general, have a high level of corrosion resistance which can make these metals a great choice for long-term cost efficiency. Apart from that, the properties are dependent on what other elements of alloys are in the end combination. One of the most popular copper-based alloys is brass, which is a made up of copper and zinc as well as bronze – which is itself an alloy, generally made up of copper and tin and/or lead.

Copper castings have high corrosion resistance, good electrical and thermal conductivity (especially pure or near pure copper castings), and good tensile and compressive strength (certain alloys are nearly as strong as many stainless steel alloys), are non-sparking, and exhibit low friction and good wear resistance when in contact with other metals and materials. In addition, they maintain these properties at extremely low temperatures.

Copper castings are especially amenable to post-casting operations such as machining, brazing, soldering, polishing, and plating. Typical applications for copper castings include valves that control the flow of liquids and gases; plumbing fixtures such as faucets; power plant water impellers; architectural applications (e.g., door hardware); ship propellers; bearing sleeves; and electrical circuit parts (e.g., circuit breakers).

Detailed properties of specific copper alloys could be found in the appropriate industry standards and references. Just to mention some of them:

ASTM B824 – 11. Standard Specification for General Requirements for Copper Alloy Castings

ASTM B22. Specification for Bronze Castings for Bridges and Turntables

ASTM B61. Specification for Steam or Valve Bronze Castings

ASTM B62. Specification for Composition Bronze or Ounce Metal Castings

ASTM B66. Specification for Bronze Castings for Steam Locomotive Wearing Parts.

7. Nickel-based alloys have excellent corrosion resistance. Nickel is often coupled with copper, chromium, zinc, iron, and manganese to achieve different properties. The right combinations can have the tensile strength of carbon steel with good ductility and wear resistance. Alloys containing high levels of nickel are often used in chemical handling equipment.

8. Aluminum alloy, a popular choice in die casting, is a very castable alloy. Other great qualities of aluminum are its high level of machinability, which can reduce costs, and its high level of corrosion resistance, which allows aluminum to have a wide range of applications.

The strength-to-weight ratio of aluminum is among the highest of all metals, which has enabled lighter weight aluminum to find a niche in almost every segment of the transportation industry, particularly in aerospace where aluminum castings are used for such applications as engine and airframe parts.

Detailed properties of specific aluminum alloys could be found in the appropriate industry standards and references. Just to mention some of them:

ASTM B26 / B26M – 12. Standard Specification for Aluminum-Alloy Sand Casting

ASTM B85 / B85M – 10. Standard Specification for Aluminum-Alloy Die Castings.

The following chart (Table 8) offers a comparison of characteristics of different alloys, including corrosion resistance, machinability, price, tensile strength, hardness, weldability, wear resistance and toughness.

According to the alternative classification casting metals and alloys are divided into groups based on composition: ferrous metals, nonferrous metals and alloys.

Ferrous metals may be subdivided according to carbon content and classified as steel or cast iron.

Nonferrous alloys are classified according to the base elements of which they are composed. The base elements commercially are mainly copper, aluminum, magnesium, lead, tin, and zinc. To obtain the desired physical and mechanical properties, it is necessary to vary the amounts of these elements.

An alloy is a substance having metallic properties and composed of two or more chemical elements of which at least one is metal. There are different specific types of metal by combining the base alloy with other alloys to bring steel, iron, aluminum, brass, bronze or any other grade of material to a specific grade much like a receipt. Each application may call for something different such as hardness, tensile strength, wearability or corrosion resistance etc. Then each casting may have to be annealed heat treated quenched and tempered or a combination of several of these processes.

I. Ferrous metals.

Typical casting groups classified as ferrous grades of metal are as follows:

1. Gray iron castings.

Gray iron can be cast in various tensile strength ranges from soft, machineable, low strength irons of near 20,000 psi tensile strength to hard, wear-resistant irons of 60,000 psi.

Various casting markets are served by individual classifications of gray iron (Tables 2,3).

Table 2 – Grey iron castings classification

Class 20	Class 30	Class 40	Class 50	Class 60
Ingot mold	Auto	Valves	Engine	Engine
Municipal	Farm	Machine tool	Special industries	Machine tool
Soil pipe	Construction	Machinery	Compressor	Mining
Motors	Home appliances	Gears	Pumps	Gears

Table 3 – Grey iron alloys classification

White iron Ni-Hard High chrome	Alloyed Irons, Ni-Resist	Compacted Graphite Iron
Metalworking engine	Engine	Molds and stools
Cement	Pumps	Exhaust manifolds
Rolls	Food production	Flywheels
Coal pulverizer	Marine	Axle housings, hydraulic valves

2. Ductile iron castings.

Since ductile iron was developed in the 1940s, this remarkable metal has proved its value in tens of thousands of engineering and casting applications. Ductile iron is created by an alloying process that converts the crack-promoting graphite flakes of gray iron into nodules. With this microstructural transformation, the metal acquires superior ductility, elongation characteristics, and machinability. The ductile iron family offers the design engineer a unique combination of strength, wear resistance, fatigue resistance, and toughness, as well as excellent ductility characteristics.

Ductile iron combines the processing advantages of gray iron (low melting point, good fluidity and castability, and ready machinability) with many of the engineering advantages of steel (high strength, ductility and wear resistance), which allows for higher material properties as tensile and yield strength than gray iron. Table 4 shows the properties of various grades of ductile iron.

In all its grades, ductile iron exhibits mechanical properties that make it an ideal alloy for sand and investment castings.

Table 4 – Ductile iron grades

60–45–15 60–45–12 60–40–18	80–55–06 80–60–03	100–70–03 120–90–02 130–100–04
Valves	Pumps	Refrigeration
Pipe	Electric	Gears
Farm	Motor vehicles	Tool and dies
Construction	Machine and tool	Shafts
Special industries	Machine tool	Farm equipment

3. Malleable iron.

Malleable iron is a desirable engineering material because of its ease of machineability, its toughness, ductility, and wide range of strengths. Some of the principal industries using castings made of malleable iron are automotive, hand tools, valves and fittings. Malleable iron castings continue to decline in usage due to the competitive advantages of ductile iron.

4. Meehanite iron.

Meehanite metals are a licensed process for the manufacture of gray flakes and nodular cast irons. In the early period of American metal casting, 1900–1930, the metallurgical theories of irons were not well understood. Certain foundry practices were known to produce consistent metals. These irons were typically called Pro-Iron or Semi-Steel. Meehanite developed a set of procedures that produce a high-quality engineered iron which permitted engineers and designers to rely upon the integrity of the metal. Meehanite at the time corresponded to Semi-Steels.

The meehanite process filled a void until metallurgy, the science caught up with the art form of the metal casting trade. With the advent of specifying and testing bodies such as A.S.T.M., S.A.E., and military specifications, uniform physical, mechanical, and chemical properties were required of the metal casters. Uniformity has caused designers or buyers to designate metal types according to the desired end-use. A.S.T.M. and meehanite both specify the same final properties.

Therefore, in selecting a meeehanite metal, it can be crossed-referenced to any other specifying body with the assurance that all will be obtained as specified. Meehanite flake gray irons are designated by the following letters (Table 5).

Table 5 – Meehanite flake gray irons classification

GE	GD	GC	GA	GM
Class 30	Class 35	Class 40	Class 50	Class 60

Nodular irons are proceeded by the letter S, abrasion by the letter W, heat resisting by the letter H, and corrosion by the letter C.

Any meehanite metal selected can be certified to A.S.T.M. standards.

5. Steel alloys.

Steel is an alloy of iron and carbon that may contain either elements and in which the carbon content does not exceed approximately 1.7%.

Steel is considered the ideal metal for many types of casting applications because its chemical analysis as well as its mechanical and physical properties are easily varied over a wider range than other cast metals. This is achieved by varying the carbon content, the chemical composition, or by heat treatment. It is strong, tough, dependable, and readily joined by welding or bolting to other metal forms, such as rolled products, forgings, or other castings. Steel castings are used in many industries. These include railroad, automotive, marine, farm equipment, machinery for highway, construction, mining, metalworking, power transmission, valves and fittings.

6. Stainless steels.

A wide range of steels containing chromium or chromium and nickel exhibits high resistant to corrosion or heat.

7. Corrosion resistant stainless steels.

Corrosion resistant casting alloys are those compositions consisting basically of nickel, chromium and iron, sometimes including other alloying elements, which perform satisfactorily when used in a large variety of corrosive environments. Castings made of these materials offer two basic advantages: facility for the production of complex shapes at low cost t ease of securing rigidity and high strength-to-weight ratios). Corrosion-resistant stainless steel castings are used in the following markets (Table 6).

Table 6 – Application of corrosion-resistant stainless steel castings

Ship propellers	Impellers
Ship and boat building	Internal combustion engine turbines
Special industrial machine components	Oil field machinery and equipment
Valves and fittings	Roll mill machinery

8. Heat-resistant stainless steels.

Heat-resistant casting alloys are compositions performing satisfactorily when used temperatures above 1200° F. Heat-resistant casting alloy combinations are composed principally of nickel, chromium and iron, together with small percentages of other elements. Nickel and chromium both contribute to the superior heat resistance of these alloys. Castings made of these alloys meet two basic requirements:

– good surface film stability (oxidation and corrosion resistance) in various atmospheres and at the temperatures to which they are subject;

– the necessary mechanical strength and ductility to meet high-temperature service conditions.

Table 7 – Application of heat-resistant stainless steels

Nonelectric heating	Tool and dies
Industrial furnaces and ovens	Mining
Blowers and fans	Rolling mill machines
Valves	Oil field equipment
Power plants	

9. Manganese wear-resistance steels.

Manganese alloy steels, which cannot be made except by the casting process, have excellent resistance to wear: they work harden during use.

Potential markets include:

- construction and mining equipment;
- special industrial machinery;
- railroad equipment;
- crushing equipment industry.

10. Tool steels.

Any high-carbon or alloy steel used to make cutting tools for machining metals and for metal casting dies.

II. Nonferrous alloys.

Nonferrous alloys are classified according to the base elements of which they are composed. The base elements used commercially are mainly copper, aluminum, magnesium, lead, tin, and zinc. To obtain the desired physical and mechanical properties, it is necessary to vary the amounts of these elements. Typical nonferrous grades of metal most commonly used are as follows:

1. Brass. Copper-based alloys of copper and zinc are commonly classified as brass. Copper-zinc are the major group of metals used, due to their desirable properties and relatively low cost.

Yellow brass is the most ductile of all the brass. Its ductility makes possible the use of this alloy for jobs requiring the most severe cold-forging operations, such as deep-drawing, stamping, and spinning.

Red brass is composed of 2% to 8% zinc, has a reddish color, great resistant to corrosion and good workability. Red brass alloys have good casting and machining characteristics. They are readily shaped by stamping, drawing, forging, and spinning. Applications of red brass include valves, fitting, rivets, radiator cores, plumbing pipe, flexible hose, and cloth.

As with aluminum alloys, certain copper-base alloys are more readily cast in the permanent mold. Because of some of the alloy families' limitations, it is important to consult the metal caster to determine the ability to cast an alloy for a certain application. The following alloys are arranged by the family with the unified numbering system five-digit code developed by the Copper Development Association:

Yellow Brasses (C8330–C89990) – These are copper alloys in which zinc is the alloying element. Although corrosion resistance in these alloys is lower than its counterparts, the high-strength yellow brasses (C86200 and C86500) are used for mechanical products requiring good wear.

Silicon Bronzes/Brasses (C87300–C87900) – These are intermediate-strength alloys. They exhibit good corrosion resistance in the water, good casting characteristics and acceptable machinability. The silicon imparts the ability to cast fine detail and improves the casting's surface finish.

Aluminum Bronzes (C95200–C95900) – These contain 3–12% aluminum, and iron, silicon, nickel and manganese are added singly or in combination for higher strength and corrosion resistance. These alloys form protective, alumina-rich corrosion product films, which provide exceptional oxidation and corrosion resistance. In addition, they exhibit moderate to high strengths and can be heat-treated to tensile strengths over 100 ksi.

SeBiLoy III (C89550) – This alloy is a selenium-bismuth containing yellow brass that was specifically developed for permanent mold casting. It is a lead-free, free-machining brass for potable water applications that exhibits improved mechanical properties, hot tearing and fluidity. The strength of the alloy also exceeds yellow brass.

2. Nickel-based alloys.

Nickel-base alloys have great resistance to corrosion in the presence of most mineral acids, most organic acids, and alkalies. They are not resistant to oxidizing salts. They have good mechanical strength, ductility, and resistance to wear, although they cannot be used for bearings, except under light loads and at slow speeds.

An alloy of 70% nickel and 30% copper is known as Monel. When silicon is added to it, it becomes age-hardened, and thus more wear-resistant. An alloy of 80% nickel and 20% chromium, known as Nichrome, is used for electrical resistance heaters. An alloy of 80% nickel, 14% chromium, and 6% iron, known as Inconel, is used where oxidation resistance with high strength at elevated temperatures is needed.

Casting metals and alloys with a high percentage of nickel are used for chemical equipment, such as implements used in the dyeing of textiles and the manufacture of caustics, as well as for making water-softening equipment, valves and pump parts, and food-handling equipment.

An alloy consisting of 20% zinc, 20% manganese, 1% aluminum, and the balance of copper produces white-bronze casting that is strong, ductile, and corrosion-resistant. It can be polished to a high, silvery luster which makes it useful in architectural and marine hardware, plumbing fixtures, ornamental castings, hospital equipment, and swimming pool equipment.

Casting markets using brass, bronze copper, and copper-base alloys include the following:

- plumbing valves and sanitary fixtures and fittings;
- pumps; electric equipment and apparatus;
- power transmission equipment;
- marine hardware and ship propellers;
- metalworking machinery and equipment;
- ball and roller bearings.

3. Zinc-based alloys.

Zinc base alloys are widely used in die casting. The alloy elements are principally copper, aluminum, and magnesium. The amount of each used depends on the properties desired. High-purity zinc is used as the base metal, the addition of copper increases the strength but reduces ductility. The addition of aluminum improves the strength of the alloy and delays the rate of attack of the alloy on steel dies thus improving the life of the die. Additions of magnesium added to the dimensional stability of the die casting.

Casting metals and alloys development is a continuous process and the producers should be contacted when there is a question regarding the alloy to be used with the casting process being considered.

Zinc die casting includes the following:

- bathroom and plumbing fixtures;
- door, window and furniture hardware;
- hand tools.

4. Aluminum alloys.

Pure aluminum is a poor casting material and is limited to the casting of rotors where high electrical conductivity is an advantage. Almost all aluminum castings are made of an alloy of aluminum. The selection of a particular alloy depends on the criteria demanded of the alloy- the mechanical strength, machinability, surface appearance, resistance to corrosion, conductivity, pressure tightness, and other factors. The principal alloying elements are copper, silicon, magnesium, zinc, chromium, manganese, tin, and titanium.

Iron is often present in small quantities, and is usually considered an impurity. Although all of the alloys are commercially castable by a specified process, namely sand casting, permanent mold casting, or die casting, the casting industry has established a preference for certain alloys in each casting process.

319 – This alloy and its variants are used when moderate mechanical properties without heat treatment are satisfactory.

333 and A333 – These alloys have unusually good casting characteristics in permanent mold and develop better as-cast mechanical properties than 319-type alloys.

355 and 356 – These heat-treatable alloys have good castability and are used when good tensile properties are required. 356 also has excellent corrosion resistance. By decreasing the impurities in these alloys to form C355 and A356, the mechanical properties of the alloys greatly improve.

443 – This alloy and its variants are used when high ductility and corrosion resistance are required but high strength isn't important.

513 – As a straight aluminum-magnesium alloy, with the addition of 2% zinc, alloy 513 can be used for simple castings in which outstanding corrosion resistance and a good surface finish are required. The metal casting industry has been researching, trialing and proving the permanent mold casting of a variety of new alloys, such as A206. Customers should always check with their foundry supplier for other possible alloy options that may be good choices.

5. Sand casting and permanent mold alloys.

In sand casting and permanent mold, alloys with additions of silicon in the range of 5% to 8% copper in the 1% to 5% range, and magnesium in the 0.2% to 1% range are used to produce most aluminum castings.

Sand cast and permanent mold aluminum casting markets are as noted:

- internal combustion engine;
- lawn and garden equipment;
- power hand tools;
- office machines and computers;
- aircraft parts;
- household appliances.

6. Die-casting alloys.

In die casting, approximately 80% of the castings produced use an alloy with the addition of 2% to 5% copper, 7% to 10% silicon, 1% to 3% zinc, and 1% iron.

Castings produced using the die-casting process are used for the following:

- automotive and truck combustion engines;
- furniture, fixtures household appliances;
- toy, sporting goods, bicycles, motorcycles;

- motors, generators, regulators, instruments;
- power tools.

7. Aluminum-magnesium alloys.

Aluminum-magnesium alloys are characterized by excellent mechanical properties and machinability, as well as resistance to corrosion. They have good resistance to impact and high ductility.

These casting metals and alloys are used in:

- marine applications;
- highway fixtures.

8. Magnesium alloys.

Magnesium high-purity alloys with various amounts of aluminum, zinc, zirconium, and rare earths are used to produce sand castings, permanent mold castings, and die casting, with die casting the predominant method. Magnesium die casting markets include the following:

- aircraft components;
- power tools and sporting goods;
- automotive – transmission cases, clutch housing, timing chain covers, wheels, hinges, brackets, brake pedals, headlamp frames, oil filter adapters, etc.

The general properties of the material suitable for casting are the following: requires coating to resist corrosion; high density. lightweight; high dimensional stability; easy to cast; good corrosion resistance; high thermal and electrical conductivity; retains strength at high temperature.

Also, there are the main characteristics of a good casting material: being cast with desired quality, an alloy must have various characteristics including ease of feeding, fluidity (flowability), low hot tearing tendency, low porosity caused by gas dissolution, no macrosegregation, no tendency to solder to the die, and no tendency to form sludge.

Selecting the proper cast and mold materials for a particular project can be an important concern. Some of the factors to consider when making a casting decision include:

- level of volume required;
- cost-effectiveness;
- melting temperature;
- cooling speed;
- wear resistance;
- weight;

– damping capabilities.

Zinc is an efficient choice for die cast operations, however, its low wear resistance and durability may not be ideal for certain applications, such as those involving a high risk of corrosion or material strain.

For die cast projects that focus on performance and resilience, aluminum can be a helpful option. For example, aluminum alloy is a frequently used casting material for lawnmower housings, dental equipment, frying skillets, aircraft hardware and marine hardware.

For structural applications or other tasks that emphasize strength and durability, gray iron or ductile iron may be worthwhile considerations. Gray iron can be effective for projects that require shrinkage-free, intricate castings such as those found in motor blocks.

Ductile cast iron is useful for parts that stress strength and toughness, such as critical engine components (crankshafts, truck axles, disk brake calipers, etc.).

Table 8 – Casting metal comparison chart

Characteristic	Gray iron	White iron	Ductile iron	Stainless steel	Alloy steel	Carbon steel	Copper based alloy	Nickel based alloy	Aluminum
Corrosion resistance	very low	very low	very low	high	low	low	high	very high	medium
Machinability	very high	high	high	low	medium	medium	high	low	High
Price	very low	very low	very low	high	medium	low	very high	very high	medium
Tensile strength	medium	very high	medium	very low	high	medium	low	medium	Low
Hardness	high	very low	high	low	high	medium	low	medium	very low
Weldability	very low	very high	very low	medium	low	very high	very high	low	medium
Wear resistance	high	very low	medium	very low	high	medium	low	low	Low
Toughness	very low	very low	very low	very high	low	high	medium	high	medium

Multiple Choice Questions

3.1. Which of the listed types of metals are used in the foundry?
1) cast iron;
2) gray iron;
3) white iron;
4) malleable iron;
5) ductile iron;
6) low-carbon iron.

3.2. Which one of the following casting metals is most important commercially?
1) aluminum and its alloys;
2) bronze;
3) cast iron;
4) cast steel.

3.3. A mixture of a metal(s) and a non-metal(s) is called:
1) composite;
2) alloy;
3) dislocation;
4) cermet.

3.4. Casting metals and alloys are divided into groups based on the composition of:
1) stainless steel and ductile iron;
2) ferrous metals, nonferrous metals and alloys;
3) stainless steel and gray iron;
4) nonferrous metals and ductile iron.

3.5. Ferrous metals may be subdivided according to the iron content and classified as:
1) ductile iron and steel;
2) cast iron and gray iron;
3) steel and cast iron;
4) stainless steel and gray iron.

3.6. Nonferrous alloys are classified according to:
1) base elements of which they are composed;

2) metal elements with excellent corrosion resistance;
3) content of aluminum and copper components;
4) physical and mechanical properties.

3.7. The base elements of nonferrous alloys are:
1) cast iron and gray iron;
2) ductile iron and white iron;
3) malleable iron and low-carbon iron.
4) copper, aluminum, magnesium, lead, tin, and zinc.

3.8. Which of the listed types of steels are used in the foundry?
1) cast steel;
2) carbon steel;
3) alloy steel;
4) structural steel;
5) stainless steel.

3.9. Which of the listed alloys of non-ferrous metals are used in the foundry?
1) copper-dazed alloy;
2) molybdenum alloy;
3) nickel-based alloy;
4) chromium-based alloy;
5) aluminum alloy.

3.10. Depending on the class of gray iron, can be achieved at different levels of:
1) weldability;
2) machinability;
3) shock viscosity;
4) strength;
5) hardness.

3.11. What are the mechanical properties of white iron?
1) softer, more machinable gray iron is better processing;
2) good corrosion resistance;
3) excellent wear resistance;
4) structural plasticity;
5) high strength.

3.12. What mechanical property distinguishes ductile iron?
1) high ranges in strength;
2) good corrosion resistance;
3) good wear resistance;
4) excellent wear resistance;
5) structural plasticity.

3.13. What mechanical property distinguishes malleable iron?
1) structural plasticity;
2) a wide range of strengths;
3) excellent wear resistance;
4) excellent machinability;
5) good corrosion resistance.

3.14. The corrosion-resistant casting alloys are compositions consisting basically of:
1) aluminum and copper;
2) chromium and magnesium;
3) nickel, chromium and iron;
4) lead, tin, and zinc;
5) aluminum and lead.

3.15. What are the mechanical properties of stainless steel?
1) good weldability;
2) corrosion resistance;
3) high wear resistance;
4) high level of toughness;
5) high level of machinability.

3.16. What are the mechanical properties of carbon steel?
1) excellent wear resistance;
2) very high level of processability;
3) weldability high level;
4) increased hardness;
5) corrosion resistance.

3.17. What are the mechanical properties of alloy steels?
1) improved tensile strength;
2) high compressive strength;

3) hardness;
4) shock viscosity;
5) wear resistance.

3.18. What is the main property of copper-based alloys?
1) high level of processability;
2) high level of corrosion resistance;
3) good casting properties;
4) high level of plasticity;
5) high level of strength.

3.19. What is the main property of nickel-based alloys?
1) high level of strength;
2) impact strength;
3) excellent corrosion resistance;
4) increased hardness;
5) weldability high level.

3.20. What are the mechanical properties of aluminum alloy?
1) good casting properties, very castable;
2) high level of machinability;
3) impact strength;
4) high level of corrosion resistance;
5) improved tensile strength.

3.21. Heat-resistant casting alloy combinations are composed principally of:
1) chromium and magnesium;
2) nickel, chromium and iron;
3) aluminum and copper;
4) lead, tin, and zinc;
5) vanadium, magnesium and aluminum.

3.22. What alloys are used to make cutting tools for machining metals and for metal casting dies?
1) malleable iron and low-carbon iron;
2) ductile iron and steel;
3) high-carbon or alloy steel;
4) steel and cast iron;
5) stainless steel and gray iron.

4. CLASSIFICATION OF METAL CASTING PROCESSES

The casting processes can be classified into two broad categories: expendable mold casting processes and permanent mold casting processes. Fig. 5 depicts a general classification of the casting processes [36].

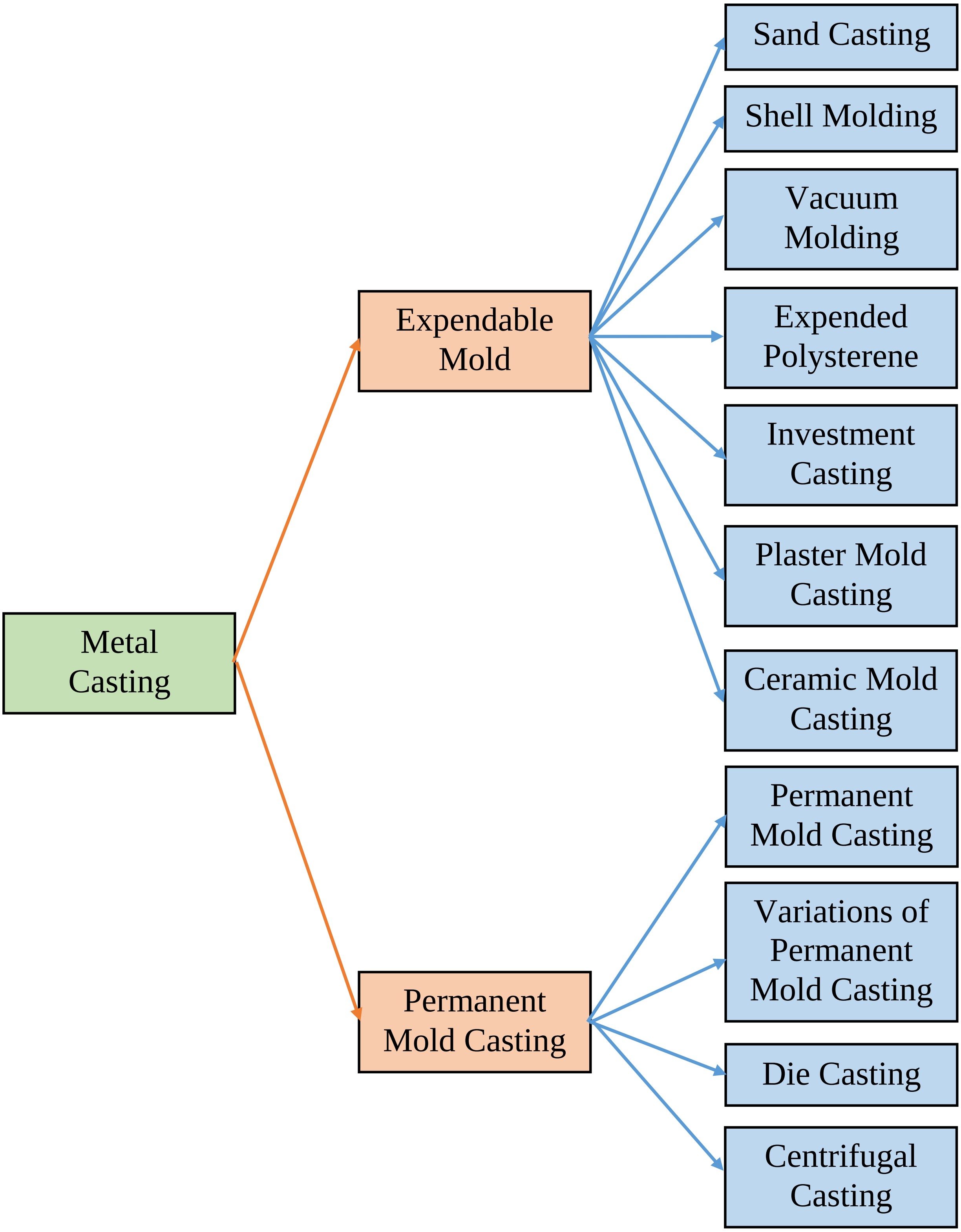


Figure 5 – Classification of the metal casting processes [36]

In expendable mold casting processes, the mold is usually broken to free the solidified cast whereas the mold can be reused in case of permanent mold casting. The pattern used to prepare the molds can also be permanent and expendable, and subsequently, the expendable mold casting processes are further categorized as expendable pattern expendable mold and permanent pattern expendable mold processes. Typically, permanent molds are made from metals that retain their strength at high temperatures.

The permanent mold casting process has different variations and types, a detailed classification of which is recommended and presented in Fig. 6.

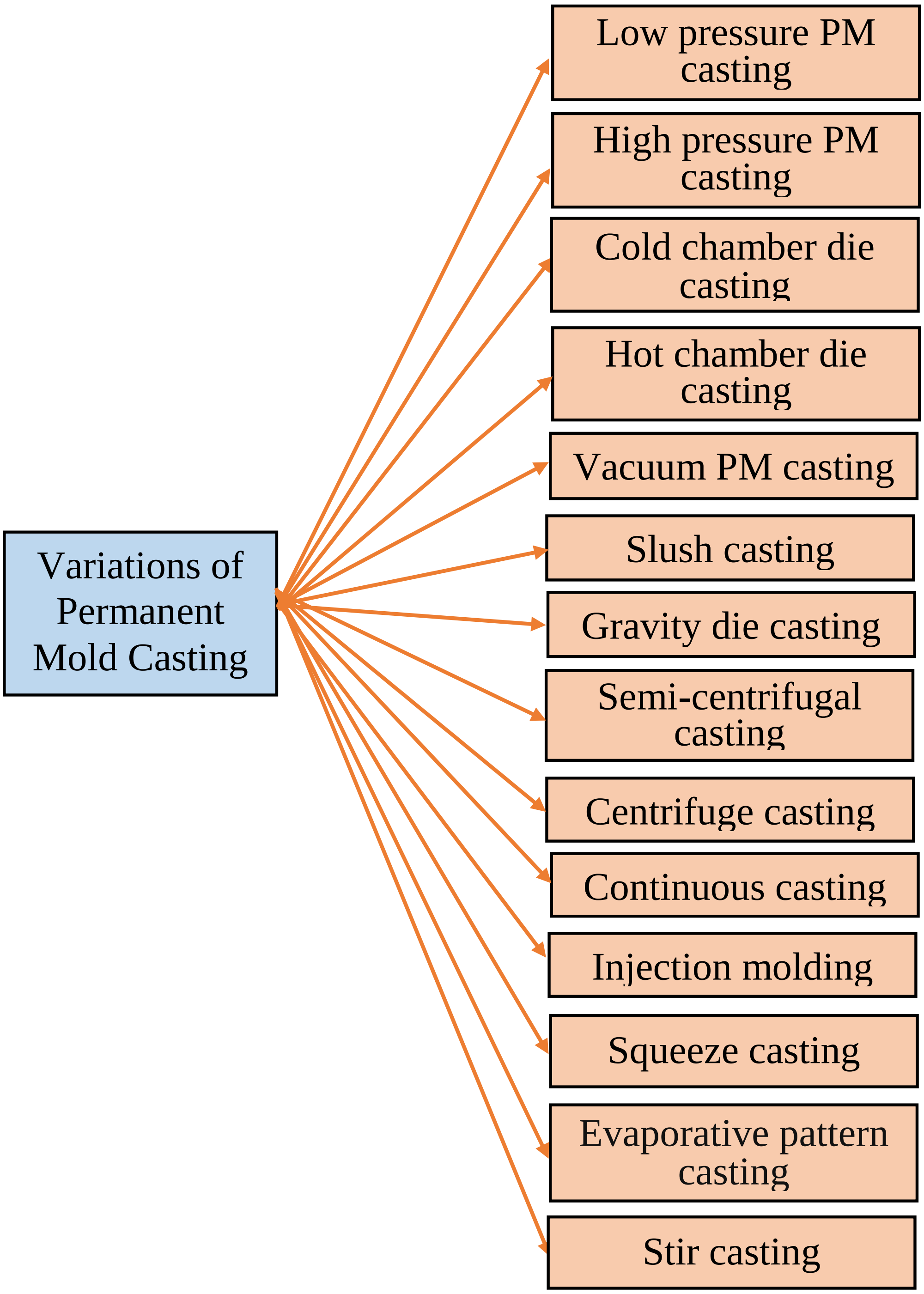


Figure 6 – Classification of the permanent mold casting processes

Expendable mold casting refers to the molds that are used for the molten metal during the pour to create the part. Also, it refers to any manufacturing technique where the molds become expendable instead of reused. So, the lost-wax process, sand casting, and investment casting fall into the expendable mold casting category.

For processes that retain the mold so that it may be reused again and again, these techniques fall into the non-expandable mold casting category. Centrifugal casting, die casting, continuous casting and permanent molding are all non-expendable casting processes.

Investment casting falls into the expendable mold casting category as the ceramic mold is knocked out after the metal hardens. In certain manufacturing processes, the mold's materials may be retained to form another mold in the future. This is the case with sand casting.

The sand from the mold is broken apart and shaken from the formed metal part. The sand is reclaimed, yet because its molded form was broken when getting to the metal part, it cannot be reused immediately in the molten pour process. Instead, it will need to be reformed into the shell mold again.

Thus, the difference between expendable mold casting processes and permanent mold casting processes is as follows:

1. In permanent mold casting the molten metal is poured into a metallic mold and around the metallic core.
2. In this process produce mass amounts of casting.
3. In expendable mold the molten metal is poured into the mold cavity and produces casting.
4. Expendable molds are made in sand and one mold to produce one casting.

As can be seen from Fig. 5, numerous casting processes can be used. Most can accommodate complex geometry in various weights and sizes, materials and configurations.

There are also other classifications of foundry processes and castings, for example, according to the materials of the workpieces (Fig. 7).

However, overall casting processes are used because:

– they can produce complex shapes with internal cavities or hollow sections;
– many casting processes can produce very large parts;
– they can process materials difficult to process otherwise.

There are many other factors used to assess the suitability of specific casting processes for a particular part. These are discussed under the heading of general characteristics.

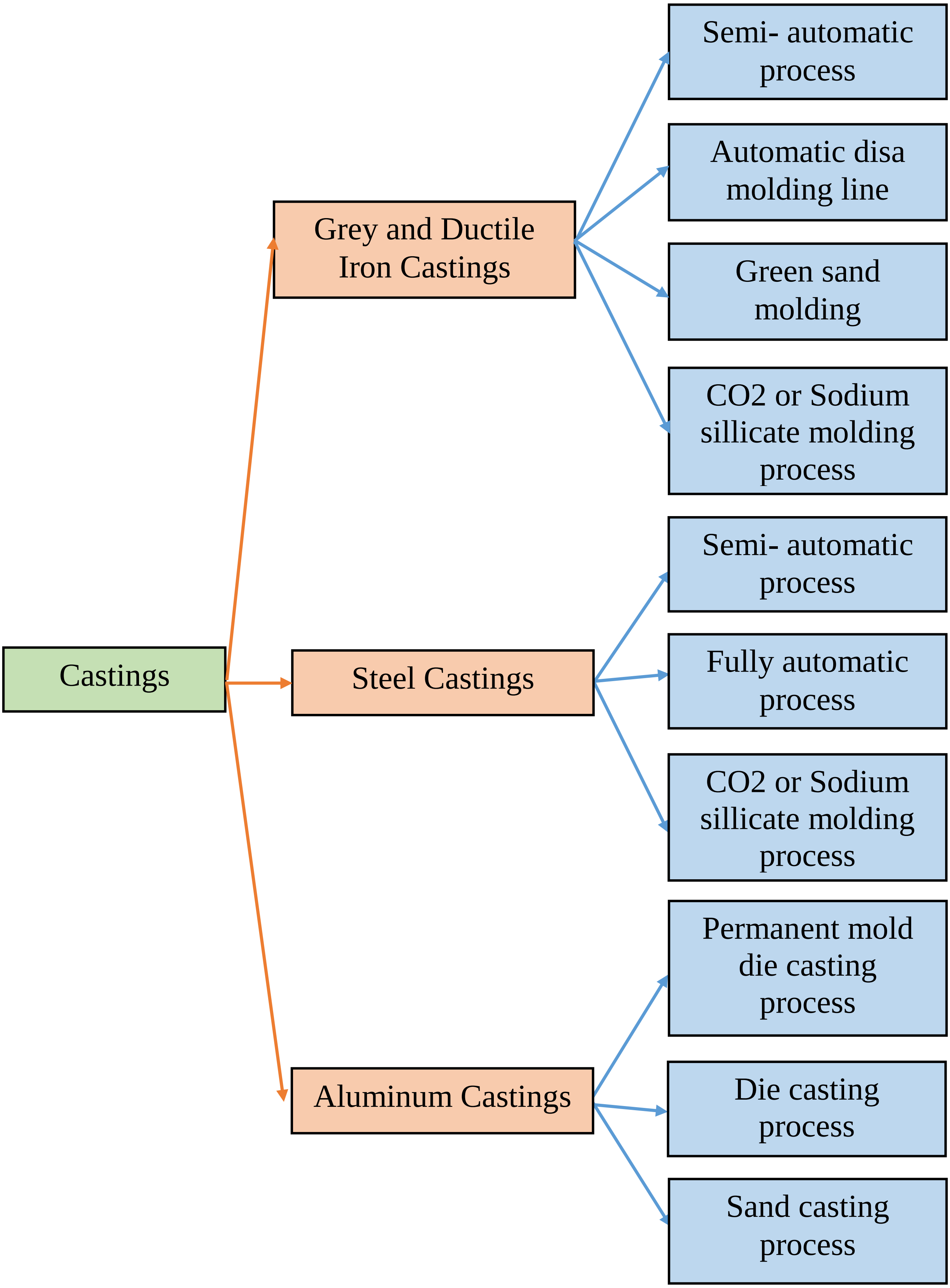


Figure 7 – Classification of foundry processes by casting materials

Multiple Choice Questions

4.1. The casting processes can be classified into two broad categories:

1) sand casting and metal casting processes;
2) die casting and continuous casting processes;
3) expendable mold casting and permanent mold casting processes;
4) investment casting and permanent mold casting processes;
5) hot casting and warm casting processes.

4.2. Which of the following is a permanent mold casting process?

1) centrifugal casting;
2) investment casting;
3) vacuum casting;
4) shell molding.

4.3. What are the types of pressure die casting processes?

1) open pressure and close pressure die casting;
2) cold pressure and hot pressure die casting;
3) gravity die casting and investment casting;
4) low pressure and high pressure die casting, gravity die casting;

4.4. Which of the following processes are expendable mold casting?

1) investment casting, sand casting, shell molding and vacuum molding;
2) low pressure casting;
3) sand casting;
4) shell molding and slush casting.

4.5. In expendable mold casting the molten metal is poured into the:

1) mold cavity to produce casting;
2) sand mold and one mold to produce one casting;
3) metallic mold and around the ceramic core;
4) metallic mold and around the metallic core.

4.6. What are the types of die casting processes?

1) open chamber and close chamber die casting;
2) cold chamber and hot chamber die casting;
3) gravity die casting and investment casting;
4) cold chamber and warm chamber die casting.

4.7. Which of the following processes is permanent mold operations?

1) centrifugal casting;
2) die casting;
3) vacuum permanent-mold casting;
4) sand casting.

4.8. The difference between expendable mold casting processes and permanent mold casting processes is as follows:

1) in an expendable mold the molten metal is poured into the mold cavity and produces casting;
2) permanent mold can produce one casting;
3) in permanent mold casting the molten metal is poured into a metallic mold and around the metallic core;
4) expendable molds are made in sand and one mold to produce one casting.

4.9. Which of the following is not a casting process?

1) Carthias process;
2) extrusion;
3) semi-centrifugal process;
4) slush process.

4.10. In permanent mold casting the molten metal is poured into the:

1) mold cavity to produce casting;
2) sand mold and one mold to produce one casting;
3) metallic mold and around the ceramic core;
4) metallic mold and around the metallic core.

4.11. Which of the following process is a combination of casting & forging?

1) die casting;
2) centrifugal casting;
3) squeeze casting;
4) investment casting.

4.12. Classification of foundry processes by casting materials:

1) ceramic mold casting and plaster mold casting;
2) grey and ductile iron castings; steel casting; aluminum castings;
3) sand casting and injection molding;
4) slush casting, stir casting and squeeze casting.

5. FUNDAMENTALS OF METAL CASTING

5.1. Metal casting basics

A mold is formed into the geometric shape of a desired part. Molten metal is then poured into the mold, the mold holds this material in shape as it solidifies. A metal casting is created.

Although this seems rather simple, the manufacturing process of metal casting is both a science and an art. Let's begin our study of metal casting with the mold. First, molds can be classified as either open or closed. An open mold is a container, like a cup, that has only the shape of the desired part. The molten material is poured directly into the mold cavity which is exposed to the open environment.

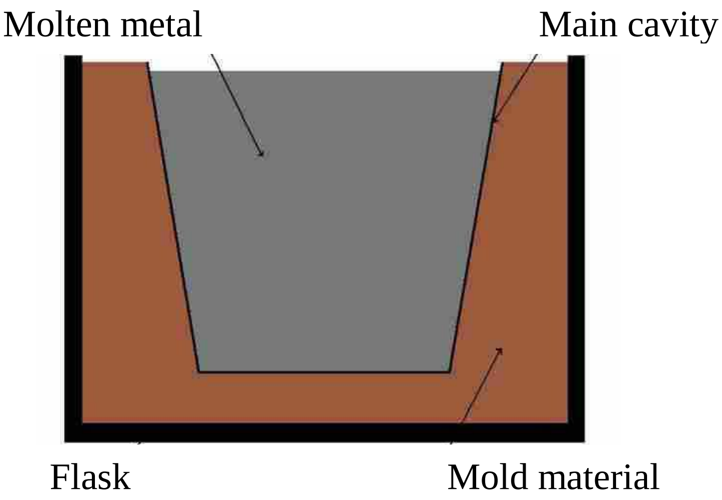


Figure 8 – Open mold

This type of mold is rarely used in manufacturing production, particularly for metal castings of any level of quality. The other type of mold is a closed mold, it contains a delivery system for the molten material to reach the mold cavity, where the part will harden within the mold. A very simple closed mold is shown in Figure 9. The closed mold is, by far, more important in manufacturing metal casting operations.

There are many different metal casting processes used in the manufacture of parts. Two main branches of methods can be distinguished by the basic nature of the mold they employ. There is expendable mold casting and permanent mold casting. As the name implies, expendable molds are used for only one metal casting while permanent molds are used for many. When considering manufacturing processes, there are advantages and disadvantages to both.

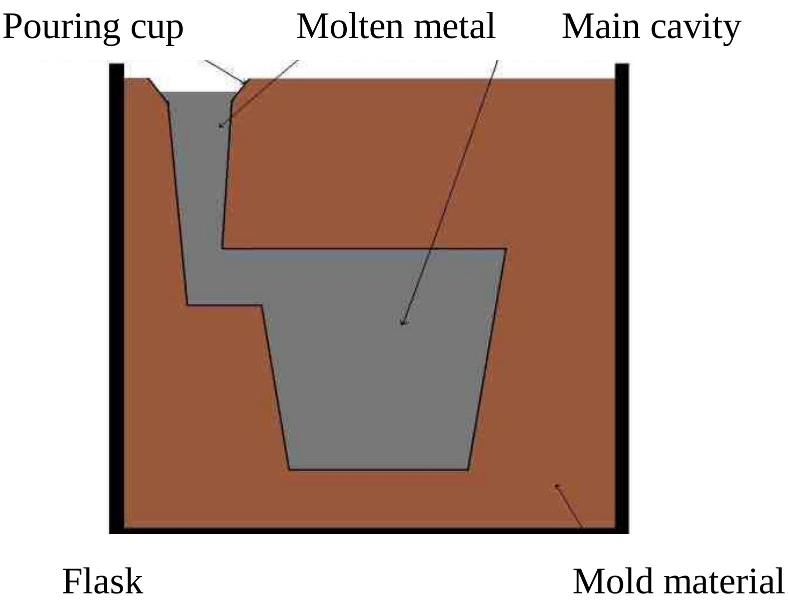


Figure 9 – Closed mold

Expendable mold	**Permanent mold**
• Can produce one metal casting only.	• Can manufacture many metal castings.
• Made of sand, plaster, or other similar material.	• Usually made of metal or sometimes a refractory ceramic.
• Binders used to help material hold its form.	• Mold has sections that can open or close, permitting removal of the casting.
• Mold that metal solidifies in must be destroyed to remove the casting.	• Need to open mold limits part shapes.
• More intricate geometries are possible for casting.	

Patterns.

Expendable molds require some sort of pattern. The interior cavities of the mold, in which the molten metal will solidify, are formed by the impression of this pattern. Pattern design is crucial to success in manufacturing by expendable mold metal casting. The pattern is a geometric replica of the metal casting to be produced. It is made slightly oversize to compensate for the shrinkage that will occur in the metal during the casting's solidification, and whatever amount of material that will be machined off the cast part afterward. Although machining will add an extra process to the manufacture of a part, machining can improve surface finish and part dimensions considerably. Also, increasing the machine finish allowance will help compensate for unknown variables in shrinkage, and reduce trouble from areas of the metal casting that may have been originally too thin or intricate.

Pattern material.

The material from which the pattern is made is dependent upon the type of mold and metal casting process, the casting's geometry and size, the dimensional accuracy required, and the number of metal castings to be manufactured using the pattern. Patterns can be made from wood, like pine (softwood), or mahogany (hardwood) and various metal, like aluminum, cast iron, or steel. In most manufacturing operations, patterns will be coated with a parting agent to ease their removal from the mold.

Cores.

For metal castings with internal geometry cores are used. A core is a replica, (actually an inverse), of the internal features of the part to be cast. Like a pattern, the size of the core is designed to accommodate shrinkage during the metal casting operation. Unlike a pattern, a core remains in the mold while the metal is being poured. Hence, a core is usually made of a similar material as the mold. Once the metal casting has hardened, the core is broken up and removed much like the mold. Depending upon the location and geometry of the core within the casting, it may require that it is supported during the operation to prevent it from moving or shifting. Structural supports that hold the core in place are called chaplets. The chaplets are made of a material with a higher melting temperature than the casting's material and become assimilated into the part when it hardens. Note that when manufacturing a metal casting with a permanent mold process, the core will be a part of the mold itself.

The mold.

A typical mold is shown in Fig. 10.

When manufacturing by metal casting, consideration of the mold is essential. The pattern is placed in the mold and the mold material is packed around it. The mold contains two parts, the drag (bottom), and the cope (top).

The parting line between the cope and drag allows for the mold to be opened and the pattern to be removed once the impression has been made.

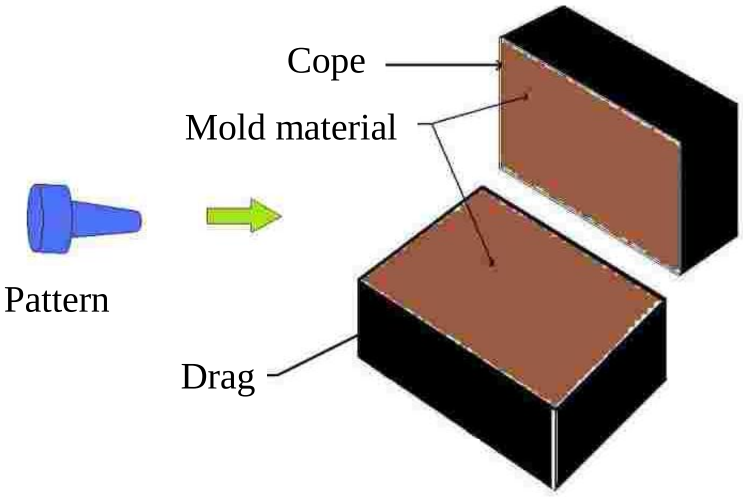


Figure 10 – Typical mold

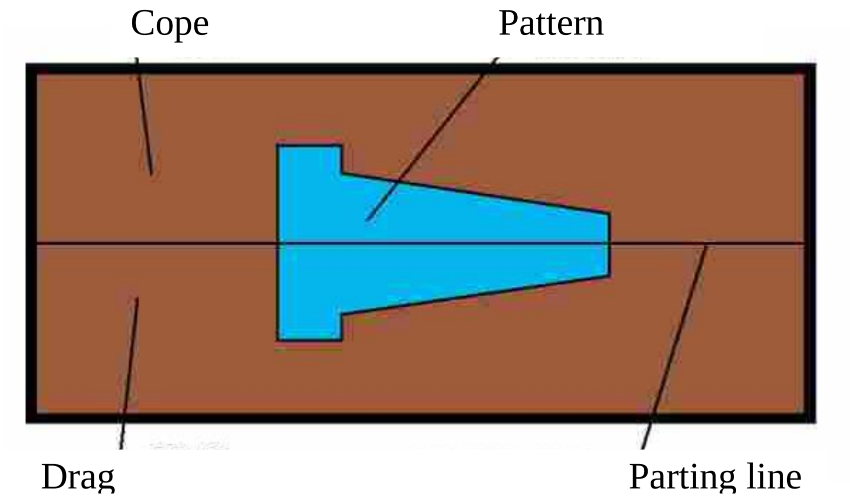


Figure 11 – Elements of the mold in manufacturing by metal casting

The core is placed in the metal casting after the removal of the pattern. Fig. 12 shows the pattern impression with the core in place.

Now the impression in the mold contains all the geometry of the part to be cast. This metal casting setup, however, is not complete. For this mold to be functional to manufacture a casting, in addition to the impression of the part, the mold cavity will also need to include a gating system. Sometimes the gating system will be cut by hand or in more adept manufacturing procedures, the gating system will be incorporated into the pattern along with the part. Basically, a gating system functions during the metal casting operation to facilitate the flow of the molten material into the mold cavity.

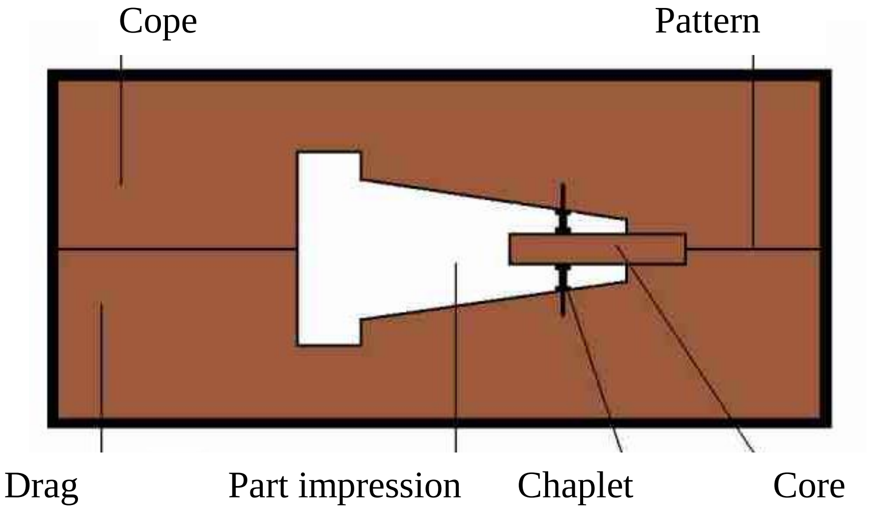


Figure 12 – Pattern impression with the core in place

Types and elements of gating system.

A typical system includes the pouring basin, the sprue, the well, the runner, as well as the ingate. It can be classified based on the position of the parting plane and the position of the ingate.

1. Horizontal system. This type of gating system is ideal for flat casting, which is achieved by filling the mold cavity with gravity. Generally, it is used in ferrous metal sand casting and non-ferrous metal die casting processes.
2. Vertical system. This type of system is suitable for tall casting. It is used for high pressure sand casting, shell mold casting, and die casting.
3. A top-gate system. It is used in processes where molten metal is poured into the top space of a casting. This promotes directional solidification. During the filling process, the system is suitable only for flat casting to limit the metal’s damage.
4. Bottom gating system. It is used for tall castings. The metal enters slowly from the bottom of the cavity.
5. The middle gating system. It combines the features of the bottom and top gates.

Pouring basin.

This is where the molten metal employed to manufacture the part enters the mold. The pouring basin should have a projection with a radius around it to reduce turbulence.

Down sprue.

From the pouring basin, the molten metal for the casting travels through the down sprue. This should be tapered so its cross-section is reduced as it goes downward.

Sprue base.

The down sprue ends at the sprue base. It is here that the casting's inner cavity begins. Sprues should preferably be small at the bottom and big at the top.

Ingate/choke area.

Once at the sprue base, the molten material must pass through the ingate to enter the inner area of the mold. The ingate is very important for flow regulation during the metal casting operation.

Runners.

Runners are passages that distribute the liquid metal to the different areas inside the mold. The purpose of the device is primarily to slow down the flow rate of molten metal during its free fall from the above-mentioned channel to the ingate.

Main cavity.

The impression of the actual part to be cast is often referred to as the main cavity.

Vents:

Vents help to assist in the escape of gases that are expelled from the molten metal during the solidification phase of the metal casting process.

Risers.

Risers are reservoirs of molten material. They feed this material to sections of the mold to compensate for shrinkage as the casting solidifies. There are different classifications for risers.

1. Top risers. Risers that feed the metal casting from the top.
2. Side risers. Risers that feed the metal casting from the side.
3. Blind risers. Risers that are completely contained within the mold.
4. Open risers. Risers that are open at the top to the outside environment.

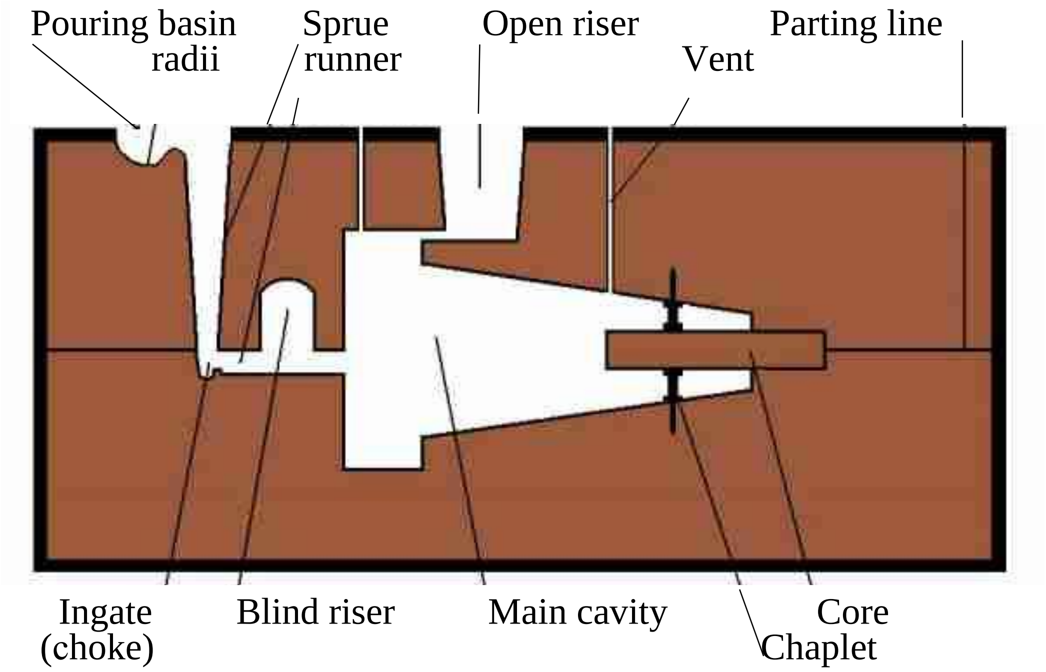


Figure 13 – Gating system for casting

Functional requirements of molding materials.

A foundry molding mixture passes through four main production stages, namely preparation and distribution, mold and core production, casting, and cleaning and reclamation. The property requirements of the materials are determined by molding and casting conditions; the preparation and reclamation stages will, however, also be considered, with particular reference to integrated sand systems.

The principal properties required at the molding stage are flowability and green strength: the former is a measure of the ability of the material to be compacted to a uniform density. The ideal balance of these properties depends largely upon the intended method of compaction, which may vary from hand ramming with tools to jolt, squeeze and impact ramming on molding machines and high-velocity delivery on sand slingers and core blowers. High flowability is particularly necessary in the case of the non-selective ramming action of the molding machine, where the compaction energy must be transmitted throughout the sand mass.

The need for green strength arises when the pattern is withdrawn and the mold must retain shape independently without distortion or collapse. The stress to which the molding material is subjected at this stage depends upon the degree of support from box bars, lifters and core irons and upon the shape and dimensions of the compact: less green strength is needed for a shallow core supported on a core plate or carrier than for a cod of sand forming a deep mold projection.

In many cases, however, dimensional stability and high accuracy may be achieved without the need for appreciable green strength, as when the mold or core is hardened in contact with the pattern surface, a common circumstance when modern bonding systems are employed.

Moving to the pouring stage, many molds are cast in the green state, but others, including most of those for heavy castings, are hardened to generate greater rigidity under the pressure and erosive forces of the liquid metal. This state was formerly achieved by the high-temperature drying of clay-bonded sands or the baking of traditional cores ends, but this has been largely superseded by the chemical hardening of sands containing reactive binders of the modern organic and silicate types. At this stage, therefore, dry strength i.e. strength in the hardened or dried condition is significant; even in greensand practice dry strength is required, to avoid friability should the mold partially dry out during standing before casting.

The other main requirement at the casting stage is for refractoriness, or the ability of the mold material to withstand high temperatures without fusion or other physical change. This property is primarily important in the manufacture of high melting point alloys, especially steel; for alloys of lower melting point, refractoriness can be subordinated to other requirements. In the production of very heavy castings, a considerable layer of molding material rises to a temperature at which normal mechanical properties are no longer the main criterion governing dimensional stability and resistance to contraction. Depending upon the mass of the casting, the sand may require an appropriate combination of high-temperature properties, including hot strength to withstand distortion and the capacity for deformation to yield to the contraction of the casting. Collapsibility determines the readiness with which the molding material will break down in knockout and cleaning operations.

A further feature of the casting stage is the gas evolved and displaced from the mold. Much of this can be exhausted through open feeder heads and vents, but a large volume must also be dissipated through the pore spaces of the sand. This problem is greatest for greensands and core sands. The evaporation of each 1% of moisture from green molding sand can be shown to generate over 30 times its volume of steam; this is paralleled in other types of sand by gases from volatilization and decomposition of organic compounds. To provide a path for the escape of gas, permeability is an essential property, giving protection against surface blows and similar defects. Fineness is required for the prevention of metal penetration and the production of smooth casting surfaces. Since both permeability and fineness are functions of grain size and distribution, the two properties are in conflict and a compromise is usually necessary. Fineness may be achieved by using fine-grained sands, by continuous grading or by the incorporation of filler materials, but all these measures also reduce permeability. An alternative approach is to use a highly permeable molding material and to obtain surface fineness by the use of mold coatings.

Molding materials need certain further qualities which are not necessarily measurable by standard tests. Examples are bench life, the ability to retain molding properties on standing or storage, and durability, the capacity to withstand repeated cycles of heating and cooling in integrated sand systems. It is thus evident that the qualities required in a molding material cannot readily be defined in terms of simple physical properties. For complex aggregates, bulk properties are of greater significance and some of these can be measured directly by simple tests upon sand compacts. Other qualities are represented in specially developed empirical tests designed to reproduce conditions encountered in the foundry. These tests, in conjunction with the direct measurement of more fundamental characteristics such as mechanical grading and chemical composition, provide the basis for the control and development of molding material properties.

Many castings, including most of those made by machine molding, are cast in greensand molds, and the introduction of high-pressure molding machines enabled even castings in the tonnage weight range to be produced to acceptable quality standards. There are strong economic incentives to use this low-cost system, but hardened molds are preferred in many cases, particularly for heavier castings.

Bonding materials.

The function of the binder is to produce cohesion between the refractory grains in the green or hardened state. Since bonding materials are not highly refractory, the required strength must be obtained with the minimum possible addition.

Many substances possess bonding qualities, including clays, starch compounds, silicates and numerous organic resins and oils, both synthetic and natural: they may be used singly or in combination. Clay-bonded sands are distinguished by the fact that they can be recirculated in closed systems and the bond regenerated by the addition of water; the action of most other binders is irreversible and the molding material has to be discarded after a single production cycle, although it is normally reclaimed at least in part for further use after suitable treatment.

5.2. Metal casting operations

In the previous section the fundamentals of the metal casting process, as the basic starting point for metal fabrication and part manufacture, were covered. The setup and design of a system to perform a casting operation was explained. The main topics were molds, patterns, cores, and the elements of a gating system. In this section, we will explain the operation itself. We will begin by assuming that there is a mold with a proper gating system in place and prepared for the metal casting operation.

Pouring of the metal.

When manufacturing by metal casting, pouring refers to the process by which the molten metal is delivered into the mold. It involves its flow through the gating system and into the main cavity (casting itself).

Goal. Metal must flow into all regions of the mold, particularly the casting's main cavity, before solidifying.

Factors of pouring.

Pouring temperature.

Pouring temperature refers to the initial temperature of the molten metal used for the casting as it is poured into the mold. This temperature will be higher than the solidification temperature of the metal. The difference between the solidification temperature and the pouring temperature of the metal is called the superheat.

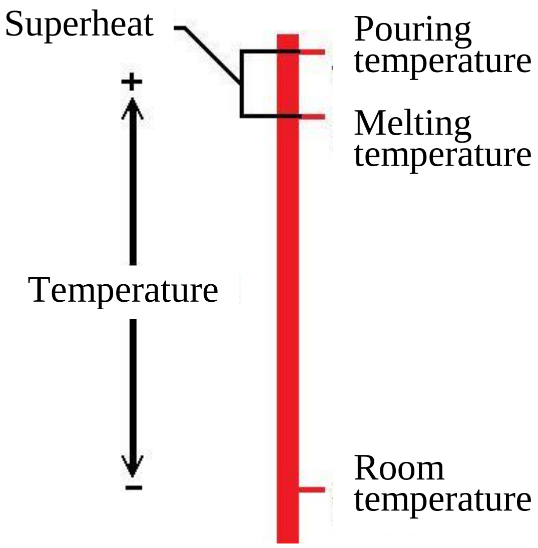


Figure 14 – Allocating temperatures

Pouring rate.

The volumetric rate in which the liquid metal is introduced into the mold. The pouring rate needs to be carefully controlled during the metal casting operation since it has certain effects on the manufacture of the part. If the pouring speed is too large, it will cause the metal liquid to flow violently in the mold and produce a spraying phenomenon, which will lead to slag inclusion or iron beans, and the metal liquid with too high speed will cause a great impact on the sand mold wall, which is easy to destroy the mold and produce sand holes, etc. Casting defects and casting speed also affect the exhaust sequence of the cavity.

Turbulence.

Turbulence is inconsistent and irregular variations in the speed and direction of flow throughout the liquid metal as it travels through the casting. The random impacts caused by turbulence, amplified by the high density of liquid metal, can cause mold erosion. An undesirable effect in the manufacturing process of metal casting, mold erosion is the wearing away of the internal surface of the mold.

It is particularly detrimental if it occurs in the main cavity since this will change the shape of the casting itself. Turbulence is also bad because it can increase the formation of metal oxides which may become entrapped, creating porosity in the solid casting.

Fluidity.

Pouring is a key element in the manufacturing process of metal casting and the main goal of pouring is to get metal to flow into all regions of the mold before solidifying. The properties of the melt in a casting process are very important. The ability of a particular casting melt to flow into a mold before freezing is crucial in the consideration of metal casting techniques. This ability is termed the fluidity of the liquid metal.

Test for fluidity.

In manufacturing practice, the relative fluidity of a certain metal casting melt can be quantified by the use of a spiral mold. The geometry of the spiral mold acts to limit the flow of liquid metal through the length of its spiral cavity. The more fluidity possessed by the molten metal, the farther into the spiral it will be able to flow before hardening. The maximum point the metal reaches upon the casting's solidification may be indexed as that melts relative fluidity.

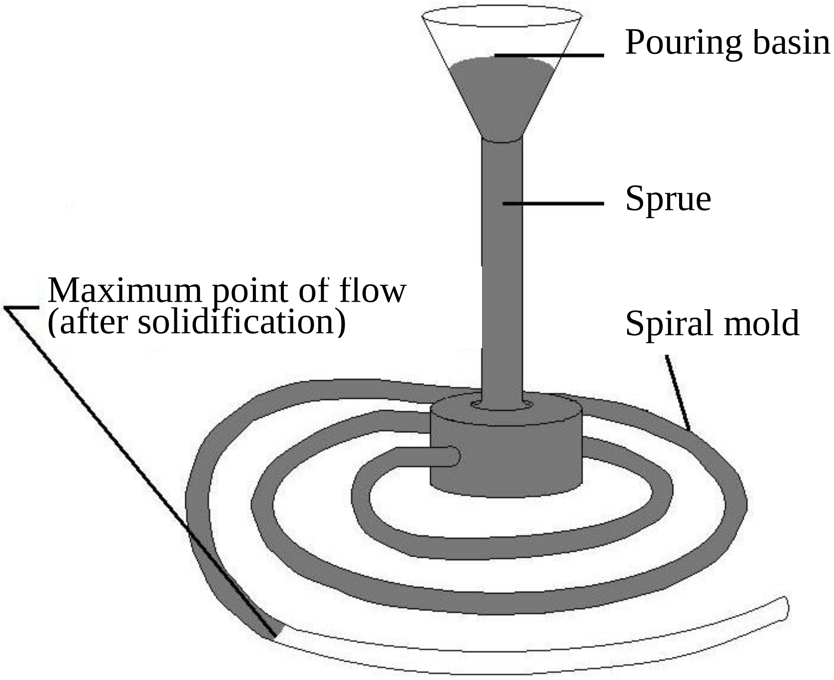


Figure 15 – Spiral mold test

How to increase fluidity in metal casting?

Increase the superheat. If a melt is at a higher temperature relative to its freezing point, it will remain in the liquid state longer throughout the metal casting operation, and hence its fluidity will increase. However, there are disadvantages to manufacturing a metal casting with an increased superheat. It will increase the melts’ likelihood to saturate gases and the formation of oxides. It will also increase the molten metal's ability to penetrate the surface of the mold material.

Choose an eutectic alloy or pure metal.

When selecting a manufacturing material, consider that metals that freeze at a constant temperature have a higher fluidity. Since most alloys freeze over a temperature range, they will develop solid portions that will interfere with the flow of the still-liquid portions, as the freezing of the metal casting occurs.

Choose a metal with a higher heat of fusion. The heat of fusion is the amount of energy involved in the liquid-solid phase change. With a higher heat of fusion, the solidification of the metal casting will take longer and fluidity will be increased.

Shrinkage.

Most materials are less dense in their liquid state than in their solid state, and more dense at lower temperatures in general. Due to this nature, a metal casting undergoing solidification will tend to decrease in volume. During the manufacture of a part by casting this decrease in volume is termed shrinkage. Shrinkage of the casting metal occurs in three stages:

1. Decreased volume of the liquid as it goes from the pouring temperature to the freezing temperature.

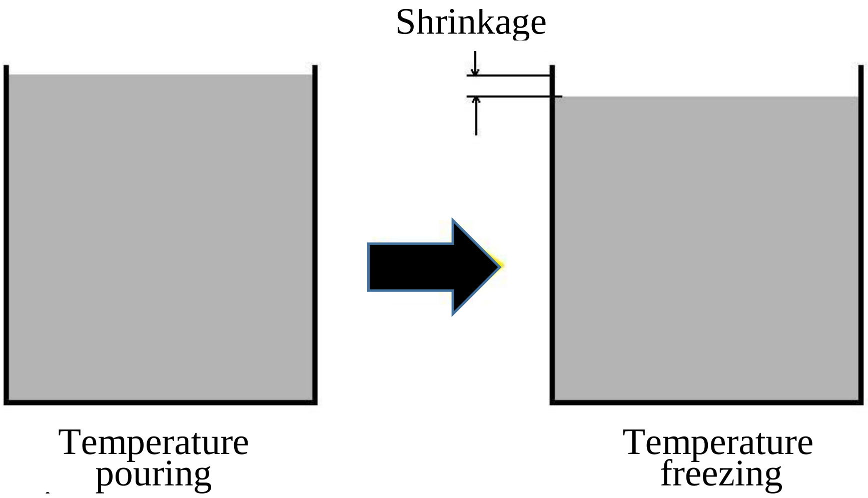


Figure 16 – The first stage

2. Decreased volume of the material due to solidification.

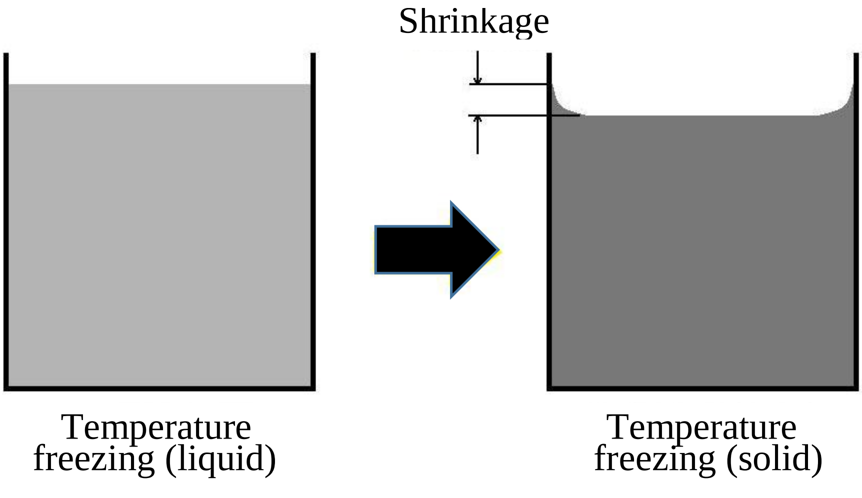


Figure 17 – The second stage

3. Decreased volume of the material as it goes from freezing temperature to room temperature.

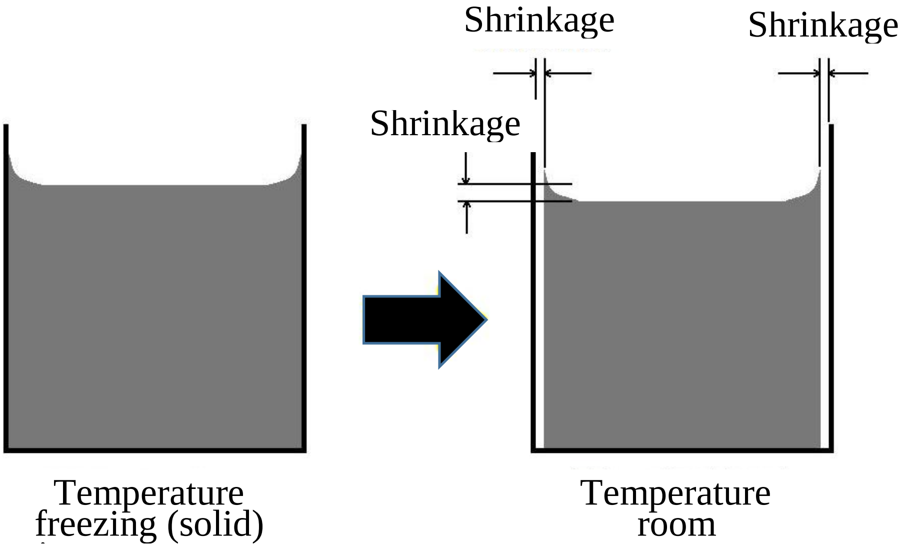


Figure 18 – The third stage

Risers.

When designing a setup for manufacturing a part by metal casting, risers are almost always employed. As the metal casting begins to experience shrinkage, the mold will need additional material to compensate for the decrease in volume. This can be accomplished by the employment of risers. Risers are an important component in the casting's gating system. Risers, (sometimes called feeders), serve to contain additional molten metal. During the metal's solidification process, these reservoirs feed extra material into the casting as shrinkage is occurring.

Thus, supplying it with an adequate amount of liquid metal. A successful riser will remain molten until after the metal casting solidifies. To reduce premature solidification of sections within the riser, in many manufacturing operations, the tops of open risers may be covered with an insulating compound, (such as a refractory ceramic), or an exothermic mixture.

Porosity.

One of the biggest problems caused by shrinkage, during the manufacture of a cast part, is porosity. It happens at different sites within the material when liquid metal can not reach sections of the metal casting where solidification is occurring. As the isolated liquid metal shrinks, a porous or vacant region develops.

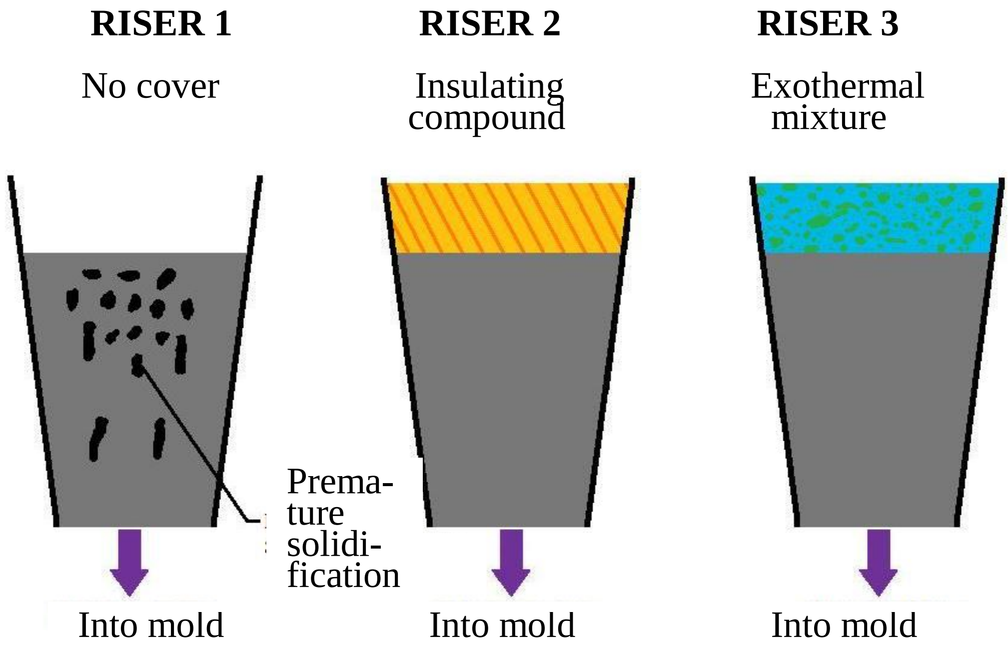


Figure 19 – Types of risers

Development of these regions can be prevented during the manufacturing operation, by strategically planning the flow of the liquid metal into the casting through good mold design, and by the employment of directional solidification. These techniques will be covered in detail in the gating system and mold design section. Note that gases trapped within the molten metal can also be a cause of porosity. The effects of gases while manufacturing parts by metal casting will be discussed in the gases section. Although proper metal casting methods can help mitigate the effects of shrinkage, some shrinkage, (like that which occurs in the cooling of the work metal from the top of the solid state to room temperature), can not be avoided. Therefore, the impression from which the metal casting is made is calculated oversized to the actual part, and the thermal expansion properties of the material used to manufacture the part will be necessary to include in the calculation.

Other defects.

The formation of vacancies within the work material due to shrinkage is a primary concern in the metal casting process. Numerous other defects may occur, falling into various categories.

Metal projections.

The category of metal projections includes all unwanted material projected from the surface of the part. The projections could be small, creating rough surfaces on the manufactured part, or be gross protrusions.

Cavities.

Any cavities in the material, angular or rounded, internal or exposed, fit into this category. Cavities as a defect of metal casting shrinkage or gases would be included here.

Discontinuities.

Cracks, tearing, and cold shuts in the part qualify as discontinuities. Tearing occurs when the metal casting is unable to shrink naturally and a point of high tensile stress is formed. This could occur, for example, in a thin wall connecting two heavy sections. Cold shuts happen when two relatively cold streams of molten metal meet in the pouring of the casting. The surface at the location where they meet does not fuse together completely resulting in a cold shut.

Defective surface.

Defects affecting the surface of the manufactured part. Blows, scabs, laps, folds, scars, blisters, etc.

Incomplete casting.

Sections of the metal casting did not form. In a manufacturing process causes for incomplete metal castings could be; an insufficient amount of material poured, loss of metal from mold, insufficient fluidity in molten material, cross-section within casting's mold cavity is too small, pouring was done too slowly, or pouring temperature was too low.

Incorrect dimensions or shape.

The metal casting is geometrically incorrect. This could be due to unpredicted contractions in the part during solidification. A warped casting. Shrinkage of the metal casting may have been miscalculated. There may have been problems with the manufacture of the pattern.

Inclusions.

Unwanted particles contained within the material act as stress raisers, compromising the casting's strength. During the manufacturing process, the interaction of the molten metal with the environment, such as the mold surfaces and the outside atmosphere, (chemical reactions with oxygen in particular), can cause inclusions within a metal casting. As with most casting defects, good mold maintenance and process design is important in their control.

5.3. Gases in metal casting

The molten metal used during the casting process may trap and contain gases. There are various reasons that gases are absorbed into the metal melt during manufacture. The turbulent flow of the casting material through the system may cause it to trap gas from the air. Gases may be trapped from material or the atmosphere in the crucible when the melt is being prepared. Gases may be trapped from reactions between the molten metal and the mold material.

Since liquid metal has a much higher solubility than solid metal, as the casting solidifies these gases are expelled. If they can not escape they may form vacancies in the material, causing porosity in the metal casting.

Whether a vacancy in a cast material is a result of gases or shrinkage is sometimes hard to tell. If the vacancies are spherical and smooth they are most likely a result of gases. Angular and rough vacancies are most likely a result of shrinkage. Gross absences of material within the metal casting are a result of shrinkage.

Typical types of gas defects during casting.

1. Pinholes. As the name suggests, have the appearance of very small holes and tend to be around 2 mm in size. Generally, pinholes are found in the cope (upper part of the mold) in areas that are poorly ventilated. They tend to form in clusters at the surface of the metal meaning, it is achievable to identify them without the use of specialized equipment.

2. Blowholes. Also known as ‘blows’, are a larger type of gas porosity defect compared to pinholes. Unfortunately, these larger defects can occur within the structure of the metal, making them difficult to detect and sometimes only detected as a result of the following machining operations. On the other hand, blowholes in the center of the casting structure will require non-destructive testing such as ultrasonic testing to detect or control them.

3. Open holes. They are gas porosity defects that are on the surface and ‘open’ to the surface. Due to being on the surface, they are very easy to detect.

Prevention of gas defects when manufacturing a part by casting:

- Gases being expelled by the material during solidification can be eliminated by a proper venting system in the mold. This can be planned out during the manufacturing design phase of the metal casting process.

- Mitigating the amount of turbulence in the fluid flow will reduce gas absorption into the metal.
- Removal of slag will help eliminate gases and other impurities in the casting.
- Gases may be removed by flushing a metal melt with inert gas.
- Elimination of gases may also be accomplished by pouring the metal casting in a vacuum.
- Melting the metal in a vacuum or an environment of low solubility gases such as carbon dioxide or argon.
- Melting the metal under a flux to prevent the metal from reacting with the atmosphere.
- Using a mold design that minimizes the turbulent flow of the molten metal because turbulent flow introduces gases.

Material selection.

The selection of proper materials is important in the design of a metal casting process. Here are a few things to remember when selecting manufacturing materials.

1. Metals may react a certain way with other materials they encounter during the casting process. This should always be a consideration. For example, liquid aluminum will react readily with iron. Iron ladles and surfaces contacting the molten aluminum can be covered with a spray-on ceramic coating to prevent this.
2. When selecting a type of manufacturing process, remember that some materials may be more applicable to different metal casting techniques than others.
3. Knowing the specific heat of the mold and that of the metal used for the casting will be influential in controlling the thermal gradients in the system.
4. The section of casting metal will factor heavily into the melt's fluidity.
5. A material with a high heat of fusion will take longer to solidify and may improve flow characteristics within the casting.
6. When manufacturing a casting with a metal alloy that freezes over a temperature range, problems may occur due to the solid phase interfering with the liquid phase, both of which will be present within the temperature range. To reduce this problem, a metal alloy with a shorter solidification temperature range may be selected to manufacture the casting. Or select a mold material with a high thermal conductivity, which could reduce the time spent in the solidification range by increasing the cooling rate.

5.4. Metal casting design

In the previous sections, we discussed the fundamental aspects of manufacturing parts by metal casting. We covered the creation of patterns and the setup of the mold and gating system. Also, we discussed the metal casting operation itself, including the pouring of the molten material into the mold, the elements and functions of the different parts of the mold during the manufacture of the cast part, and the problems and possible defects encountered during the employment of the manufacturing process of metal casting.

In this section, we will examine the specifics of good mold and gating system design to manufacture higher-quality metal castings and minimize defects that may occur during the casting process. This section will be useful to those designing a system to manufacture a part by metal casting, or to help as a troubleshooting guide for improvement upon an existing system.

Gating system and mold design.

When selecting to manufacture a part by casting one must consider the material properties and possible defects that this manufacturing process produces. The primary way to control metal casting defects is through good mold design considerations in the creation of the casting's mold and gating system. The key is to design a system that promotes directional solidification.

Directional solidification, in casting manufacture, means that the material will solidify in a manner that we plan, usually as uniformly as possible with the areas farthest away from the supply of molten metal solidifying first and then progressing towards the risers. The solidification of the casting must be such that there are never any solid areas that will cut off the flow of liquid material to unsolidified areas creating isolated regions that result in vacancies within the casting's material, as discussed in the Metal Casting Operation section and shown in Fig. 20.

It is important to create an effective manufacturing process. Gating system design is crucial in controlling the rate and turbulence in the molten metal being poured, the flow of liquid metal through the gating system, and the temperature gradient within the metal casting.

Hence a good gating system will create directional solidification throughout the casting since the flow of molten material and temperature gradient will determine how the metal casting solidifies.

When designing a mold for a metal casting or trying to fix or improve upon an existing design the following aspects must be considered.

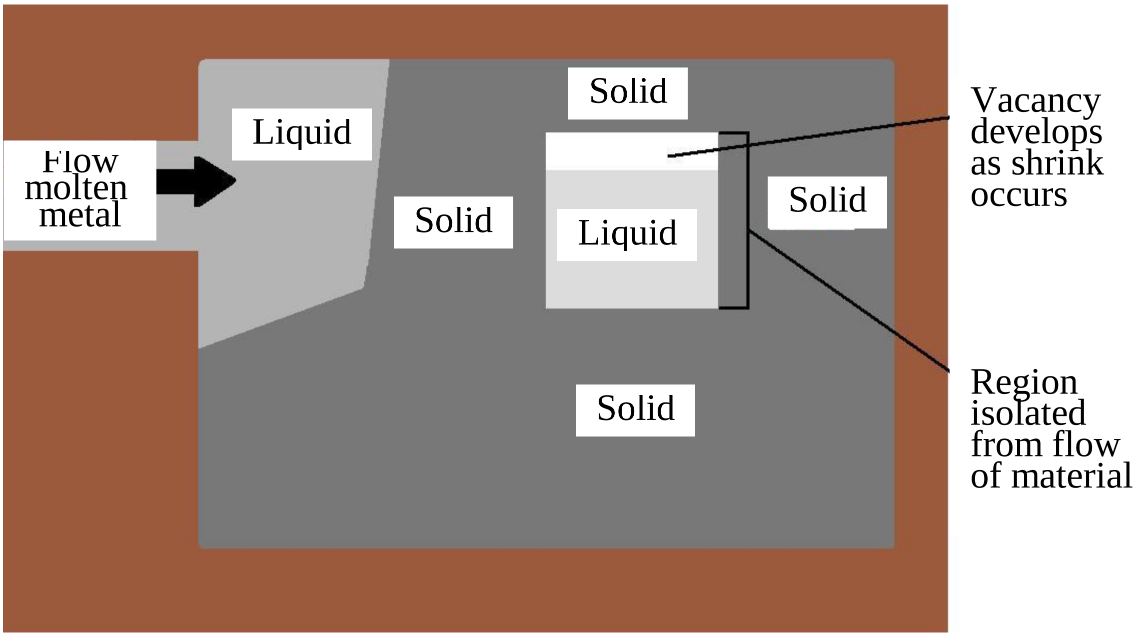


Figure 20 – Liquid and solid areas of material

Ensure that you have adequate material.

This may seem very obvious, but in the manufacturing of parts, many incomplete castings have been a result of insufficient material. It is always necessary to make sure that the volume of all areas of the casting, taking into account shrinkage, is correctly calculated.

Consider the superheat.

Increasing the superheat, (temperature difference between the metal at pouring and freezing), as mentioned previously can increase the fluidity of the material for the casting, which can assist with its flow into the mold.

This causes a compromise in the manufacturing process. Increasing the superheat has problems associated with it, such as increased gas porosity, increased oxide formation, and mold penetration.

Insulate risers.

Since the riser is the reservoir of molten material for the casting, it should last to solidify. Insulating the top as mentioned earlier, shown in Fig. 19, will greatly reduce cooling in the risers from the steep temperature gradient between the liquid metal of the casting, and the room temperature air.

Consider V/A ratios.

In casting manufacture, the V/A ratio stands for volume to surface area or mathematically (volume/surface area). When solidification of a casting begins a thin skin of solid metal is first formed on the surface between the casting and the mold wall. As solidification continues the thickness of this skin increases towards the center of the liquid mass.

Sections in the casting with low volume to surface area will solidify faster than sections with higher volume to the surface area. When manufacturing a part by metal casting consideration of the V/A ratios is critical in avoiding premature solidification of the casting and the formation of vacancies.

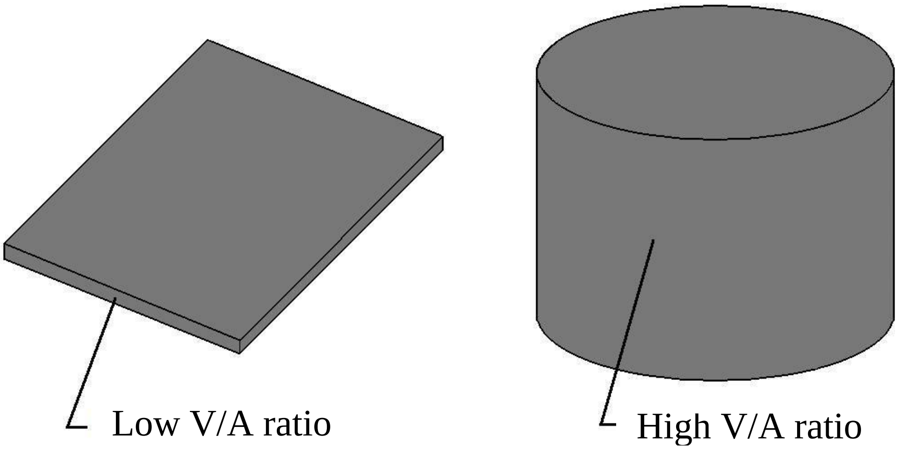


Figure 21 – Low and high V/A ratio

Heat masses.

Avoid large heat masses in locations distant to risers. Instead, locating sections of the casting with low V/A ratios further away from the risers will ensure a smooth solidification of the casting.

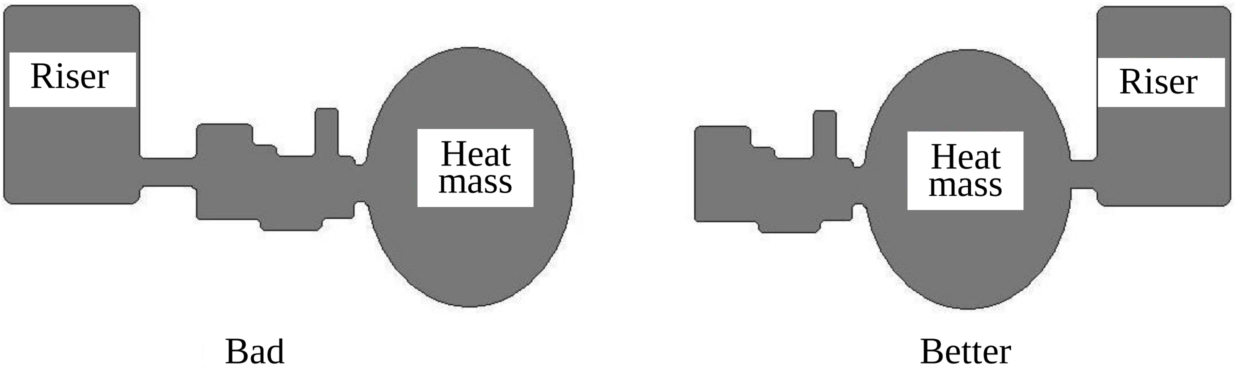
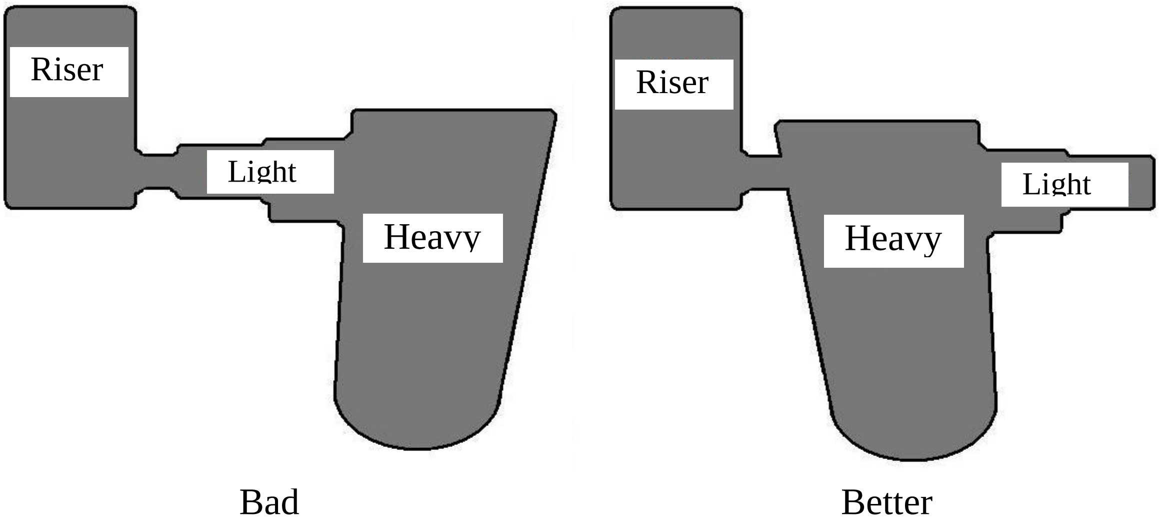


Figure 22 – Locating sections of the casting

Sections of the casting.

The flow of material is very important to the manufacturing process. Do not feed a heavy section through a lighter one.



Bad Better

Figure 23 – Sections of the casting

Be careful with consideration to L, T, V, Y and + junctions.

Due to the nature of the geometry of these sections, they will likely contain an area where the metal casting's solidification is slower than the rest of the junction. These hot spots are circled in white in Fig. 24. They are located such that the material around the flow of molten metal.

Some possible design alternatives are shown in Fig. 24. These should reduce the likelihood of the formation of hot spots.

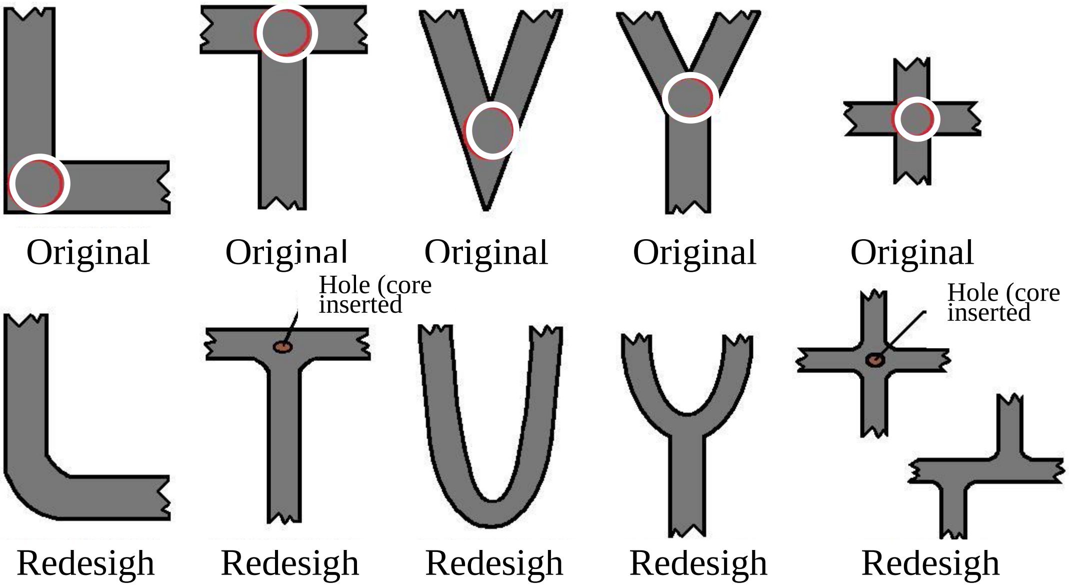


Figure 24 – Design of the metal casting

The flow of casting material must be carefully considered when manufacturing such junctions. If there is some flexibility in the design of the metal casting and it is possible you may want to think about redesigning the junction.

Prevent planes of weakness.

When metal castings solidify, columnar grain structures tend to develop, in the material, pointing towards the center. Due to this nature, sharp corners in the casting may develop a plane of weakness. By rounding the edges of sharp corners this can be prevented.

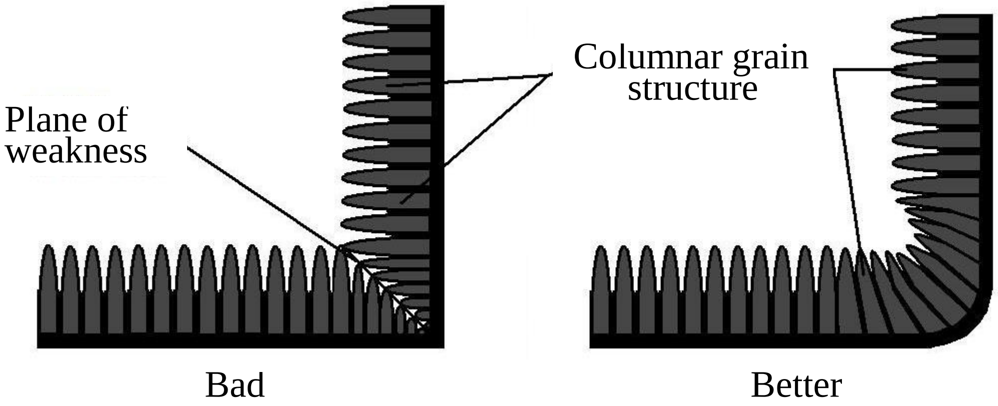


Figure 25 – Sharp corners in the casting

Reduce turbulence.

When manufacturing a metal casting, turbulence is always a factor in the flow of molten metal. Turbulence, as covered earlier in the pouring section, is bad because it can trap gases in the casting material and cause mold erosion. Although not altogether preventable in the manufacturing process, turbulence can be reduced by the design of a gating system that promotes a more laminar flow of the liquid metal. Sharp corners and abrupt changes in sections within the metal casting can be a leading cause of turbulence. Their effect can be mitigated by the employment of radii.

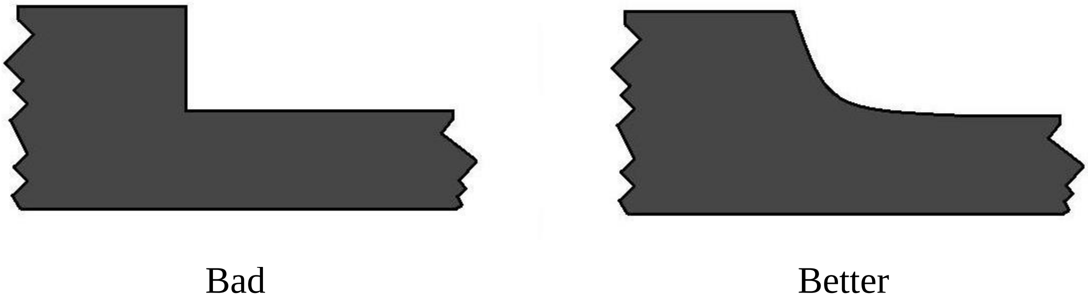


Figure 26 – Turbulences

Turbulence refers to the variations that occur in both the direction and the speed of flow of the liquid metal when casting. Besides, there are numerous other reasons for gas to be trapped in the molten metal as well. For instance, gases can get into the material or the air present in the crucible during the preparation phase.

Connection between riser and casting must stay open.

Riser design is very important in metal casting manufacturing. If the passage linking the riser to the metal casting solidifies before the casting, the flow of molten metal to the casting will be blocked and the riser will cease to serve its function. If the connection has a larger cross-sectional area it will decrease its time to freeze.

Good manufacturing design, however, dictates that we minimize this cross-section as much as possible to reduce the waste of material in the casting process. By making the passageway short we can keep the metal in its liquid state longer since it will be receiving more heat transfer from both the riser and the casting.

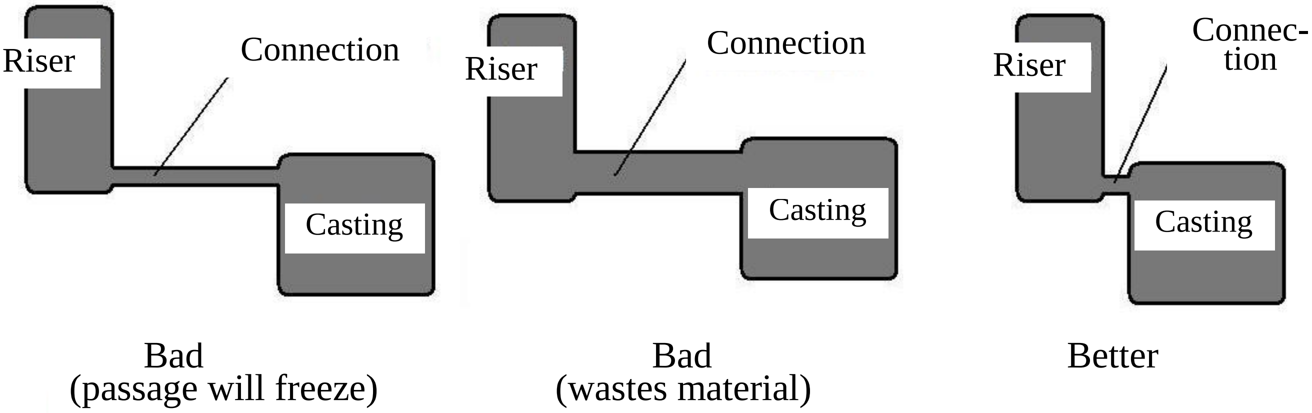


Figure 27 – Connection between riser and casting

Tapered down sprue.

Flow considerations for our metal casting manufacture begin as soon as the molten metal enters the mold. The liquid metal for the casting travels from the pouring basin through the down sprue. As it goes downward it will pick up speed, and thus it will tend to separate from the walls of the mold. The down sprue must be tapered such that continuity of the fluid flow is maintained. Remember the fluid mechanic's equation for continuity $A_1V_1 = A_2V_2$. Where V is the velocity of the liquid and A is the cross-sectional area that it is traveling through. If it is not possible to make these measurements, it would simply be better to err on the side of making A_2 smaller, provided the pouring rate does not become too slow. In other words, taper a little more and just adjust the pouring of the casting so that keep a consistent flow of liquid metal.

Ingate design.

The ingate is another aspect of manufacturing design that relates to the flow of metal through the casting system. The ingate, is basically where the casting material enters the actual mold cavity.

It is a crucial element, and all other factors of the metal casting's mold design are dependent on it. In the location next to the sprue base the cross-sectional area of the ingate is reduced (choke area). The cross-sectional reduction must be carefully calculated.

The flow rate of casting material into the mold can be controlled accurately in this way. The flow rate of the casting metal must be high enough to avoid any premature solidification.

However, it needs to be sure that the flow of molten material into the mold does not exceed the rate of delivery into the pouring basin and thus ensure that the casting's gating system stays full of metal throughout the manufacturing process.

Other flow considerations.

In the manufacturing design phase, when planning the metal casting process, the analysis of the path of flow of liquid metal within the mold must be carefully calculated. At no point in the filling of the casting cavity should two separate streams of liquid metal meet. The result could be an incomplete fusion of the casting material (cold shut), as covered in the defects section under discontinuities.

Use of chills.

As mentioned earlier directional solidification is very important to the manufacture of a part during the metal casting process, to ensure that no area of the casting is cut off from the flow of liquid material before it solidifies. To achieve directional solidification within the metal casting, it is important to control the flow of fluid material and the solidification rate of the different areas of the metal casting.

Concerning the solidification of the metal casting's different sections, regulation of thermal gradients is the key. Sometimes we may have an area of the metal casting that will need to solidify at a faster rate to ensure that directional solidification occurs properly. Manufacture planning and design of flow and section locations within the mold may not be sufficient. To accelerate the solidification of a section like this in our casting, we may employ the use of chills. Chills act as heat sinks, increasing the cooling rate in the vicinity where they are placed.

Fig. 28 demonstrates the use of the two types of chills to solve the hot spot problem in a + and T junction.

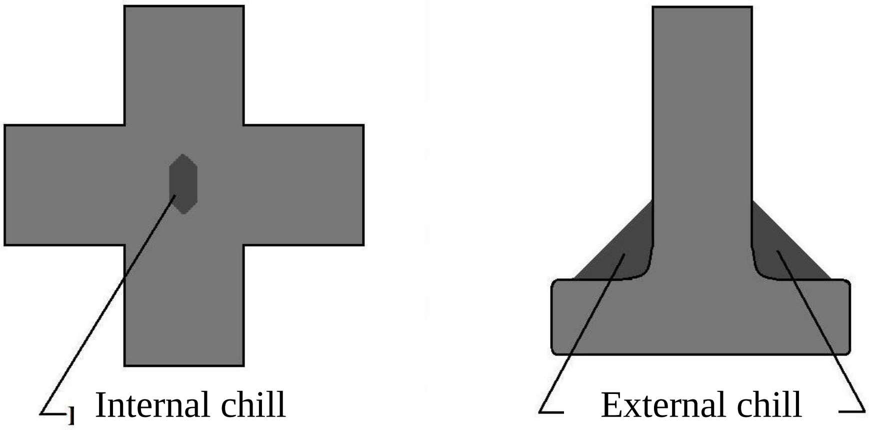


Figure 28 – Two types of chills

Chills are solid geometric shapes of material, manufactured for this purpose. They are placed inside the mold cavity before pouring. Chills are of two basic types. Internal chills are located inside the mold cavity and are usually made of the same material as the casting. When the metal solidifies the internal chills are fused into the metal casting itself. External chills are located just outside of the casting. External chills are made of a material that can remove heat from the metal casting faster than the surrounding mold material. Possible materials for external chills include iron, copper, and graphite.

In metal casting, various methods are adopted to prevent gas from being trapped inside and thus cause defects. These techniques are adopted by most of the die cast industries to ensure that their finished components bear no internal weaknesses in the form of porosity and other defects. The inclusion of a proper venting system in the mold can prevent any gas defects to occur in the mold. This is usually done in the manufacturing design stage of the die casting process. The other includes reducing the amount of turbulence in the flow of the molten metal, which will considerably minimize the absorption of gas into the metal. Slag removal is another method that will remove any gases and other impurities in the casting material. Other techniques like vacuum casting are also utilized to eliminate gases from the metal casting.

Multiple Choice Questions

5.1. Molds can be classified as:

1) open or closed;
2) permanent or disposable;
3) internal or external;
4) small or large;
5) manual or mechanical.

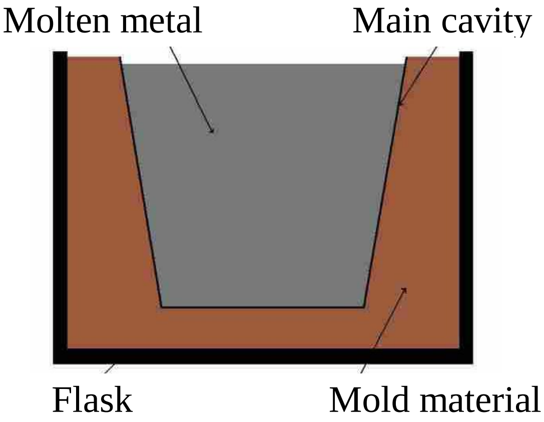
5.2. Define what is an open mold for casting molten material.

1) an open mold is a cavity designed for pouring molten metal by hand;
2) an open mold is a hollow container designed for cooling the molten metal;
3) an open mold is a container, like a cup, that has only the shape of the desired part;
4) an open mold is a technological equipment in foundry production for molding castings.

5.3. What is the characteristic feature of open molds for metal casting?

1) the open mold is designed for casting molten metal under the influence of gravity;
2) open molds are used only for pouring molten metal by hand;
3) the molten metal is poured directly into the mold cavity which is exposed to the open environment;
4) molten metal is poured into the cavity of the open mold for faster cooling of the casting.

5.4. Name the mold for metal casting shown in the figure.



1) external mold;
2) closed mold;
3) manual mold;
4) open mold;
5) mold for the vertical pouring of molten metal.

5.5. What is a characteristic feature of closed molds for metal casting?

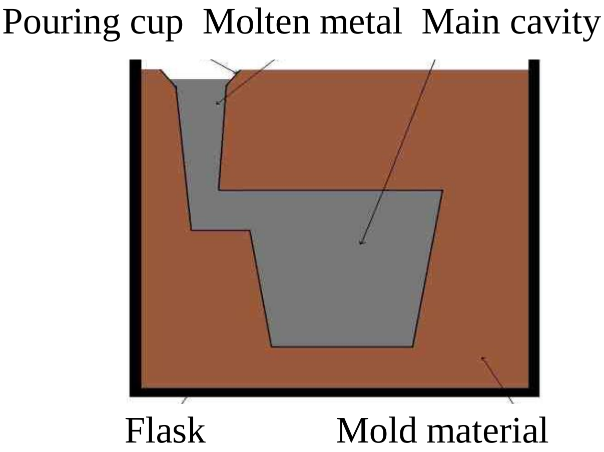
1) the molten metal is poured directly into the cavity of the closed mold;

2) the closed mold protects the molten metal from the influence of the external environment;
3) closed mold contains a delivery system for the molten material to reach the mold cavity, where the part will harden within the mold;
4) the closed mold is designed for casting molten metal under pressure.

5.6. How are molten material casting processes classified by the nature of the mold?

1) expendable mold casting;
2) casting into the internal mold;
3) permanent mold casting;
4) casting in combined molds;
5) casting in special molds.

5.7. Name the scheme of the mold for casting shown in the figure.



1) external mold;
2) permanent mold;
3) closed mold;
4) manual mold;
5) combined mold;
6) special mold.

5.8. Establish correspondence between the types of forms and their use.

A	Expendable molds
B	Permanent molds

1	are used for only one metal casting process.
2	are used only for double metal casting.
3	are used for repeated metal casting.
4	are used for many metal casting operations.
5	are used for metal casting in unlimited quantities.

1) A – 1;
2) A – 3;
3) A – 4;
4) B – 3;
5) B – 4;
6) B – 5.

5.9. What are the advantages of expendable molds for casting?

1) easy to manufacture;
2) easy to use;

3) binders used to help material hold its form;
4) more intricate geometries are possible for casting.

5.10. What are the disadvantages of expendable molds for casting?
1) can produce one metal casting only;
2) made of sand, plaster, or other similar material;
3) low accuracy of the shape of castings;
4) mold that metal solidifies in must be destroyed to remove the casting.

5.11. What are the advantages of permanent molds for casting?
1) can manufacture many metal castings;
2) usually made of sand, plaster, or other similar materials;
3) usually made of metal or sometimes a refractory ceramic;
4) mold has sections that can open or close, permitting removal of the casting;
5) low production cost.

5.12. What are the disadvantages of permanent molds for casting?
1) can produce one metal casting only;
2) low production cost;
3) need to open mold limits part shapes;
4) mold that metal solidifies in must be destroyed to remove the casting.

5.13. The interior cavities of the mold, in which the molten metal will solidify, are formed by the impression:
1) prototype of the finished casting;
2) standard of the finished casting;
3) pattern;
4) core;
5) rod.

5.14. What is a pattern in foundry production?
1) a tool for filling the inner cavity of the mold;
2) a device for pouring molten metal into the mold;
3) a geometric replica of the metal casting to be produced;
4) replica, (actually an inverse), of the internal features of the part to be cast.

5.15. What are the dimensions of the pattern relative to the dimensions of the casting?

1) it is made slightly oversize than the dimensions of the casting;
2) it is made exactly according to the dimensions of the casting;
3) the dimensions of the pattern are smaller than the dimensions of the casting;
4) patterns are made in arbitrary sizes.

5.16. Why is the pattern made a little larger concerning the size of the casting?

1) to compensate for the tolerance on the dimensions of the pattern during its manufacture;
2) to compensate for the shrinkage that will occur in the metal during the casting's solidification;
3) to compensate for excess molten metal after filling the inner mold cavity;
4) whatever amount of material will be machined off the cast part afterward.

5.17. What provides an increase in the tolerance for mechanical processing of the casting?

1) increasing the accuracy of casting dimensions after machining or shaping;
2) improvement of the quality of the surface of the casting after mechanical processing;
3) increasing the machine finish allowance will help compensate for unknown variables in shrinkage;
4) reducing trouble from areas of the metal casting that may have been originally too thin or intricate.

5.18. The material from which the pattern is made is dependent upon the:

1) type of mold and metal casting process;
2) casting's geometry and size;
3) dimensional accuracy required castings;
4) production cost of castings;
5) a number of metal castings to be manufactured using the pattern.

5.19. Patterns can be made from:

1) wood, like pine (softwood), or mahogany (hardwood);

2) plastics: polyethylene (polyplast) or polystyrene (reactoplast);
3) various metals, like aluminum, cast iron, or steel;
4) ceramic materials (heat-resistant).

5.20. The patterns are coated with a release agent to:
1) increase their wear resistance;
2) improve the quality of the adjacent surface of the casting;
3) ensure their corrosion resistance;
4) ease their removal from the mold.

5.21. For which metal castings are cores used?
1) for metal castings with external dimensions;
2) for metal castings with internal geometry;
3) for non-metallic castings of any size;
4) for hollow metal castings of complex shape;
5) for hollow metal castings of a simple shape.

5.22. What is a core?
1) replica, (actually an inverse), of the internal features of the part to be cast;
2) a tool for filling the inner cavity of the mold;
3) a device for pouring molten metal into the mold;
4) a geometric replica of the metal casting to be produced.

5.23. What is the function of cores used in casting?
1) to remove dissolved gases;
2) to avoid defects;
3) to form a hollow region;
4) to reduce shrinkage porosity.

5.24. The size of the core is designed:
1) to compensate for the tolerance on the dimensions of the pattern during its manufacture;
2) to compensate for excess molten metal after filling the inner mold cavity;
3) to accommodate for shrinkage during the metal casting operation;
4) whatever amount of material will be machined off the cast part afterward.

5.25. While the metal is being poured:
1) core remains in the mold;
2) core removes from the mold during metal pouring;
3) core serves as a catalyst during the pouring and solidification of the metal;
4) core serves as an alloying element during the pouring of metal into the inner cavity of the mold.

5.26. What material are the cores made of?
1) cores are made of structural steels;
2) cores are made of alloy steels;
3) cores are made of hard alloy materials;
4) cores are made of non-ferrous metals and alloys;
5) cores are usually made of the same material as the mold.

5. 27. Cores are not made up of:
1) sand;
2) wax;
3) plaster;
4) ceramics;
5) glass.

5.28. Structural supports that hold the core in place are called:
1) chaplets;
2) rods;
3) patterns;
4) drags;
5) stiffeners.

5.29. What are the chaplets?
1) metal supports of various designs used to hold the core in place in the metal mold;
2) sand supports of various designs used to hold the core in place in the sand mold;
3) metal supports of various designs used to hold the core in place in the sand mold;
4) sand supports of various designs used to hold the core in place in the metal mold.

5.30. The chaplets are made of material with:

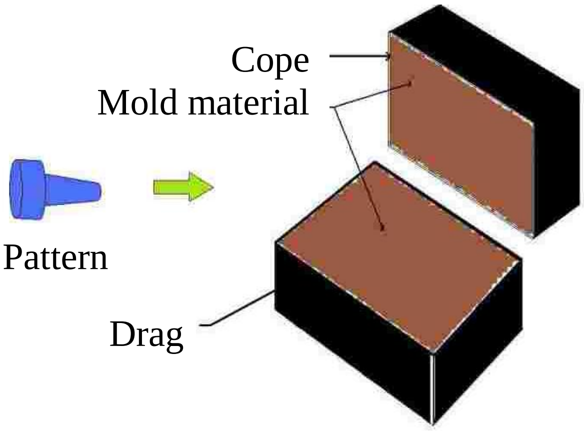
1) minimum melting temperature of the casting's material;
2) lower melting temperature than the casting's material;
3) equal to the melting temperature of the casting's material;
4) higher melting temperature than the casting's material.

5.31. What parts does the mold consist of?

1) the cope (top);
2) the parting line;
3) the drag (bottom);
4) chaplets;
5) patterns.

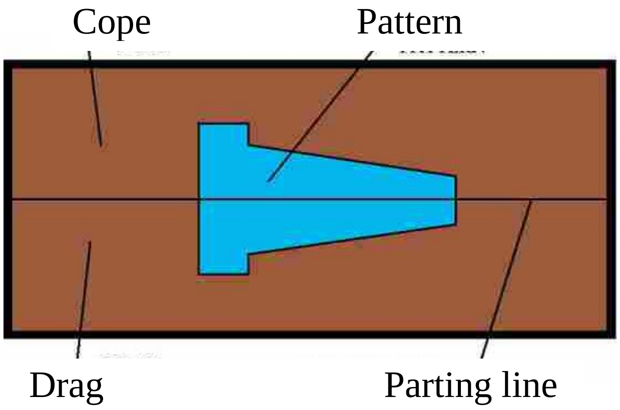
5.32. What is shown in the figure?

1) scheme of forming the inner cavity of the mold for casting;
2) a flask for filling the material of the mold;
3) contours of the rod to form a cavity in which the molten metal solidifies;
4) typical casting mold.



5.33. The figure demonstrates:

1) scheme of forming the inner cavity of the mold for casting;
2) a flask for filling the material of the mold;
3) elements of the mold in manufacturing by casting;
4) scheme of installing the core in the mold for casting.

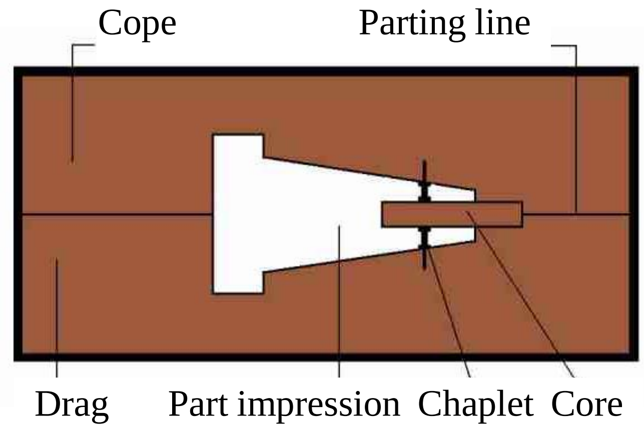


5.34. The core is placed in the metal casting:

1) before removing the pattern from the mold
2) during the removal of the pattern;
3) after the removal of the pattern;
4) during removing cope.

5.35. What is shown in the figure?

1) a flask for filling the material of the mold;
2) pattern impression with the core in place;
3) scheme of forming the inner cavity of the mold for casting;
4) elements of the mold in casting.



5.36. Which of the following is not a requirement of a good pattern?

1) it should be light in weight to handle easily;
2) it should be smooth to make the casting surface smooth;
3) it should have low strength to break it and to remove casting easily;
4) it should have high strength to break it and to remove casting easily.

5.37. The patterns which are made in two or more pieces are called:

1) solid patterns;
2) split patterns;
3) loose piece patterns;
4) open pattern.

5.38. In addition to the impression of the part, the mold cavity needs to include:

1) mold cooling system;
2) mold lubrication system;
3) a gating system;
4) ventilation system.

5.39. What is the gating system for?

1) to ensure lubrication of the mold before pouring the molten metal;
2) to provide ventilation of the mold during solidification of the casting;
3) to ensure cooling of the mold after pouring the molten metal;
4) to facilitate the flow of the molten material into the mold cavity.

5.40. In which type of gating system aspiration effect takes place?

1) vertical;
2) horizontal;
3) diagonal;
4) bottom.

5.41. The time required to fill the mold of the vertical gating system is:
1) less to bottom gating system;
2) more to bottom gating system;
3) equal to bottom gating system;
4) sometimes more and sometimes less to bottom gating system.

5.42. A small funnel-shaped cavity at the top of the mold into which the metal is poured is known as:
1) sprue;
2) core;
3) pouring basin;
4) gate.
5) pattern.

5.43. The pouring basin is where:
1) the molten metal employed to manufacture the workpiece enters the mold;
2) the molten metal enters the inner cavity of the mold for casting;
3) the molten metal flows between the mold halves;
4) the molten metal is located to feed the casting and compensate for shrinkage during solidification.

5.44. The pouring basin should have a projection with a radius around it in order to:
1) to slow down the process of solidification of the metal during casting;
2) to speed up the process of metal solidification during casting;
3) to reduce the flow rate of molten metal;
4) to increase the flow rate of molten metal;
5) to reduce turbulence.

5.45. From the pouring basin, the molten metal for the casting travels:
1) through the down sprue;
2) through the top sprue;
3) through the ingate;
4) through the bottom sprue;
5) through the vents;
6) through the risers.

5.46. Down sprue should be tapered:

1) to speed up the process of metal solidification during casting;
2) to reduce the flow rate of molten metal;
3) to increase the flow rate of molten metal;
4) to reduce its cross-section as the molten metal goes downward.

5.47. The down sprue ends:

1) at the ingate;
2) at the sprue base;
3) at the top of the sprue;
4) at the riser;
5) at the bottom sprue.

5.48. Where does the inner cavity of the casting begin?

1) at the core;
2) at the pattern;
3) at the top of the sprue;
4) at the sprue base;
5) at the riser.

5.49. Which of the following is used to support the cavity from the inside?

1) chill;
2) chaplet;
3) sprue;
4) core.

5.50. In casting, a flask is which one of the following?

1) beverage bottle for foundry man;
2) box which holds the cope and drag;
3)container for holding liquid metal;
4) metal that extrudes between the mold halves.

5.51. The lower molding flask is also known as:

1) drag;
2) cope;
3) check;
4) chill.
5) chaplet.

5.52. In order to enter the inner area of the mold the molten material must pass through:

1) the vents;
2) the ingate;
3) the pattern;
4) the core;
5) the parting line.

5. 53. What is ingate?

1) is a horizontal channel connecting the sprue to the gates;
2) is the end of the path and where the mold cavity begins;
3) is where the liquid metal flows from the runner into the mold cavity;
4) is where the casting material enters the actual mold cavity.

5.54. The ingate is important during the metal casting operation:

1) to control the process of metal hardening during casting;
2) for hermetically closing the mold when pouring molten metal into the mold;
3) to adjust the volume of supply of molten metal into the mold;
4)for flow regulation during the metal casting operation;
5) to facilitate the removal of the casting from the mold.

5.55. What are the types of ingates?

1) open ingate;
2) top ingate;
3) bottom ingate;
4) parting line ingate.

5.56. Top ingate is:

1) the gate located in the part of the mold;
2) the gate located in the drag mold part;
3) the large gate for fasting solid casting;
4) the gate located along the parting line.

5.57. Bottom ingate is:

1) the large gate for fasting solid casting;
2) the gate located in the drag mold part;
3) the gate located along the parting line;
4) the gate located in the part of the mold.

5.58. Parting line ingate is:

1) the gate located in the part of the mold;
2) the gate located in the drag mold part;
3) the large gate for fasting solid casting;
4) the gate located along the parting line.

5.59. Runners are:

1) passages that distribute the liquid metal to the different areas inside the mold;
2) openings through which ventilation of all zones of the mold takes place;
3) hollow areas that provide heat removal during cooling of the casting in the mold;
4) slits, which are used to tightly close the mold when pouring molten metal.

5.60. In foundry work, a runner is which one of the following?

1) channel in the mold leading from the down sprue to the main mold cavity;
2) openings through which ventilation of all zones of the mold takes place;
3) vertical channel into which molten metal is poured into the mold;
4) horizontal channel into which molten metal is poured into the mold.

5.61. The impression of the actual part to be cast is often referred to as:

1) the pattern;
2) the core;
3) the sprue;
4) the main cavity.

5.62. What is the function of vents during the solidification phase of the metal casting process?

1) vents distribute the liquid metal to different zones inside the mold;
2) the ventilation holes provide the removal of heat, which is released from the molten metal;
3) vents help to assist in the escape of gases that are expelled from the molten metal;
4) the ventilation holes improve the crystallization process of the metal during its solidification in the mold.

5.63. Risers are:

1) reservoirs of molten material;
2) distributors of liquid metal in different parts of the mold;
3) channels where the molten metal enters the mold;
4) zones where additional heating of the molten metal takes place before pouring into the mold.

5.64. A riser in casting is described by which of the following?

1) an insert in the casting that inhibits buoyancy of the core;
2) gating system in which the sprue feeds directly into the cavity;
3) metal that is not part of the casting, a source of molten metal to feed the casting and compensate for shrinkage during solidification, waste metal that is usually recycled;
4) waste metal that is usually recycled.

5.65. What is the function of risers as the casting solidifies?

1) risers help to assist in the escape of gases that are expelled from the molten metal;
2) risers distribute the liquid metal to different zones inside the mold;
3) risers feed molten material to sections of the mold to compensate for shrinkage as the casting solidifies;
4) risers provide the removal of heat, which is released from the molten metal.

5.66. The riser is a reservoir of molten metal provided in the casting so that hot metal can flow back into the mold cavity when there is a reduction in the volume of metal due to:

1) compression;
2) solidification;
3) expansion;
4) melting.

5.67. Classifications of risers:

1) top risers;
2) low risers;
3) side risers;
4) blind risers;
5) close risers;
6) open risers.

5.68. Top risers are the:

1) risers that feed the metal casting from the top;
2) risers that feed the metal casting from the side;
3) risers that are completely contained within the mold;
4) risers that are open at the top to the outside environment;
5) risers that hold the top of the mold.

5.69. Side risers are the:

1) risers that provide the removal of heat, which is released from the molten metal;
2) risers that feed the metal casting from the side;
3) risers that are completely contained within the mold;
4) risers that are open at the side to the outside environment;
5) risers that hold the top of the mold.

5.70. Blind risers are the:

1) risers that do not feed the metal casting from the top and side;
2) risers that provide the removal of heat, which is released from the molten metal;
3) risers that are completely contained within the mold;
4) risers that are open at the side to the outside environment;
5) risers that feed the metal casting from the top and side.

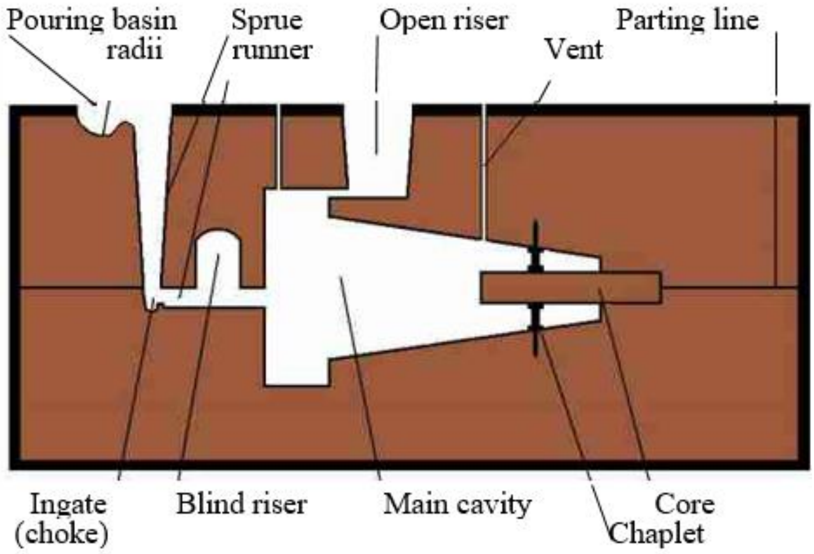
5.71. Open risers are the:

1) risers that help to assist in the escape of gases that are expelled from the molten metal;
2) risers that provide the removal of heat, which is released from the molten metal;
3) risers that feed the metal casting from the top;
4) risers that are open at the top to the outside environment.
5) risers that are open at the casting's inner cavity

5.72. A riser that is completely enclosed within the sand mold and connected to the main cavity by a channel to feed the molten metal is called which of the following?

1) blind riser and side riser;
2) open riser;
3) low riser;
4) top riser.

5.73. What is shown in the figure?
1) close pattern for machine casting;
2) gating system for casting;
3) elements of the mold in manufacturing by metal casting;
4) pattern impression with the core.



5.74. A foundry molding mixture passes through main production stages, which include:
1) preparation and distribution;
2) weighing and mixing;
3) mold and core production;
4) drying;
5) casting;
6) cleaning and reclamation.

5.75. The property requirements of the materials are determined:
1) by molding conditions;
2) by casting conditions;
3) by a rate of production;
4) by preparation stage;
5) by reclamation stage;
6) by disposal stage.

5.76. The principal properties of a foundry molding mixture required at the molding stage are:
1) flowability;
2) ductility;
3) green strength;
4) resistance to high temperatures;
5) corrosion resistance.

5.77. What methods are used to compact the foundry molding mixture?
1) manual ramming;

2) machine ramming;
3) squeeze ramming;
4) static ramming;
5) impact ramming.

5.78. What equipment is used to compact the foundry molding mixture?
1) packing machines;
2) molding machines;
3) electric pulse machines;
4) sand slingers;
5) core blowers.

5.79. The high flowability of a foundry molding mixture is particularly necessary in the case:
1) of the non-selective ramming action of the molding machine;
2) of the selective ramming action of the molding machine;
3) of using manual ramming;
4) of using the machine ramming;
5) of use the impact method of compaction a foundry molding mixture.

5.80. The need for green strength arises:
1) when the mold is opened;
2) when the mold is closed;
3) when the pattern is withdrawn;
4) when the core is inserted.

5.81. The stress to which the molding material is subjected at the molding stage depends upon:
1) the degree of support from box bars;
2) the lifters and core irons;
3) the pattern and core;
4) the shape and dimensions of the compact;
5) type of casting mold.

5.82. Less green foundry molding mixture strength is needed for:
1) hand molding a foundry molding mixture;
2) the interior cavities of the open mold;
3) a shallow core supported on a core plate;
4) a carrier than for a cod of sand forming a deep mold projection.

5.83. For heavy castings to generate greater rigidity under the pressure and erosive forces of the liquid metal, mols:

1) are constructively strengthened;
2) are hardened;
3) are tempered;
4) are cast in the green state;
5) are surface hardened.

5.84. Define the refractoriness of the mold for the casting:

1) the ability of the mold material to withstand the temperature of the mesh from the temperature of the molten metal;
2) the ability of the mold material to withstand temperatures higher than the temperature of the overheated metal that is poured into the mold;
3) the ability of the mold material to withstand high temperatures without fusion or other physical change;
4) the ability of the mold material to withstand the effect of temperature during its heat treatment
5) the ability of the mold material to withstand the cyclic effect of temperature during its repeated use.

5.85. Gas evolved and displaced from the mold can be exhausted through:

1) the open feeder heads;
2) the vents;
3) the top sprue;
4) open risers;
5) the pore spaces of the sand.

5.86. Molding materials need certain further qualities such as:

1) material and production cost;
2) environmental friendliness;
3) bench life;
4) the ability to retain molding properties on standing or storage;
5) durability, the capacity to withstand repeated cycles of heating and cooling in integrated sand systems.

5.87. The function of the binder is to produce:

1) adhesion between the refractory grains in the green state;
2) adhesion between in the hardened state;

3) cohesion between the refractory grains in the green state;
4) cohesion between the refractory grains in the hardened state;
5)) crystal lattice between atoms of binding and forming materials;
6) intermolecular bonds between grains of molding materials.

5.88. What substances possess bonding qualities?
1) clays;
2) silicates;
3) protein compounds;
4) starch compounds;
5) polyamide compounds.

5.89. What substances in combination possess bonding qualities?
1) vegetable fats;
2) organic resins;
3) inorganic resins;
4) synthetic oils;
5) natural oils.
6) inorganic oils.

5.90. Which of the following are used to mold the sand mixture into the shape of the casting and may be made of wood, plastic or metal?
1) vents;
2) patterns;
3) cores;
4) chills;
5) chaplets.

5.91. Which of the following is used for making the hollow cavities in the casting?
1) chaplet;
2) vent rod;
3) core;
4) chill.

5.92. When manufacturing by metal casting, pouring refers to the process:
1) by which the molten metal is delivered into the mold;
2) which ensures foam formation of the casting in the mold cavity;
3) which provides cooling and crystallization of the metal in the mold;

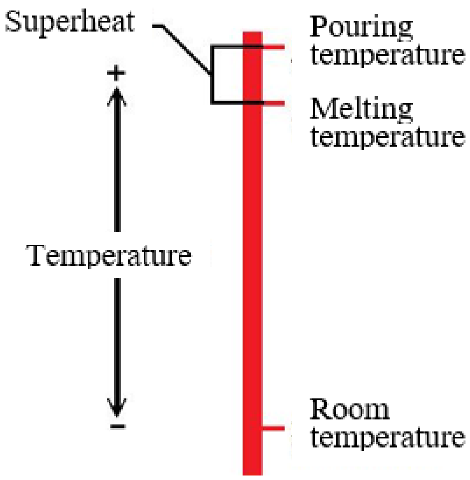
4) which provides solidification and recrystallization of the metal in the main cavity of the casting;
5) which ensures the structural transformation of the metal from the liquid phase to the solid state.

5.93. Pouring temperature refers to:
1) the temperature of the molten metal when it is heated in the furnace;
2) the temperature of the molten metal before it is poured into the mold;
3) the initial temperature of the molten metal used for the casting as it is poured into the mold;
4) the minimum temperature of the molten metal before solidification.

5.94. The difference between the solidification temperature and the pouring temperature of the metal is called:
1) hardening threshold;
2) crystallization zone;
3) recrystallization zone;
4) phenomenon of metal underheating;
5) the superheat.

5.95. If the pouring rate is too fast, then turbulence can result:
1) overheating;
2) shrinkage;
3) cracking process;
4) turbulence;
5) laminarity.

5.96. What temperature rate is shown in the picture?
1) iron-carbon diagram;
2) allocating temperatures during metal pouring;
3) the process of heating the metal before pouring it into the mold;
4) the process of metal cooling in the main mold cavity;
5) diagram of the thermal transformation of the casting metal.



5.97. If the pouring rate is too fast, then turbulence can result:

1) overheating;
2) shrinkage;
3) cracking process;
4) turbulence;
5) laminarity.

5.98. If the pouring rate is too slow, then:

1) metal may begin to solidify before filling the mold;
2) the metal may begin to harden after filling the mold;
3) the metal may begin to shrink in the sprue system;
4) the metal can start recrystallization;
5) metal can start refining.

5.99. Turbulence in pouring metal is:

1) the process of liquid metal cooling when it is poured;
2) constant and regular changes in the speed and direction of flow in liquid metal during casting;
3) inconsistent and irregular variations in the speed and direction of flow throughout the liquid metal as it travels through the casting;
4) the process of changing the internal energy of the molten metal flow during molding of the casting.

5.100. The random impacts caused by turbulence, amplified by the high density of liquid metal, can cause:

1) dynamic loads on the mold;
2) opening of the mold during metal pouring;
3) increase the coefficient of linear expansion of the main mold cavity;
4) damage to the sprue system of the mold;
5) mold erosion.

5.101. Mold erosion is particularly detrimental if it occurs in the main cavity, as it causes:

1) changing the structure of the casting itself;
2) changing the shape of the casting itself;
3) changing the crystal structure of the casting metal;
4) deterioration of the process of removing the casting from the mold;
5) reducing the shelf life of the mold.

5.102. The main goal of pouring is:

1) to isolate the molten metal from contact with the environment;
2) to prevent cooling of the molten metal after pouring;
3) to ensure the molding process of the casting in the main cavity of the mold;
4) to get metal to flow into all regions of the mold before solidifying;
5) to force the metal to fill all areas of the mold during solidification.

5.103. What is crucial in the consideration of metal casting techniques?

1) the ability of a particular casting melt to flow into a mold before freezing;
2) the ability of a specific casting melt to provide the molding of casting in the main cavity of the mold;
3) the ability of a specific casting melt to retain its shape and size after solidification;
4) the ability of a specific casting melt to retain its physical and chemical properties after solidification;
5) the ability of a specific casting melt to thermal and mechanical processing after solidification.

5.104 The ability of a particular casting melt to flow into a mold is called:

1) viscosity;
2) fluidity;
3) turbulence;
4) velocity;
5) hardening.

5.105. In manufacturing practice, the relative fluidity of a certain metal casting melt can be quantified:

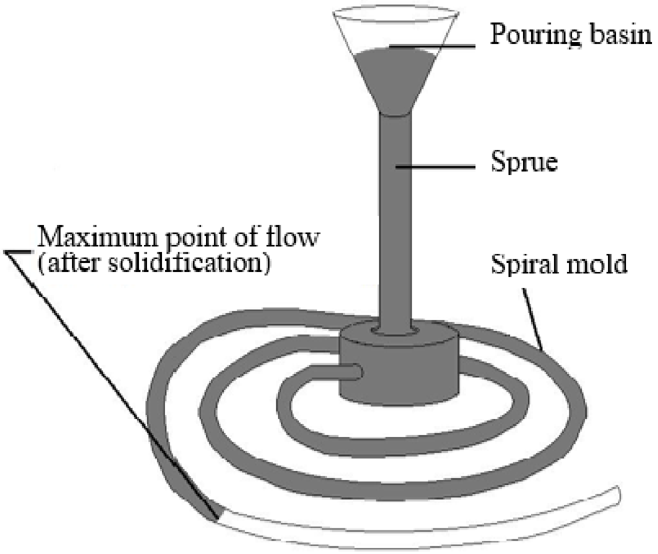
1) by the use of reference data and industry recommendations;
2) by the use of mathematical calculations;
3) by the use of a special form;
4) by the use of a spiral mold;
5) by an experimental method for a specific metal foundry melt.

5.106. The maximum point the metal reaches upon the casting's solidification in the spiral mold may be indexed as:

1) melts relative fluidity;
2) melts absolute fluidity;

3) melts relative viscosity;
4) melts absolute viscosity;
5) melts solidification point.

5.107. What is shown in the picture?
1) spiral mold test for determining the maximum solidification point of the flow of molten metal;
2) spiral mold test for determining melts absolute fluidity;
3) spiral mold test for determining melt relative fluidity;
4) special form for determining melts absolute viscosity;
5) special form for determining melts relative viscosity.



5.108. How does increasing the superheat of the molten metal relation to its freezing point, affect its fluidity?
1) liquidity does not change;
2) liquidity decreases;
3) fluidity increases;
4) fluidity of the molten metal is inversely proportional to the increase in its overheating.

5.109. What are the disadvantages of manufacturing a metal casting with an increased superheat?
1) increasing the melts likelihood to saturate gases;
2) formation of oxides;
3) deterioration of the crystal structure of the casting;
4) additional energy costs for metal overheating;
5) increasing the ability of the molten metal to penetrate the surface of the mold material.

5.110. Metals that freeze at a constant temperature have:
1) lower liquidity;

2) higher fluidity;
3) lower viscosity;
4) greater viscosity;
5) greater turbulence.

5.111. Define what is the heat of fusion?
1) the temperature at which a substance changes from solid state to liquid state;
2) the amount of heat needed to transform a substance from a crystalline structure to an amorphous state;
3) the amount of substance involved in the phase transformation from solid to liquid;
4) the amount of energy involved in the liquid-solid phase change.

5.112. Establish correspondence between a higher heat of fusion and its influence:

A	With a higher heat of fusion

1	the solidification of the metal casting will last faster.
2	the solidification of the metal casting will take longer.
3	the solidification of the metal casting will stop.
4	fluidity will be increased.
5	fluidity will be decreased.
6	turbulence will be increased.

1) A – 1
2) A – 2
3) A – 3
4) A – 4
5) A – 5
6) A – 6

5.113. Establish correspondence:

A	Most materials are less dense
B	Most materials more dense

1	in a solid state.
2	in a liquid state.
3	at high temperatures.
4	at low temperatures.

1) A – 1;
2) A – 2;
3) B – 3;
4) B – 4.

5.114. Metal casting undergoing solidification will tend to:
1) decrease in volume;
2) change the metal structure;
3) recrystallization;

4) phase transformation;
5) increase in volume.

5.115. During the manufacture of a part by casting decrease in volume is termed:

1) crystallization;
2) recrystallization;
3) shrinkage;
4) solidification;
5) phase transformation.

5.116. Name the stages of shrinkage of melting metal.

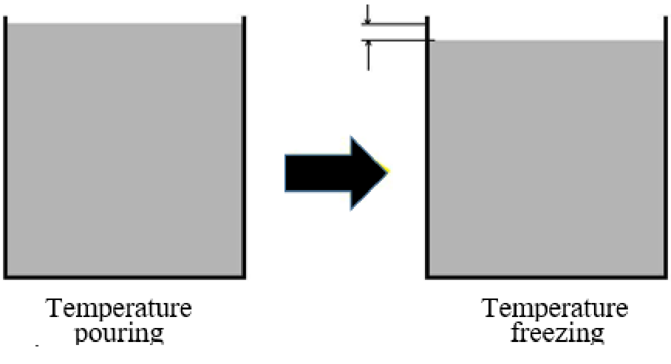
1) decreased volume of the liquid as it goes from the pouring temperature to the freezing temperature;
2) increased volume of the liquid as it goes from the pouring temperature to the freezing temperature;
3) decreased volume of the material due to solidification;
4) increased volume of the material due to solidification;
5) decreased volume of the material as it goes from freezing temperature to room temperature;
6) increased volume of the material as it goes from freezing temperature to room temperature.

5.117. Risers (sometimes called feeders) serve:

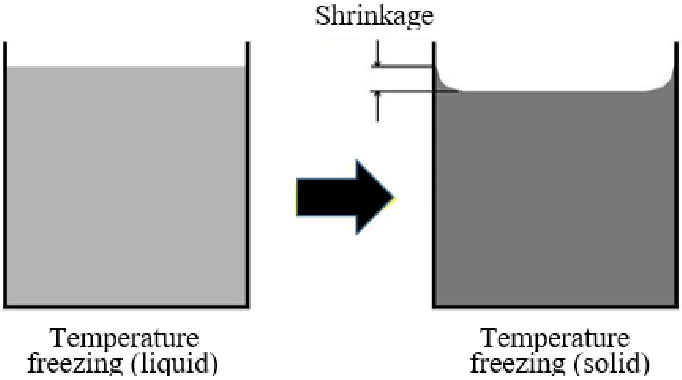
1) to contain additional molten metal;
2) to heat additional molten metal;
3) to heat removal during casting cooling;
4) to remove gases from the main cavity of the mold;
5) to keep the mold from opening when pouring molten metal.

5.118. What is shown in the picture?

1) the first stage of shrinkage of casting metal;
2) the second stage of shrinkage of casting metal;
3) the third stage of shrinkage of casting metal;
4) the fourth stage of shrinkage of casting metal.

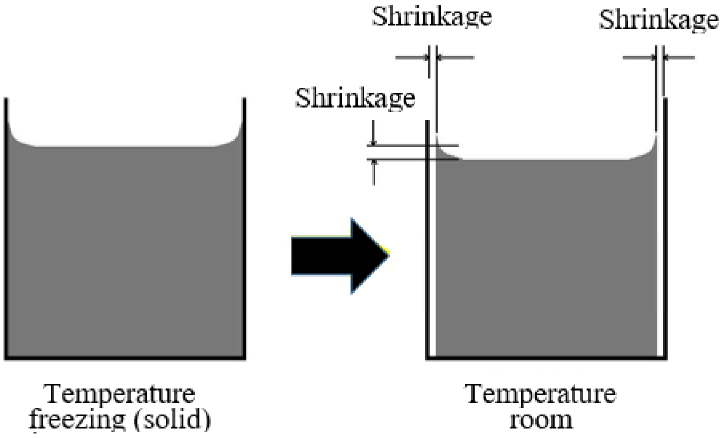


5.119. What is shown in the picture?



1) the first stage of shrinkage of casting metal;
2) the second stage of shrinkage of casting metal;
3) the third stage of shrinkage of casting metal;
4) the fourth stage of shrinkage of casting metal.

5.120. What is shown in the picture?



1) the first stage of shrinkage of casting metal;
2) the second stage of shrinkage of casting metal;
3) the third stage of shrinkage of casting metal;
4) the fourth stage of shrinkage of casting metal.

5.121. As the metal casting begins to experience shrinkage, the mold will need additional material:

1) to compensate for the decrease in volume;
2) to compensate for the increase in volume;
3) to ensure the release of gases;
4) to ensure heat dissipation;
5) to prevent casting shrinkage.

5.122. The riser is a reservoir of molten metal provided in the casting so that hot metal can flow back into the mold cavity when there is a reduction in the volume of metal due to:

1) compression;
2) solidification;
3) expansion;
4) melting;
5) recrystallization.
6) heating.

5.123. A successful riser will remain molten:

1) while the form is being filled out;
2) until the metal crystallizes;
3) until after the metal casting solidifies;
4) until the metal loses its viscosity;
5) while the metal is being heated.

5.124. One of the biggest problems caused by shrinkage, during the manufacture of a cast part, is:

1) fragility;
2) plasticity;
3) hardness;
4) compaction;
5) porosity.
6) recrystallization.

5.125. In which areas of the material and in which cases do porosity form when the material shrinks?

1) porosity is formed in those parts of the material where there is an accumulation of gases;
2) porosity is formed in those parts of the material where there is the accumulation of slags;
3) when liquid metal can not reach sections of the metal casting where solidification is occurring;
4) when the liquid metal, when poured into the main cavity of the mold, is heated below the solidification temperature;
5) most often, porosity is formed in thin-walled casting elements that are distant from the sprue.

5.126. When a porous or vacant region is developed?

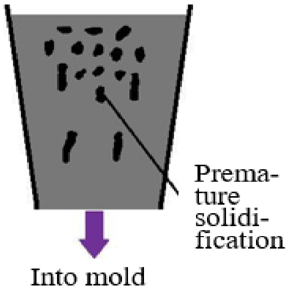
1) when the molten metal solidifies in the main cavity of the mold;
2) isolated liquid metal shrinks;
3) when there are no or non-functioning channels for removing gases from the mold;
4) when the molten metal has excessive viscosity, resulting in slag accumulation;
5) when there is not enough molten metal in the risers (sometimes they are called feeders).

5.127. What defects can occur in the working material casting in the metal casting process?

1) metal projections;
2) chemical corrosion;
3) cavities;
4) discontinuities;
5) internal tensions.

5.128. What type of riser is shown in the picture?

1) no cover riser;
2) riser with insulating compound;
3) riser with exothermal mixture;
4) riser with internal heating.



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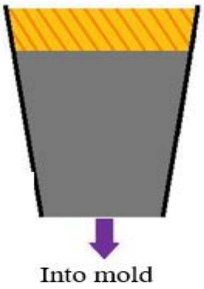
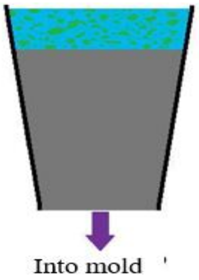


5.130. What type of riser is shown in the picture?

1) no cover riser;
2) riser with insulating compound;
3) riser with exothermal mixture;
4) riser with internal heating.



5.131. What is a chill in casting?

1) is a cold sink placed to encourage rapid freezing in certain regions of the casting;
2) is a heat sink placed to encourage rapid heating in certain regions of the casting;
3) is a heat sink placed to encourage rapid freezing in certain regions of the casting;
4) is a cold sink placed to encourage rapid heating in certain regions of the casting.

5.132. What defects can occur in the working material casting in metal casting process?

1) slag depressions;

2) incomplete casting;
3) oxidation of the surface layer of the casting;
4) irregular structure of the casting metal;
5) inclusions.

5.133. What defects can occur in the working material casting in the metal casting process?

1) defective surface;
2) exfoliation of the surface layer;
3) incorrect dimensions;
4) incorrect shape;
5) irregular crystal structure.

5.134. All unwanted material projected from the surface of the part after casting is included:

1) non-metallic inclusions;
2) metal projections;
2) metal projections;
3) slag depressions;
4) oxide residues;
5) casting defects.

5.135. What are the shapes of cavities in the casting material that occur in the casting process?

1) angular;
2) rounded;
3) through;
4) internal;
5) opened;
6) semi-closed.

5.136. Cavities as a technological defect of metal are caused by:

1) crystallization defect of metal casting;
2) shrinkage defect of metal casting;
3) defect of underheating of the molten metal;
4) defect from gases;
5) corrosion defect of castings.
6) underheating.

5.137. What defects in the part qualify as discontinuities?

1) cracks;
2) chipping;
3) tearing;
4) cuts;
5) cold shuts.

5.138. When does casting tearing occur?

1) when rapid solidification of the molten metal occurs;
2) when the metal casting is unable to shrink naturally and a point of high tensile stress is formed;
3) tearing of the casting in the form of a crack occurs when it is shaken out of the mold;
4) tearing of the casting in the form of a crack occurs during its vibration processing;
5) tearing of the casting in the form of a crack occurs during its fine jet processing.

5.139. Where tearing could occur in a casting?

1) in the zone where the casting solidifies the fastest;
2) in the zone where the smallest crystal grains are formed;
3) on the parting line of the casting between the upper and lower parts of the mold;
4) in a thin wall connecting two heavy sections;
5) in the sprue channel connecting the two sections of the mold.

5.140. What happens when two relatively cold streams of molten metal meet in the pouring of a casting?

1) cold shuts formation;
2) cavity formation;
3) crack initiation;
4) accumulation of gases;
5) slag accumulation;

5.141. Defects effecting the surface of the manufactured part include:

1) blows and scabs;
2) laps and folds;
3) breaks and cracks;
4) scars and blisters;
5) juts and cavities.

5.142. Causes for incomplete metal castings could be:

1) insufficient amount of material poured;
2) loss of metal from mold;
3) insufficient fluidity in molten material;
4) viscosity of the molten material is too high;
5) cross-section within the casting's mold cavity is too small;
6) pouring was done slowly, or the pouring temperature was too low;
7) channels for the removal of gases from the main cavity of the mold are absent or dysfunctional.

5.143. Establish correspondence:

A	The metal casting is geometrically incorrect.
B	A warped casting.

1	This could be due to unpredicted contractions in the part during solidification.
2	Shrinkage of the metal casting may have been miscalculated.
3	There may have been problems with the manufacture of the pattern.

1) A – 1; 4) B – 1;
2) A – 2; 5) B – 2;
3) A – 3; 6) B – 3.

5.144. Unwanted particles contained within the material act:

1) crack generators;
2) stress raisers;
3) gap concentrators;
4) catalysts;
5) plasticizers.

5.145. What can cause inclusions within a metal casting?

1) insufficient removal of gases from the main cavity of the mold;
2) slag formation (in particular, during solidification of molten metal);
3) interaction of the molten metal with mold surfaces;
4) interaction of the molten metal with the material of cores and patterns;
5) interaction of the molten metal with theoutside atmosphere, (chemical reactions with oxygen in particular).

5.146. Since liquid metal has a much higher solubility than solid metal, as the casting solidifies these gases are:

1) dissolved;

2) turned into slag;
3) expelled;
4) burned up;
5) entered into a chemical reaction with iron atoms.
6) removed by flushing a metal melt with inert gas.

5.147. What are the reasons that gases are absorbed into the metal melt during casting?

1) turbulent flow of the casting material through the system may cause it to trap gas from the air;
2) gases may be trapped from material or the atmosphere in the crucible when the melt is being prepared;
3) gases can be formed as a result of the boiling of molten metal in a crucible;
4) gases may be trapped from reactions between the molten metal and the mold material;
5) gases can be produced as a result of the reaction between the molten metal and the material of the cores and patterns.

5.148. Methods of preventing gas defects in manufacturing the casting part:

1) gases being expelled by the material during solidification can be eliminated by a proper venting system in the mold;
2) the choice of the correct temperature rate for the casting process contributes to the release of gases from the molten metal;
3) mitigating the amount of turbulence in the fluid flow will reduce gas absorption into the metal;
4) increasing the liquid flow rate will reduce gas absorption into the metal;
5) removal of slag will help eliminate gases and other impurities in the casting.

5.149. Dissolved gases may be removed from molten metal by:

1) flushing or purging with inert gas;
2) melting and pouring the metal in a vacuum;
3) flushing or purging with inert gas or melting and pouring the metal in a vacuum;
4) melting and pouring the metal with inert gas;
5) melting and pouring the metal in a nitrogen atmosphere.

5.150. Specify the methods of preventing gas defects during the production of parts by casting:

1) gases can be removed by adding special catalysts to the molten metal;
2) gases may be removed by flushing a metal melt with inert gas;
3) filtration of the liquid metal will help eliminate gases and other impurities in the casting;
4) elimination of gases may also be accomplished by pouring the metal casting in a vacuum.

5.151. To permit the escape of gases generated in the mold, which of the following are provided?

1) vent holes;
2) chills;
3) chaplets;
4) patterns;
5) core print.

5.152. The primary way to control metal casting defects is:

1) good pattern design considerations in the creation of the casting's pattern and gating system;
2) correct part design considerations in the creation of the elements of the gating system;
3) good mold design considerations in the creation of the casting's mold and gating system;
4) correct gating system design considerations in the creation of the mold’s elements.

5.153. Directional solidification, in casting manufacture, means that:

1) material will solidify with the areas closest to the molten metal supply solidifying first and then progressing towards the risers;
2) material will solidify with the areas farthest away from the supply of molten metal first moving toward the risers and then solidifying;
3) material will solidify with the areas farthest away from the supply of molten metal solidifying first and then progressing towards the risers;
4) material will solidify with the areas closest to the molten metal supply first moving toward the risers and then solidifying.

5.154. Gating system design is crucial in controlling:

1) temperature gradient within the metal casting;
2) rate in the molten metal being poured;
3) turbulence in the molten metal being poured;
4) flow of liquid metal through the gating system;
5) flow of liquid material to unsolidified areas.

5.155. Which of the following gating systems is useful for casting drossy alloys?

1) pressurized gating system;
2) partially pressurized gating system;
3) high pressurized gating system;
4) non-pressurized gating system.

5.156. What factors determine directional solidification throughout the casting?

1) rate in the molten metal being poured;
2) flow of liquid metal through the gating system;
3) temperature gradient within the metal casting;
4) turbulence in the molten metal being poured.

5.157. Solidification of casting does not depend upon which factor?

1) type of metal;
2) thermal properties of metal;
3) geometric relationship between volume and surface area;
4) surface tension;
5) gating system design.

5.158. Which of the following characteristics is mainly considered for the solidification of castings?

1) appearance;
2) crystal structure;
3) molding capacity;
4) surface finish.

5.159. The directional solidification in casting can be improved by using:

1) chaplets and riser;
2) chills and padding;
3) chaplets and padding;

4) chills and riser;
5) riser and padding.

5.160. Which of the following types of crystals are formed near the mold face during solidification?
1) big crystals with random orientation;
2) small crystals with systematic orientation;
3) small crystals with random orientation;
4) big crystals with systematic orientation.

5.161. Which of the following is mostly analyzes during the casting and solidification of casting material?
1) mold coating;
2) mold material;
3) mold aesthetics;
4) heat transfer;
5) casting material.

5.162. During the solidification of an alloy when a mixture of solid and liquid metals is present, the solid-liquid mixture is referred to as which one of the following?
1) eutectic composition;
2) ingot segregation;
3) liquidus;
4) mushy zone.

5.163. Which of the following is independent of the solidification time of the casting?
1) mold material;
2) chaplets;
3) heat transfer coefficient;
4) mold wall temperature,
5) casting material.

5.164. Total solidification time is defined as which one of the following?
1) time between pouring and cooling to room temperature;
2) time between solidification and cooling to room temperature;
3) time between pouring and complete solidification;
4) time to give up the heat of fusion.

5.165. To avoid incomplete castings as a result of insufficient material, it is necessary:

1) calculate the volume of all areas of the casting taking into account shrinkage;
2) calculate the thickness and width of the casting taking into account shrinkage;
3) calculate the area of the casting taking into account shrinkage;
4) calculate the weight of the casting taking into account shrinkage.

5.166. Increasing the superheat, (temperature difference between the metal at pouring and freezing):

1) can decrease the fluidity of the material for the casting, which can assist with its flow into the mold;
2) can decrease the plasticity of the material for the casting, which can assist with its flow into the mold;
3) can increase the fluidity of the material for the casting, which can assist with its flow into the mold;
4) can increase the plasticity of the material for the casting, which can assist with its flow into the mold.

5.167. Increasing the superheat has problems associated with it, such as:

1) decreased gas porosity;
2) increased gas porosity;
3) increased oxide formation;
4) decreased oxide formation;
5) mold penetration.

5.168. Insulating the top of the riser will:

1) significantly reduce cooling in the risers due to the temperature difference between the liquid casting metal and air at room temperature;
2) significantly reduce cooling in the risers due to their pre-cooling;
3) greatly increase the cooling in the risers from the steep temperature gradient between the liquid casting metal and room temperature air.
4) greatly reduce cooling in the risers from the temperature gradient between the liquid casting metal, and the room temperature air.

5.169. In casting manufacture, V/A ratio stands:

1) for surface area to volume or mathematically (surface area/volume)

2) for volume to surface area or mathematically (volume/surface area);
3) for volume to surface length or mathematically (volume/surface length);
4) for volume to casting area or mathematically (volume/casting area)

5.170. When solidification of a casting begins:
1) a thick skin of solid metal is first formed on the surface between the casting and the mold wall;
2) a thin skin of solid metal is first formed on the surface of the casting;
3) a thin skin of solid metal is first formed on the surface between the casting and the mold wall;
4) a thick skin of solid metal is first formed on the surface of the casting.

5.171. Sections in the casting with low volume to surface area will solidify:
1) faster than sections with low volume to surface area;
2) slowly than sections with low volume to surface area;
3) slowly than sections with higher volume to surface area;
4) faster than sections with higher volume to the surface area.

5.172. In metal casting consideration of the V/A ratios is critical in avoiding:
1) premature solidification of the casting;
2) slow solidification of the casting;
3) formation of extensions;
4) formation of vacancies.

5.173. Locating sections of the casting with low V/A ratios further away from the risers:
1) will avoid large heat masses in locations distant risers;
2) will ensure a smooth solidification of the casting;
3) will ensure quick hardening of the casting;
4) will avoid large heat masses in locations far from the risers.

5.174. What is the negative impact of turbulence?
1) it can trap gases in the casting material;
2) it can spread gases in the casting material
3) it can cause mold erosion;
4) it can insure quick hardening of the casting;
5) it can cause mold deformation.

5.175. Turbulence can be reduced by:

1) more laminar flow of the liquid metal;
2) smart design of a gating system;
3) abrupt changes in sections within the metal casting can be mitigated by the employment of radii;
4) sharp corners within the metal casting can be mitigated by the employment of radii.

5.176. Turbulence refers to the variations that occur in:

1) both the direction and the speed of flow of the liquid metal when casting;
2) only the direction of flow of the liquid metal when casting;
3) both the direction and the volume of flow of the liquid metal when casting;
4) only the speed of flow of the liquid metal when casting.

5.177. If the passage linking the riser to the metal casting solidifies before the casting, then:

1) the time to freeze cross-sectional area will decrease;
2) the time to freeze cross-sectional area will increase;
3) the flow of molten metal to the casting will be blocked;
4) the riser will cease to serve its function.

5.178. Correct casting design dictates:

1) reducing the waste of material in the casting process;
2) reduction of the cross-section of connection;
3) increasing in cross-section of connection;
4) keeping the metal in its liquid state longer.

5.179. What should be the shape of the down sprue to maintain the continuity of the fluid flow?

1) cylindrical;
2) tapered;
3) spherical;
4) narrowed.

5.180. In the location next to the sprue base the cross sectional area of ingate:

1) is increased;
2) remains constant;

3) is reduced;
4) does not change in size.

5.181. Why the large or complex castings require multiple ingates?
1) to make a smooth surface finish of the casting;
2) to make uniform flow;
3) to have high strength of the casting;
4) to have good toughness of the casting.

5.182. The flow rate of the casting metal must be:
1) low enough to avoid any premature solidification;
2) high enough to ensure rapid solidification;
3) high enough to avoid any premature solidification;
4) low enough to ensure even solidification.

5.183. To achieve directional solidification within the metal casting, it is needed:
1) to use of chills;
2) to control the flow of fluid material;
3) to regulate thermal gradients;
4) to control the solidification rate of the different areas of the metal casting.

5.184. Where chills are placed?
1) outside the mold cavity after pouring;
2) inside the mold cavity before pouring;
3) inside the mold cavity after pouring;
4) outside the mold cavity before pouring.

5.185. Chills are of two basic types.
1) open and closed;
2) internal and external;
3) solid and liquid;
4) ferrous and nonferrous.

5.186. Which of the following materials are not used for making internal chills?
1) steel;
2) cast iron;

3) copper;
4) zinc;
5) aluminum.

5.187. Which of the following materials are used for making external chills?
1) iron;
2) graphite;
3) copper;
4) zinc.

5.188. What methods are adopted to prevent gas from being trapped inside casting?
1) reducing the amount of turbulence in the flow of the molten metal;
2) inclusion of a proper venting system in the mold;
3) slag removal;
4) using die or vacuum casting.

5.189. The choice of pattern material depends upon:
1) size of casting;
2) number of casting to be made from the pattern;
3) configuration of casting;
4) dimensional accuracy.

5.190. The designing of a pattern does not include which of the following feature?
1) to locate the direction of the parting line and adjust the component accordingly;
2) to determine regions and measurement of draft angles and radii of the sharp edges where allowances are to be given;
3) to recognize and abolish the region of or where the defects could take place during casting;
4) to 3D print the design for making the pattern.

5.191. The distortion in casting can not be prevented by:
1) modification of casting design;
2) providing distortion allowance;
3) providing sufficient machining allowance to cover the distortion effect;
4) providing proper shrinkage allowance.

6. EXPENDABLE MOLD CASTUNG

6.1. Sand casting

Sand casting, the most widely used casting process, utilizes expendable sand molds to form complex metal parts that can be made of nearly any alloy. Almost all casting metals can be sand cast. Because the sand mold must be destroyed to remove the part, called the casting, sand casting typically has a low production rate.

The sand casting process involves the use of a furnace, metal, pattern, and sand mold. The metal is melted in the furnace and then ladled and poured into the cavity of the sand mold, which is formed by the pattern. The sand mold separates along a parting line and the solidified casting can be removed. The steps in this process are described in detail below in this section.

Sand casting is used to produce a wide variety of metal components with complex geometries. These parts can vary greatly in size and weight, ranging from a couple of ounces to several tons. Some smaller sand cast parts include components such as gears, pulleys, crankshafts, connecting rods, and propellers. Larger applications include housings for large equipment and heavy machine bases. Sand casting is also common in producing automobile components, such as engine blocks, engine manifolds, cylinder heads, and transmission cases. Some examples of items manufactured in modern industry by sand casting processes are machine tool bases, cylinder heads, pump housings, and valves.

Sand. Product of the disintegration of rocks over long periods of time.

Most sand casting operations use silica sand (SiO_2). A great advantage of sand in manufacturing applications is that sand is inexpensive. Another advantage of sand to manufacture products by metal casting processes is that sand is very resistant to elevated temperatures. Sand casting is one of the few processes that can be used for metals with high melting temperatures such as steel, nickel, and titanium. Usually, sand is used to manufacture a mold for the casting process is held together by the mixture of water and clay.

A typical mixture by volume could be 89% sand, 4% water and 7% clay. Control of all aspects of the properties of sand is crucial when manufacturing parts by sand casting, therefore a sand laboratory is usually attached to the foundry.

Use of binder in sand casting.

A mold must have physical integrity to keep its shape throughout the casting operation. For this reason, in sand casting, the sand must contain some type of binder that acts to hold the sand particles together. Clay serves an essential purpose in the sand casting manufacturing process, as a binding agent to adhere the molding sand together. In the manufacturing industry, other agents may be used to bond the molding sand together in place of clay. Organic resins, (such as phenolic resins), and inorganic bonding agents, (such as phosphate and sodium silicate), may also be used to hold the sand together.

In addition to sand and bonding agents, the sand mixture to create the metal casting mold will sometimes have other constituents added to it in order to improve mold properties.

Types of sand used in sand casting.

There are two general types of sand used in the manufacturing process of sand casting: naturally bonded and synthetic sand.

Naturally bonded sand is less expensive but it includes organic impurities that reduce the fusion temperature of the sand mixture for the casting, lower the binding strength, and require a higher moisture content.

Synthetic sand is mixed in a manufacturing lab starting with a pure (SiO_2) sand base. In this case, the composition can be controlled more accurately, which imparts the casting sand mixture with higher green strength, more permeability, and greater refractory strength. For these reasons, synthetic sand is mostly preferred in sand casting manufacturing.

Properties of a sand casting mixture.

Type and content of binder and other additives.

As mentioned, controlling the type and content of the sand binder and other additives is the key to controlling the properties of the casting's mold sand mixture.

Moisture content.

Moisture content affects the other properties of the mixture such as strength and permeability. Too much moisture can cause steam bubbles to be entrapped in the metal casting.

Grain size.

This property represents the size of the individual particles of sand.

Shape of grains.

This property evaluates the shape of the individual grains of sand based on how round they are. Less round grains are said to be more irregular.

Strength.

The explanation of strength is the ability of the sand casting mixture to hold its geometric shape under the conditions of mechanical stress imposed during the sand casting process.

Permeability.

The ability of the sand mold to permit the escape of air, gases, and steam during the sand casting process.

Collapsibility.

The ability of the sand mixture to collapse under force. Collapsibility is a very important property in this type of casting manufacture. Collapsibility of the mold will allow the metal casting to shrink freely during the solidification phase of the process. If the molding sand cannot collapse adequately for the casting's shrinkage, hot tearing or cracking will develop in the casting.

Flowability.

The ability of the sand mixture to flow over and fill the sand casting pattern during the impression making phase of the manufacturing process, more flowability is useful for a more detailed casting.

Refractory strength.

During the pouring of the molten metal in sand casting manufacture, the sand mixture in the mold must not melt, burn, crack, or sinter. The refractory strength is the ability of the mold sand mixture to withstand levels of extreme temperature.

Reusability.

The ability of the mold sand mixture to be reused to produce other sand castings in subsequent manufacturing operations.

When planning the manufacture of a particular casting, remember some properties of a sand casting mold mixture are contradictory to each other. Tradeoffs in different properties are often needed to achieve a compromise that provides a sand casting mold mixture with adequate properties for the specific part and casting application. There are some things to consider when selecting a sand mixture for a manufacturing process. Small grain size enhances mold strength, but the large grain size is more permeable. Sand casting molds made from grains of irregular shape tend to be stronger because of grain interlocking, but rounder grains provide a better surface finish. A sand casting mold mixture with more collapsibility has less strength and a sand casting mixture with more strength has less collapsibility.

Sand conditioning for a metal casting operation.

If the sand is being reused from a previous sand casting manufacturing process, lumps should be crushed and then all particles and metal granules removed, (a magnetic field may be used to assist in this). All sand and constituents should be screened. In industrial practice shakers, rotary screens, or vibrating screens, are used in this process. Then continuous screw-mixers or mulling machines are used to mix the sand uniformly.

Types of molds used in sand casting.

Green sand molds.

A green sand mold is very typical in sand casting manufacture, it is simple and easy to make, a mixture of sand, clay and water. The term green refers to the fact that the mold will contain moisture during the pouring of the casting.

Manufacturing considerations and properties of green sand molds:

1. Has sufficient strength for most sand casting applications.
2. Good collapsibility.
3. Good permeability.
4. Good reusability.
5. Least expensive of the molds used in sand casting manufacturing processes.
6. Moisture in the sand can cause defects in some castings, dependent upon the type of metal used in the sand casting and the geometry of the part to be cast.

Dry sand molds.

Dry sand molds are baked in an oven, (at 300F – 650F for 8–48 hours), prior to the sand casting operation, in order to dry the mold. This drying strengthens the mold and hardens its internal surfaces. Dry sand molds are manufactured using organic binders rather than clay.

Manufacturing considerations and properties of dry sand molds:

- Better dimensional accuracy of sand cast part than green sand molds.
- Better surface finish of sand cast part than green sand molds.
- More expensive manufacturing process than green sand production.
- Manufacturing production rate of castings is reduced due to drying time.
- Distortion of the mold is greater, (during mold manufacture).
- The metal casting is more susceptible to hot tearing because of the lower collapsibility of the mold.
- Dry sand casting is generally limited to the manufacture of medium and large castings.

Skin-dried molds.

When sand casting a part by the skin-dried mold process a green sand mold is employed, and its mold cavity surface is dried to a depth of .5-1 inch. Drying is a part of the manufacturing process and is accomplished by the use of torches, heating lamps, or some other means, such as drying it in air.

Manufacturing considerations and properties of skin-dried molds:

- The cast part dimensional and surface finish advantages of dry sand molds are partially achieved.
- No large oven is needed.
- Special bonding materials must be added to the sand mixture to strengthen the mold cavity surface.

Cold setting processes.

In industrial sand casting manufacture, sometimes non-traditional binders other than those used in the above classifications of sand molds may be used. These binders may be made of a variety of things or materials, such as synthetic liquid resins. Conventional casting binders require heat to cure while these when mixed with the sand, bond chemically at room temperature.

Hence the term cold setting processes. Technically advanced, these relatively recent sand casting processes are growing in manufacturing. While more expensive than green sand molds, cold setting processes provide good dimensional accuracy of the casting, and have high production applications.

Mold setup for sand casting.

The setup of a sand mold in manufacturing involves using a pattern to create an impression of the part to be sand cast within the mold, removal of the pattern, the placement of cores, (if needed), and the creation of a gating system within the mold. The setup of a mold is covered in detail in the metal casting process. A mold setup such as the one in Fig. 13 could be typical in a sand casting manufacturing operation.

The pattern.

A few different types of patterns may be used in the sand casting process.

Solid pattern.

This is a one-piece pattern representing the geometry of the casting. It is an easy pattern to manufacture, but determining the parting line between cope and drag is more difficult for the foundry worker.

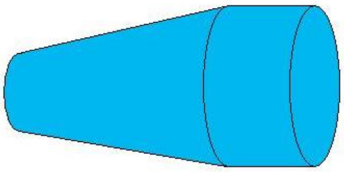


Figure 29 – Solid pattern

Split pattern.

The split pattern is comprised of two separate parts that when put together will represent the geometry of the casting. When placed in the mold properly the plane at which the two parts are assembled should coincide with the parting line of the mold. This makes it easier to manufacture a pattern with more complicated geometry. Also mold setup is easier since the pattern placement relative to the parting line of the mold is predetermined.

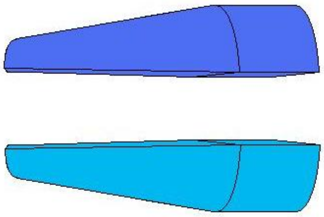


Figure 30 – Split pattern

Match plate pattern.

The match plate pattern is typically used in high-production industry runs for sand casting manufacture.

A match plate pattern is a two- piece pattern representing the casting, divided at the parting line, similar to the split pattern. In the match plate pattern, however, each of the parts is mounted on a plate. The plates come together to assemble the pattern for the sand casting process. The match plate pattern is more proficient and makes the alignment of the pattern in the mold quick and accurate.

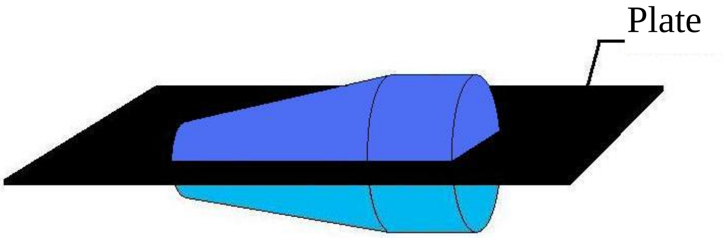


Figure 31 – Match plate pattern

Cope and drag pattern.

The cope and drag pattern is also typical in sand casting processes for high-production industry runs. The cope and drag pattern is the same as the match plate pattern in that it is a two-piece pattern representing the casting and divided at the parting line. Each of the two halves are mounted on a plate for easy alignment of the pattern and mold.

The difference between the cope and drag pattern and the match plate pattern is that in the match plate pattern, the two halves is mounted together, where as in the cope and drag pattern the two halves are separate. The cope and drag pattern enables the cope section of the mold, and the drag section of the mold to be created separately and later assembled before the pouring of the sand casting.

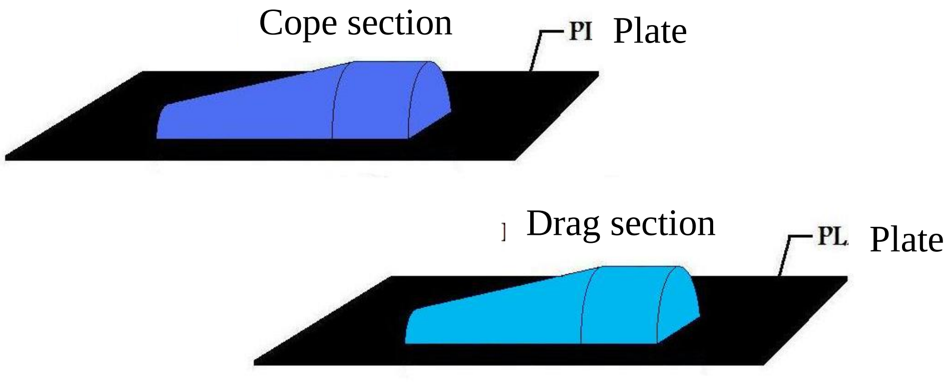


Figure 32 – Cope and drag pattern

In industrial sand casting processes a gating system, (not shown), is often incorporated as part of the pattern, particularly for a cope and drag pattern. Patterns can be made of different materials, and the geometry of the pattern must be adjusted for shrinkage, machine finish, and distortion. Pattern basics are covered in detail in the patterns section.

Cores.

Cores form the internal geometry of the casting. Cores are placed in the mold and remain there during the pouring phase of the sand casting process. The metal casting will solidify around the core. Core basics are covered in detail in the cores section. Cores are made of the highest quality sand and are subject to extreme conditions during the sand casting operation.

Cores must be strong and permeable; also, since the metal casting will shrink onto the core, cores must have sufficient collapsibility. Sometimes a reinforcing material will be placed in a sand casting core to enhance strength. The core may be manufactured with vents to facilitate the removal of gases.

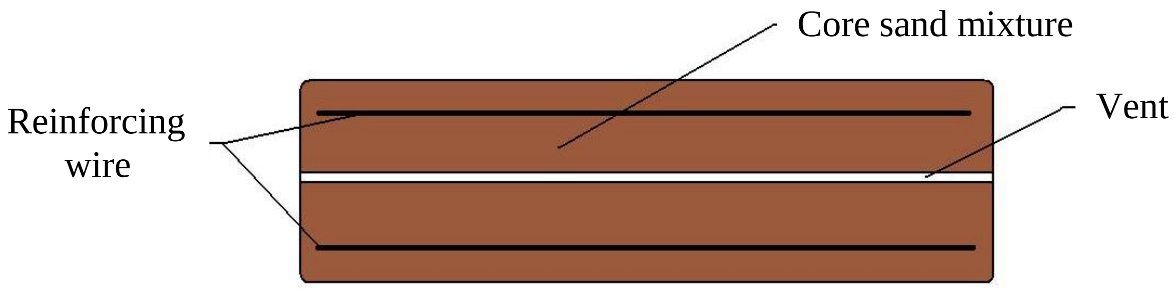


Figure 33 – Core

The sand casting operation.

The sand casting operation involves the pouring of the molten metal into the sand mold, the solidification of the casting within the mold, and the removal of the casting. The casting operation is covered in detail on the metal casting operation page.

Of specific interest to sand casting would be; the effect and dissipation of heat through the particular sand mold mixture during the casting's solidification, the effect of the flow of liquid metal on the integrity of the mold, (mold sand mixture properties and binder issues), and the escape of gases through the mixture. Sand usually can withstand extremely high-temperature levels, and generally allows the escape of gases quite well. Manufacturing with sand casting allows the creation of castings with complex geometry. Sand casting manufacture, however, only imparts a fair amount of dimensional accuracy to the cast part.

After the sand casting is removed from the sand mold it is shaken out, all the sand is otherwise removed from the casting, and the gating system is cut off the part. The part may then undergo further manufacturing processes such as heat treatment, machining, and/or metal forming. Inspection is always carried out on the finished part to evaluate the effectiveness and satisfaction of its manufacture.

The process cycle for sand casting consists of six main stages, which are explained below.

1. Mold-making. The first step in the sand casting process is to create the mold for the casting. In an expendable mold process, this step must be performed for each casting. A sand mold is formed by packing sand into each half of the mold. The sand is packed around the pattern, which is a replica of the external shape of the casting. When the pattern is removed, the cavity that will form the casting remains. Any internal features of the casting that cannot be formed by the pattern are formed by separate cores which are made of sand prior to the formation of the mold. The mold-making time includes positioning the pattern, packing the sand, and removing the pattern. The mold-making time is affected by the size of the part, the number of cores, and the type of sand mold. If the mold type requires heating or baking time, the mold-making time is substantially increased. Also, lubrication is often applied to the surfaces of the mold cavity in order to facilitate the removal of the casting. The use of a lubricant also improves the flow of the metal and can improve the surface finish of the casting. The lubricant that is used is chosen based on the sand and molten metal temperature.

2. Clamping. Once the mold has been made, it must be prepared for the molten metal to be poured. The surface of the mold cavity is first lubricated to facilitate the removal of the casting. Then, the cores are positioned and the mold halves are closed and securely clamped together. The mold halves must remain securely closed to prevent the loss of any material.

3. Pouring. The molten metal is maintained at a set temperature in a furnace. After the mold has been clamped, the molten metal can be ladled from its holding container in the furnace and poured into the mold. The pouring can be performed manually or by an automated machine. Enough molten metal must be poured to fill the entire cavity and all channels in the mold. The filling time is very short in order to prevent early solidification of any one part of the metal.

4. Cooling. The molten metal that is poured into the mold will begin to cool and solidify once it enters the cavity. When the entire cavity is filled and the molten metal solidifies, the final shape of the casting is formed. The mold can not be opened until the cooling time has elapsed. The desired cooling time can be estimated based on the wall thickness of the casting and the temperature of the metal. Most of the possible defects that can occur are a result of the solidification process. If some of the molten metal cools too quickly, the part may exhibit shrinkage, cracks, or incomplete sections. Preventative measures can be taken in designing both the part and the mold and will be explored in later sections.

5. Removal. After the predetermined solidification time has passed, the sand mold can simply be broken, and the casting removed. This step, sometimes called shakeout, is typically performed by a vibrating machine that shakes the sand and casting out of the flask. Once removed, the casting will likely have some sand and oxide layers adhered to the surface. Shot blasting is sometimes used to remove any remaining sand, especially from internal surfaces, and reduce surface roughness.

6. Trimming. During cooling, the material from the channels in the mold solidifies attached to the part. This excess material must be trimmed from the casting either manually via cutting or sawing or using a trimming press. The time required to trim the excess material can be estimated from the size of the casting envelope. A larger casting will require a longer trimming time. The scrap material that results from this trimming is either discarded or reused in the sand casting process. However, the scrap material may need to be reconditioned to the proper chemical composition before it can be combined with non-recycled metal and reused.

Table 9 – Advantages and disadvantages of sand casting

Advantages	Disadvantages
Sand casting is a very old and simple manufacturing process.	A lower degree of accuracy as compared to alternate methods.
The production time is very short.	The process yields products with a rough surface finish.
Sand casting, or sand molds, differs from other metal casting processes by requiring an easily workable material to make the mold.	Low productivity of sand casting because each pattern can only be poured once, and the pattern is damaged after obtaining the casting and must be re-molded.
The process is inexpensive and does not require expensive furnaces or equipment like centrifugal chillers.	It's impractical to use without some sort of mold, and molds have some limitations.
There are no moving parts to wear down over time.	Chances of occurring defects as tools & equipment are of low cost.
It also does not create tear-outs on the inside surface area because undercut hinges are eliminated due to the lack of dies (no undercuts).	Molds are needed every time since they do not keep their form when the hot molten metal cools within them, unlike with other casting methods such as die casting or permanent molds such as plaster molds used for rubber injection molding.
The flow of the molten metal into the cavities has an extremely strong force that perfectly captures the complexity and detail of any given part.	
It can also produce parts in a quantity never seen before, with an astonishingly low cost-per-part.	Difficult to use this method for products with pre-determined size and weight specifications.
It is not only a viable option for high-volume production, but one of choice for competitions where time or budget constraints are paramount.	Castings are easy to produce defects such as sand punching, sand trapping and porosity.
In contrast, to die casting which limits design complexity by fabricating from a flat sheet steel block, sand casting offers flexibility without sacrificing detail.	There are some limitations though that prevent us from using this process for all types of items due to the porous nature of sand a protective coating is a must.

6.2. Plaster mold casting

Plaster mold casting is a manufacturing process having a similar technique to sand casting. Plaster of Paris is used to form the mold for the casting, instead of sand. In industry parts such as valves, tooling, gears, and lock components may be manufactured by plaster mold casting.

The process.

Initially, plaster of Paris is mixed with water just like in the first step of the formation of any plaster part. In the next step of the manufacture of a plaster casting mold, the plaster of Paris and water are then mixed with various additives such as talc and silica flour. The additives serve to control the setting time of the plaster and improve its strength.

The plaster of Paris mixture is then poured over the casting pattern. The slurry must sit for about 20 minutes before it sets enough to remove the pattern. The pattern used for this type of metal casting manufacture should be made from plastic or metal. The pattern is usually made of brass and it is generally in the form of half a portion of the job to be cast and is attached firmly on a match plate which forms the bottom of the molding flask. Some parting or release agent is needed for easy withdrawal of the pattern from the mold. As the flask is filled with the slurry, it is vibrated to bubble out any air entrapped in the slurry and to ensure that the mold is completely filled up. Since it will experience prolonged exposure to water from the plaster mix, wood casting patterns tend to warp.

After striping the pattern, the mold must be baked for several hours, to remove the moisture and become hard enough to pour the metal casting. The two halves of the mold are then assembled for the casting process. Castings of high detail and section thickness as low as 0,04 -1 inch, (2,5 – 1 mm), are possible when manufacturing by plaster mold casting.

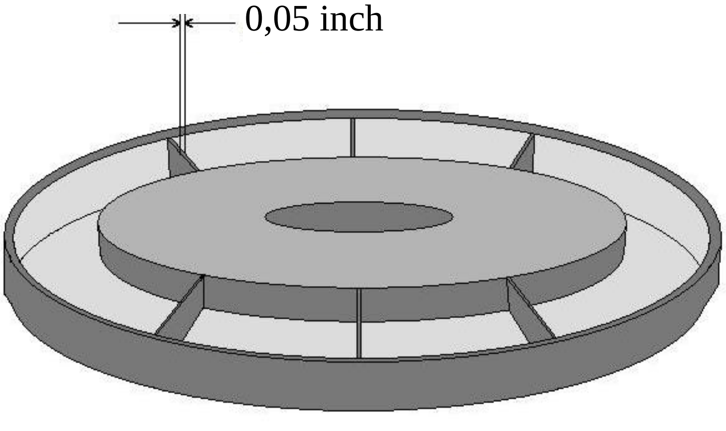


Figure 34 – Castings of high detail and section

Properties and considerations of manufacturing by plaster mold casting:

- When baking the casting mold just the right amount of water should be left in the mold material. Too much moisture in the mold can cause metal casting defects, but if the mold is too dehydrated, it will lack adequate strength.
- The fluid plaster slurry flows readily over the pattern, making an impression of great detail and surface finish. Also due to the low thermal conductivity of the mold material the casting will solidify slowly creating a more uniform grain structure and mitigating casting warping. The qualities of the plaster mold enable the process to manufacture parts with excellent surface finish, thin sections and produce high geometric accuracy.
- The plaster mold thus produced is dried in an oven to a temperature range between 200–700^oC and cooled in the oven itself. In the above manner, two halves of a mold are prepared and are joined together to form the proper cavity.
- There is a limit to the casting materials that may be used for this type of manufacturing process, due to the fact that a plaster mold will not withstand temperatures above 2200F (1200^oC). Higher melting point metals can not be cast in plaster. This process is typically used in industry to manufacture castings made from aluminum, magnesium, zinc, and copper-based alloys.
- Manufacturing production rates for this type of metal casting process are relatively slow, due to the long preparation time of the mold.
- The plaster mold is not permeable, which severely limits the escape of gases from the casting.

Solving the permeability problem.

When manufacturing a metal casting by the plaster mold casting process one of the biggest problems facing a foundry man is the lack of permeability of the plaster mold. Different techniques may be used in order to overcome this problem. The metal casting may be poured in a vacuum, or pressure may be used to evacuate the mold cavity just before pouring.

Another technique would be to produce permeability in the mold material by aerating the plaster slurry before forming the mold for casting. This «foamed plaster» will allow for the much easier escape of gases from the casting. Sometimes in the manufacturing industry, a special technique called the Antioch process may be used to make a permeable plaster metal casting mold.

The Antioch process.

This is a special case of plaster molding which was developed by Morris Bean. It is very well suited to high-grade aluminum castings. In the Antioch process, 50% plaster of Paris and 50% sand is mixed with water. The process differs from normal plaster molding in the fact that in this case once the plaster sets the whole thing is auto-laved in saturated steam at about 20 psi. Then the mold is dried in air for about 10 to 12 hours and finally in an oven for 10 to 20 hours at about 250°C. The autoclaving and drying processes create a granular structure in the mold structure which increases its permeability. The resulting mold will easily allow the escape of gases from the casting**.**

Table 10 – Advantages and disadvantages of plaster mold casting

Advantages	Disadvantages
In plaster molding a very good surface finish is obtained and the machining cost is also reduced.	There is an evolution of steam during metal pouring if the plaster mold is not dried at higher temperatures avoid this, the plaster mold may be dehydrated at high temperatures, but the strength of the mold decreases with dehydration.
Slow and uniform rate of cooling of the casting is achieved because of the low thermal conductivity of plaster and the possibility of stress concentration is reduced.	
Metal shrinkage with accurate control is feasible and thereby warping and distortion of thin sections can be avoided in the plaster molding.	The permeability of the plaster mold is low. This may be to a certain extent but it can be increased by removing the bubbles as the plaster slurry is mixed in a mechanical mixer.
Capability to make thin cross-sections.	Plaster casting requires a minimum of a 1-degree draft.
Intricate shapes with finer details are possible.	It can only be used with lower melting temperature non-ferrous materials.
Thinner, as-cast walls are also delivered by this casting process.	This process may require the frequent replacement of plaster molding materials.
Casting larger parts using this process is less expensive that it would be when using investment casting.	It is a more expensive process when compared to permanent mold and sand casting.

6.3. Ceramic mold casting

The manufacturing process of ceramic mold casting is like the process of plaster mold casting but can cast materials at much higher temperatures. Instead of using plaster to create the mold for the metal casting, ceramic casting uses refractory ceramics for a mold material. In industry, parts such as machining cutters, dies for the metalworking, metal molds, and impellers may be manufactured by this process.

The process.

The first step in manufacturing by ceramic mold casting is to combine the material for the mold. A mixture of fine-grain zircon ($ZrSiO_4$), aluminum oxide, fused silica, bonding agents, and water, creates a ceramic slurry. This slurry is poured over the casting pattern and lets set. The ceramic slurry hardens over the top of the mold. The hardening process is relatively quick. When the slurry is dry, it is the consistency of rubber. When it is removed from the pattern, it is now a mold for the tool or item that is being created. The pattern is then removed and the mold is left to dry. The mold is then fired. The mold can be placed in an oven set at a low temperature in order to remove volatiles from the mold. A flame torch may also be used, rolling the flame of the torch over each area of the mold.

The firing will burn off any unwanted material and make the mold hardened and rigid. Once the volatiles have been removed, the mold should be baked in a furnace. The furnace should be set at 1,832° F (1,000° C), which hardens the mold, truly making it a ceramic mold.

At this point, the steel or other element for creating tools or items can be poured into the mold which can sustain high-temperature pours. The mold can be used while it is hot or the person using the mold can wait for it to cool first.

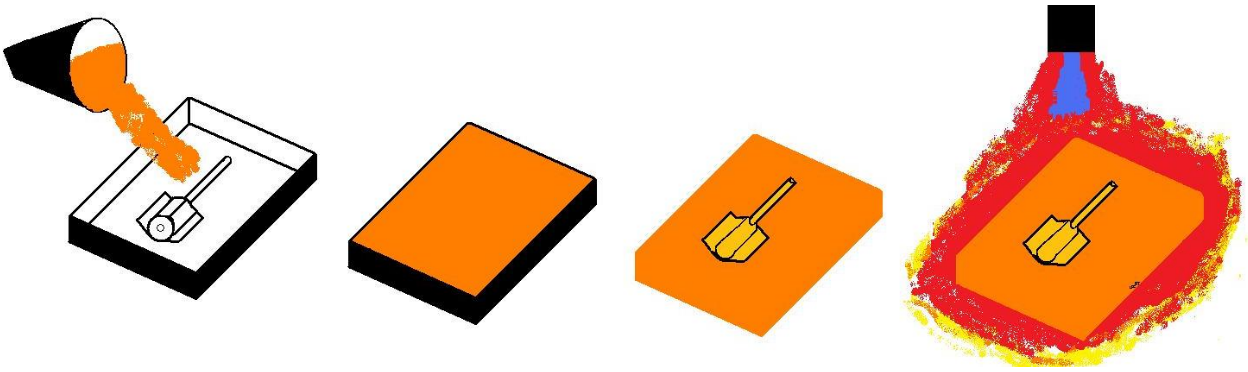


Figure 35 – The process of ceramic mold casting

The firing of the mold produces a network of microscopic cracks in the mold material. These cracks give the ceramic mold both good permeability and collapsibility for the metal casting process.

Once prepared, the two halves of the mold are assembled for the pouring of the metal casting. The two halves, (cope and drag section), may be backed up with fireclay material for additional mold strength. Often in the manufacturing industry, the ceramic mold will be preheated prior to pouring the molten metal. The metal casting is poured, and let solidify. In ceramic mold casting, like in other expendable mold processes, the ceramic mold is destroyed in the removal of the metal casting.

Typical manufacturing process of ceramic mold casting includes the following steps:

1. Refractory. Is composed of a variety of specially blended groups of refractory powders.
2. Binder. The liquid medium is visually based on ethyl silicate and is specially produced for proprietary formulations.
3. Mixing. A small percentage of gelling agents is added to the binder and mixed with the refractory powder to produce a creamy slurry.
4. Pattern. The slurry is poured over a pattern, made of metal, plaster, plastic, etc. It is then allowed to gel in about 2–3 min.
5. Stripping. The gelled refractory mass is stripped from the pattern by hand or by a mechanical stripping mechanism.
6. Burnoff. The mold is ignited. It burns until all volatiles are consumed. It sets up the microcrazed structure.
7. Baking. The shaw mold, now immune to thermal shock, is placed in a high-temperature oven until all vestiges of moisture are driven off.
8. Casting. Core and drag mold pieces are assembled along with any necessary cores and poured.

Properties and considerations of manufacturing by ceramic mold casting:

- Manufacturing by ceramic mold casting is similar to plaster mold casting in that it can produce parts with thin sections, excellent surface finish, and high dimensional accuracy. Manufacturing tolerances between .002 and .010 inches are possible with this process.
- Unlike the mold material in the plaster metal casting process, the refractory mold material in ceramic casting can withstand extremely elevated temperatures. Due to this heat tolerance, the ceramic casting process can be used to manufacture ferrous and other high melting point

metal casting materials. Stainless steels and tool steels can be cast with this process.

- To be able to cast parts with high dimensional accuracy eliminates the need for machining and the scrap that would be produced by machining. Therefore, precision metal casting processes like this are efficient to cast precious metals or materials that would be difficult to machine.
- The ceramic mold casting process is relatively expensive foundry process.
- The long preparation time of the mold makes manufacturing production rates for this process slow.
- Unlike in plaster mold casting, the ceramic mold has excellent permeability due to the microcrazing, (production of microscopic cracks), that occurs in the firing of the ceramic mold.

Ceramic mold casting has **advantages and disadvantages.** One of the primary disadvantages is that it is a very expensive process. On the flip side of the cost, however, the process can eliminate the need for secondary processes that require machines to finish or refine the process. Even though it is a very expensive process, ceramic mold casting offers several benefits, which include creating castings with fine detail. This type of casting can also create very smooth surfaces. The dimension of the tools or items created from the casting is also very accurate when it comes to the size, shape and dimensions.

The main advantages of ceramic molds are: a reusable pattern (the item used to create the shape of the mold), excellent surface finish, close dimensional tolerances, thin cross-sections, and intricate shapes can be cast. For undercuts and other difficult to cast features, part of the pattern can be made from wax in conjunction with a standard pattern; essentially using investment and ceramic mold casting techniques together.

The main disadvantages are: it is only cost-effective for small- to medium-sized production runs and the ceramic is not reusable. Ferrous and high-temperature non-ferrous are most commonly cast with these processes; other materials cast include aluminum, copper, magnesium, titanium, and zinc alloys.

Weight limits are 100 grams to several thousand kilograms (3.5 oz to several tons). Cross-sections as thin as 1.3 mm (0.051 in) are possible, with no upper limit. Typical tolerances are 0.1 mm for the first 25 mm (0.005 in for the first inch) and 0.003 mm per additional mm (0.003 in per each additional in). A draft of 1° is typically required. The typical surface finish is 2–4 um (75–150 uin) RMS.

6.4. Shell molding

Shell mold casting or shell molding is a metal casting process in the manufacturing industry in which the mold is a thin hardened shell of sand and thermosetting resin binder, backed up by some other material. Shell molding was developed as a manufacturing process during the mid-20th century in Germany.

Shell molding is similar to sand casting, but the molding cavity is formed by a hardened «shell» of sand instead of a flask filled with sand. The sand used is finer than sand casting sand and is mixed with a resin so that it can be heated by the pattern and hardened into a shell around the pattern. Because of the resin and finer sand, it gives a much finer surface finish. Shell molding, also known as shell-mold casting is an expendable mold casting process that uses resin covered sand to form the mold. As compared to sand casting, this process has better dimensional accuracy, a higher productivity rate, and lower labor requirements. It is used for small to medium parts that require high precision. Shell mold casting is a metal casting process similar to sand casting, in that molten metal is poured into an expendable mold.

However, in shell mold casting, the mold is a thin-walled shell created by applying a sand-resin mixture around a pattern. The pattern, a metal piece in the shape of the desired part, is reused to form multiple shell molds. A reusable pattern allows for higher production rates, while disposable molds enable complex geometries to be cast. Shell mold casting requires the use of a metal pattern, oven, sand-resin mixture, dump box, and molten metal.

Shell molding castings can be used for any metal, and the process generally produces castings of greater dimensional accuracy at a higher rate of production than standard sand casting. It is particularly suitable for steel castings under 20 lbs; however, almost any metal that can be cast in sand can be cast with the shell molding process. Also, much larger parts have been manufactured with shell molding. Typical parts manufactured in the industry using the shell mold casting process include cylinder heads, gears, bushings, connecting rods, gear housings, camshafts and valve bodies.

The process.

Steps of the shell molding process are the following:

1. Pattern creation. A two-piece metal pattern is created in the shape of the desired part, typically from iron or steel. Other materials are

sometimes used, such as aluminum for low volume production or graphite for casting reactive materials.

2. Mold creation. First, each pattern half is heated to 175–370 °C (350–700 °F) and coated with a lubricant to facilitate removal. Next, the heated pattern is clamped to a dump box, which contains a mixture of sand and a resin binder. The dump box is inverted, allowing this sand-resin mixture to coat the pattern. The heated pattern partially cures the mixture, which now forms a shell around the pattern. Each pattern half and the surrounding shell is cured to completion in an oven and then the shell is ejected from the pattern.

3. Mold assembly. The two shell halves are joined together and securely clamped to form the complete shell mold. If any cores are required, they are inserted prior to closing the mold. The shell mold is then placed into a flask and supported by a backing material.

4. Pouring. The mold is securely clamped together while the molten metal is poured from a ladle into the gating system and fills the mold cavity.

5. Cooling. After the mold has been filled, the molten metal is allowed to cool and solidify into the shape of the final casting.

6. Casting removal. After the molten metal has cooled, the mold can be broken and the casting removed. Trimming and cleaning processes are required to remove any excess metal from the feed system and any sand from the mold.

The first step in the shell mold casting process is to manufacture the shell mold. The sand we use for the shell molding process is of a much smaller grain size than the typical green sand mold. This fine-grained sand is mixed with a thermosetting resin binder. A special metal pattern is coated with a parting agent, (typically silicone), which will later facilitate the removal of the shell. The metal pattern is then heated to a temperature of 350F–700F degrees, (175C–370C).

The sand mixture is then poured or blown over the hot casting pattern. Due to the reaction of the thermosetting resin with the hot metal pattern, a thin shell forms on the surface of the pattern.

The desired thickness of the shell is dependent upon the strength requirements of the mold for the particular metal casting application. A typical industrial manufacturing mold for a shell molding casting process could be 0,3 inch (7,5mm) thick. The thickness of the mold can be controlled by the length of time the sand mixture is in contact with the metal casting pattern.

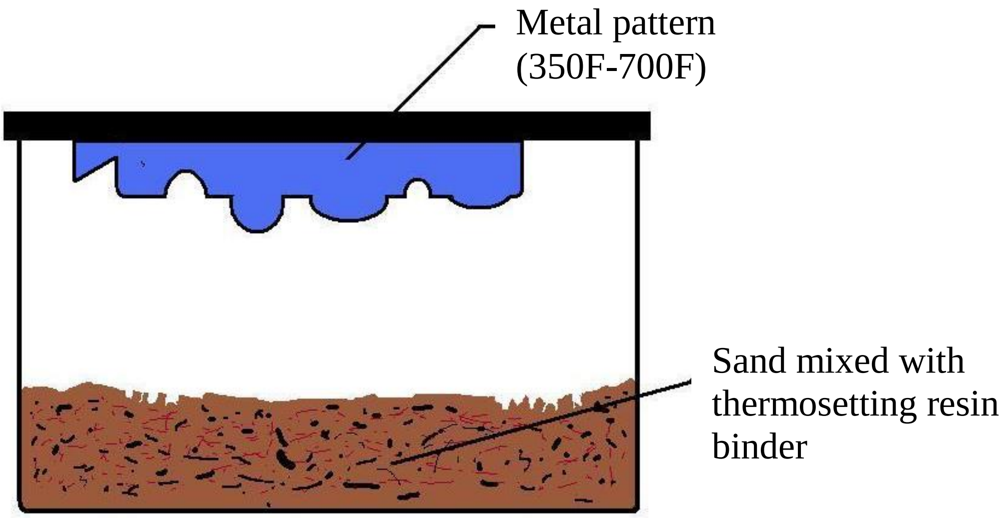


Figure 36 – The first step in shell mold casting process

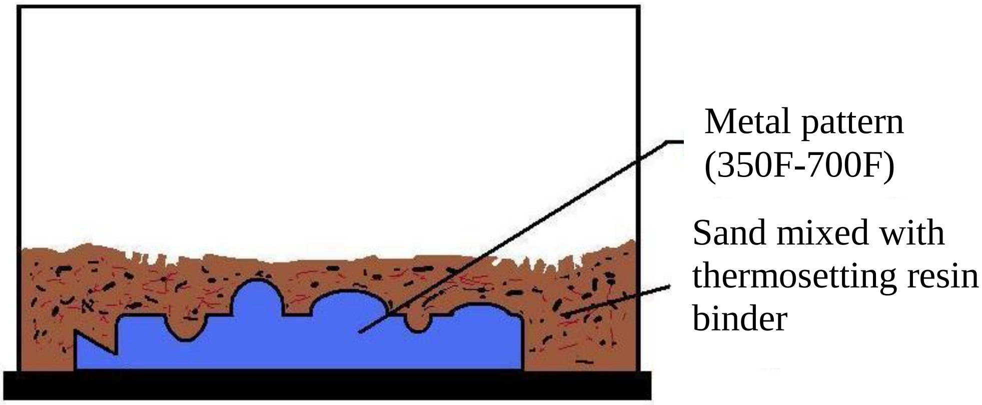


Figure 37 – The second step in shell mold casting process

The excess «loose» sand is then removed, leaving the shell and pattern.

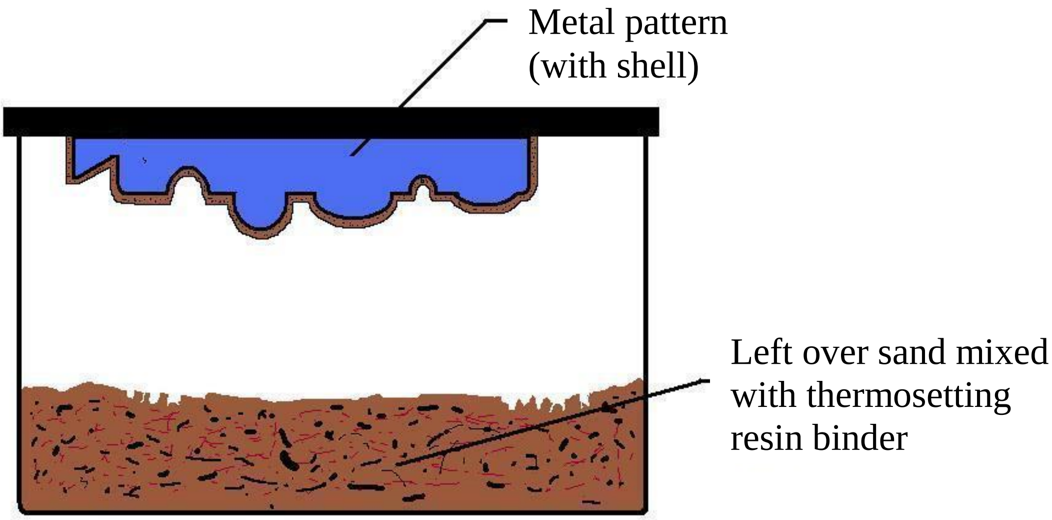


Figure 38 – The third step in shell mold casting process

The shell and pattern are then placed in an oven for a short period of time, (minutes), which causes the shell to harden onto the casting pattern.

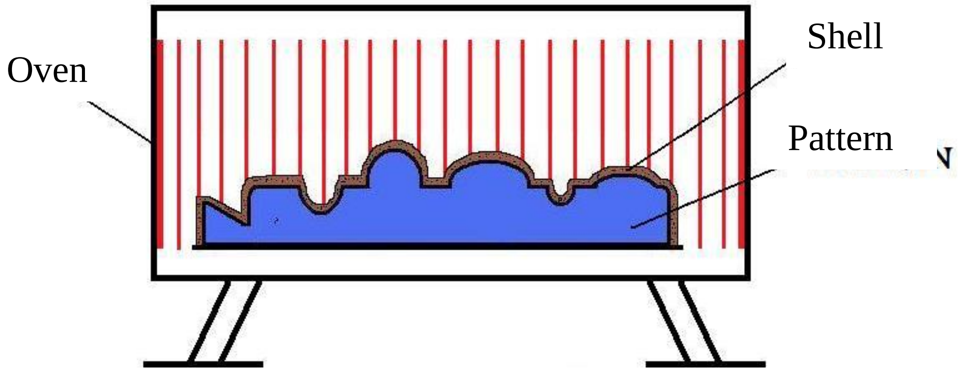


Figure 39 – Shell and pattern are baked in oven to harden shell mold

Once the baking phase of the manufacturing process is complete, the hardened shell is separated from the casting pattern by way of ejector pins built into the pattern. This manufacturing technique used to create the mold in the shell molding process can also be employed to produce highly accurate fine-grained mold cores for other metal casting processes.

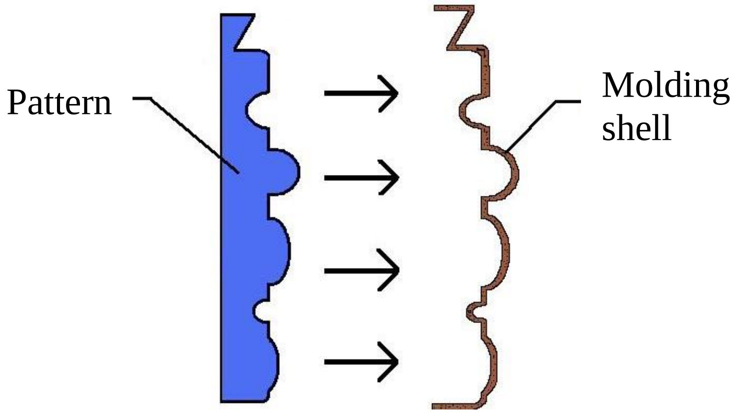


Figure 40 – The hardened shell is separated from the casting pattern

Two of these hardened shells, each representing half the mold for the casting, are assembled either by gluing or clamping.

The manufacture of the shell mold is now complete and ready for the pouring of the metal casting. In many shell molding processes, the shell mold is supported by sand or metal shot during the casting process.

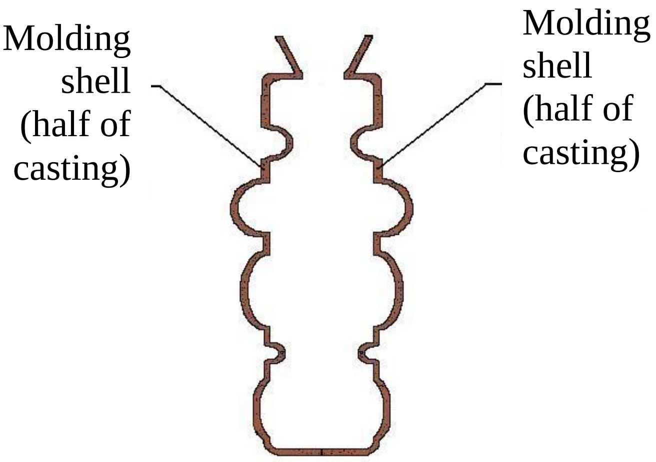


Figure 41 – Assembling of two hardened shells

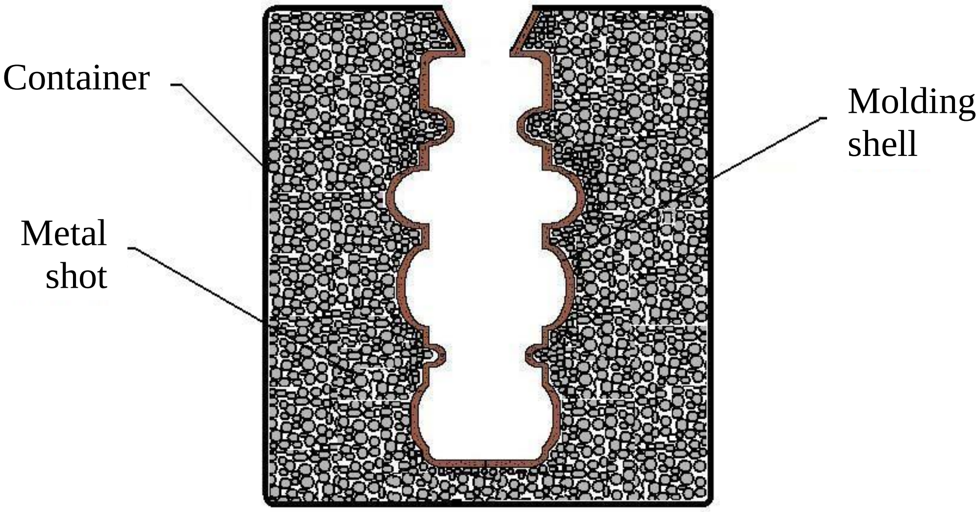


Figure 42 – The completed shell mold

Properties and considerations of manufacturing by shell mold casting:

- The internal surface of the shell mold is very smooth and rigid. This allows for an easy flow of the liquid metal through the mold cavity during the pouring of the casting, giving castings a very good surface finish. Shell mold casting enables the manufacture of complex parts with thin sections and smaller projections than green sand mold casting.
- Manufacturing with the shell mold process also imparts high dimensional accuracy. Tolerances of 0,010 inches (0,25mm) are possible. Further machining is usually unnecessary when casting by this process.

- Shell sand molds are less permeable than green sand molds and binder may produce a large volume of gas as it contacts the molten metal being poured for the casting. For these reasons, shell molds should be well-ventilated.
- The expense of shell mold casting is increased by the cost of the thermosetting resin binder but decreased by the fact that only a small percentage of sand is used compared to other sand casting processes.
- Shell mold casting processes are easily automated.
- The special metal patterns needed for shell mold casting are expensive, making it a less desirable process for short runs. However, manufacturing by shell casting may be economical for large batch production.
- The shells and cores of castings are produced by shell molding machines. These machines have dimensional limitations. So, most of the shell molding castings will be less than 400 mm in length, and less than 20kg in weight. Too long or too heavy can not be produced by this process.

The casting products possess a good surface finish and dimensional accuracy. However, the limitation of this kind of casting includes the size and weight limitation of the parts. Some other advantages and disadvantages are shown in Table 11.

Table 11 – Advantages and disadvantages of shell mold casting

Advantages	Disadvantages
Casting of thin wall thickness and complex parts.	Shell casting is more permeable so the chances of gas defect increases.
This process can be performed by semi-skilled labor.	Special metal pattern required which makes it expensive for large casting.
The products have a smooth finish.	
High rough casting dimensional accuracy is obtained.	This process needs to use metal patterns (iron patterns), which have high costs.
No further machining is required.	
Accounts for surface defects.	Limitations on size and weight.
Less manpower and molding skill requirements.	Not suitable for small-scale production.
Shell casting is easily automated process.	High production costs and casting prices.

6.5. Vacuum casting

Vacuum mold casting, also known in the manufacturing industry as the V-process, employs a sand mold that contains no moisture or binders. The internal cavity of the mold holds the shape of the casting due to forces exerted by the pressure of a vacuum. Vacuum molding is a casting process that was developed in Japan around 1970.

Vacuum casting, as the name suggests, is the type of casting where production occurs under vacuum pressure of 100 bar or less to exhaust gas from the mold cavity. In this process, molten metal is poured into the mold cavity inside a vacuum chamber in order to eliminate bubbles and air pockets. The vacuum evacuation of the die cavity reduces the entrapment of gases within the cavity during the metal injection process. Finally, the metal is cured in a heating chamber and removed from the mold.

The original inventors of this proprietary vacuum process have established working agreements on a worldwide basis so that today individually licensed foundries using the V-Process can produce castings of all sizes and shapes.

These range from thin-sectioned curtain walls in aluminum to cast iron pressure pipe fittings and stainless steel valve bodies to massive 8-tonne ship anchors. Other components being routinely cast include bathtubs, railroad bolsters and side frames, machine tools, engine parts and agricultural castings. Any metal (grey, ductile, malleable iron, various grades of steel, or aluminum and copper-base alloys) may be poured in a V-process mold, with the possible exception of magnesium.

Why use vacuum for creating complex metal parts?

Liquid metal tends to «churn» as it flows into a mold. This turbulence leads to two types of defects: oxides and porosity. Oxides are formed when metal atoms bond with oxygen. This takes place in the metal air where it forms an oxide layer. On some metals, such as aluminum, surface oxidation is beneficial because it creates a corrosion-resistant layer. However, it’s a problem during casting. This is because, as the liquid metal churns, oxides form on the surface and get incorporated into the body of the cast part. Once the metal solidifies these discontinuities form areas of weakness.

Porosity is the formation of bubbles within the body of the metal. Like oxides, these reduce strength, especially in high-stress areas when exposed to machining.

One way to minimize turbulence, oxidation and porosity is to fill slowly from the bottom of the mold. Most casting companies try to do this but part design and cycle time constraints often limit what’s possible. Another method is to extract air from the mold before the metal flows in.

Any metal suitable for casting can be processed under a vacuum. However, the process is most often used with nickel, cobalt-based super alloys and titanium alloys as these metals have exceptionally high affinity for oxygen and form oxides readily. In addition, the high value of these metals and their use in complex, high-value products makes it beneficial to minimize scrap.

The process.

A special pattern is used for the vacuum mold casting process. It is either a match plate or a cope and drag pattern with tiny holes to enable a vacuum suction. A thin plastic sheet is placed over the casting pattern and the vacuum pressure is turned on, causing the sheet to adhere to the surface of the pattern.

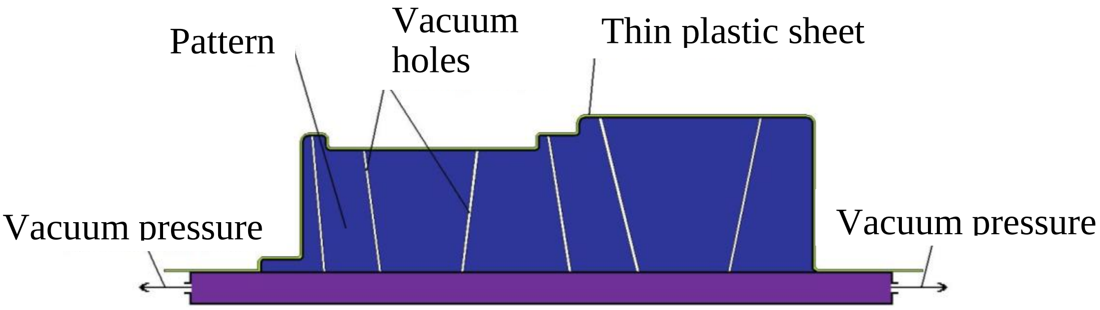


Figure 43 – Special pattern

A special flask is used for this manufacturing process. The flask has holes to utilize vacuum pressure. This flask is placed over the casting pattern and filled with sand.

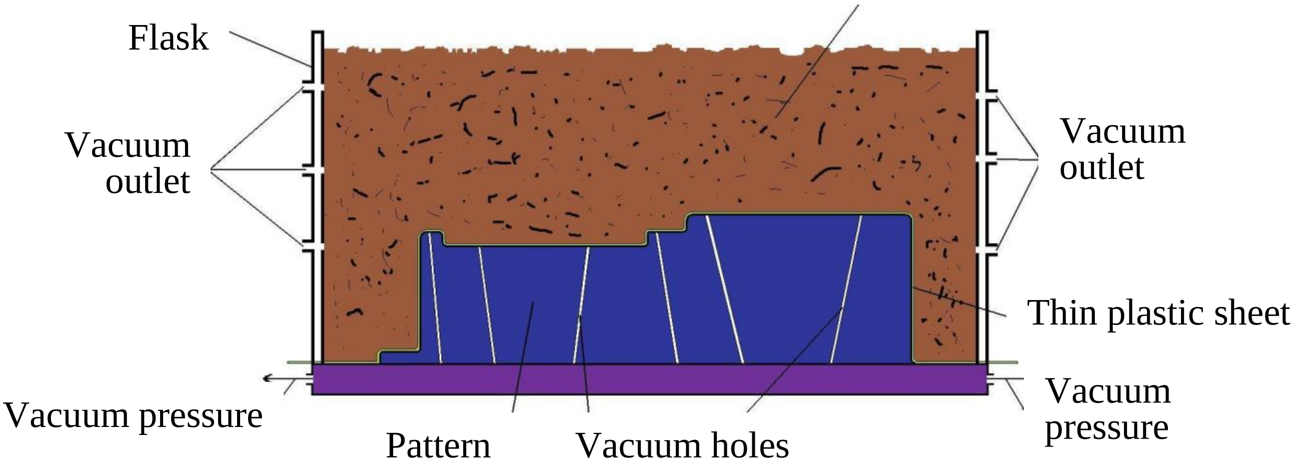


Figure 44 – Special flask

A pouring cup and sprue are cut into the mold for the pouring of the metal casting.

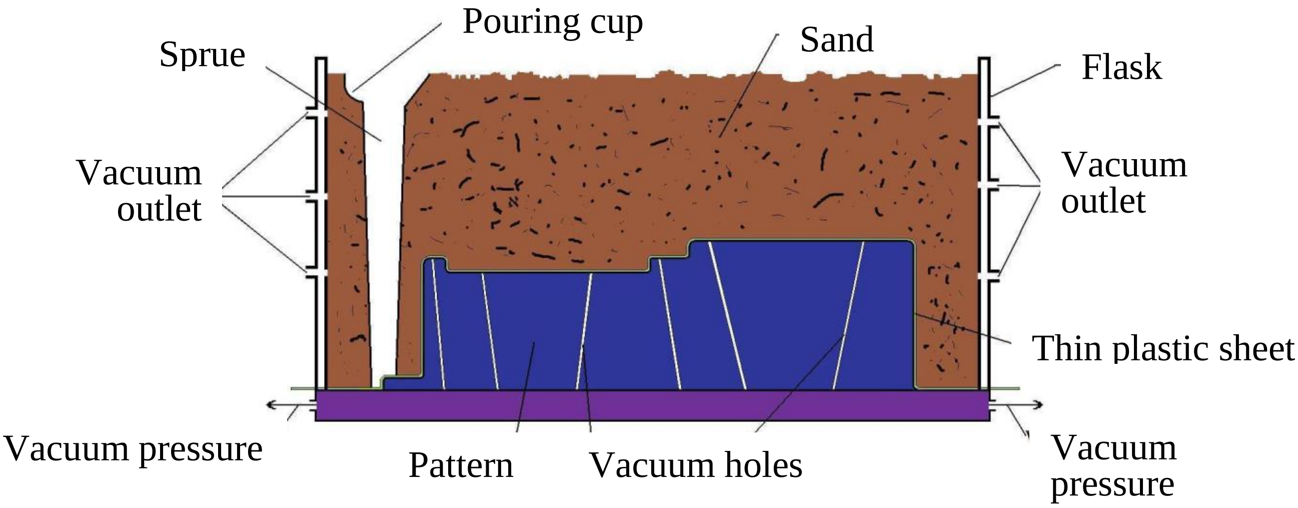


Figure 45 – Pouring cup and sprue

Next, another thin plastic sheet is placed over the top of the mold. The vacuum pressure acting through the flask is turned on, and the plastic film adheres to the top of the mold.

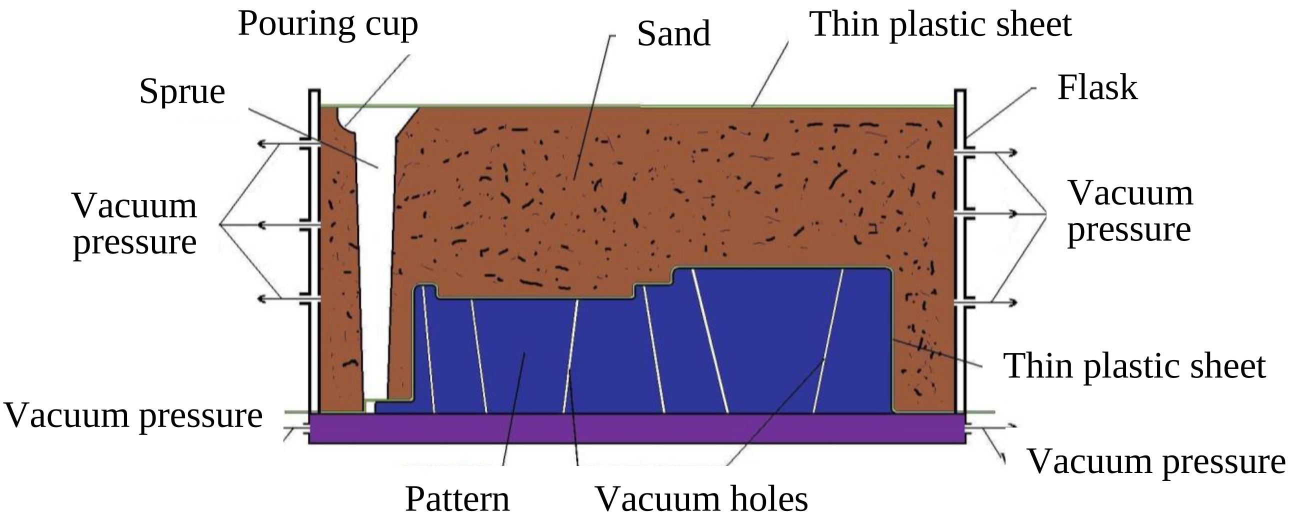


Figure 46 – Thin plastic sheets

In the next stage of vacuum mold casting manufacture, the vacuum on the special casting pattern is turned off and the pattern is removed. The vacuum pressure from the flask is still on. This causes the plastic film on the top to adhere to the top and the plastic film formerly on the pattern to adhere to the bottom. The film on the bottom is now holding the impression of the casting in the sand with the force of the vacuum suction.

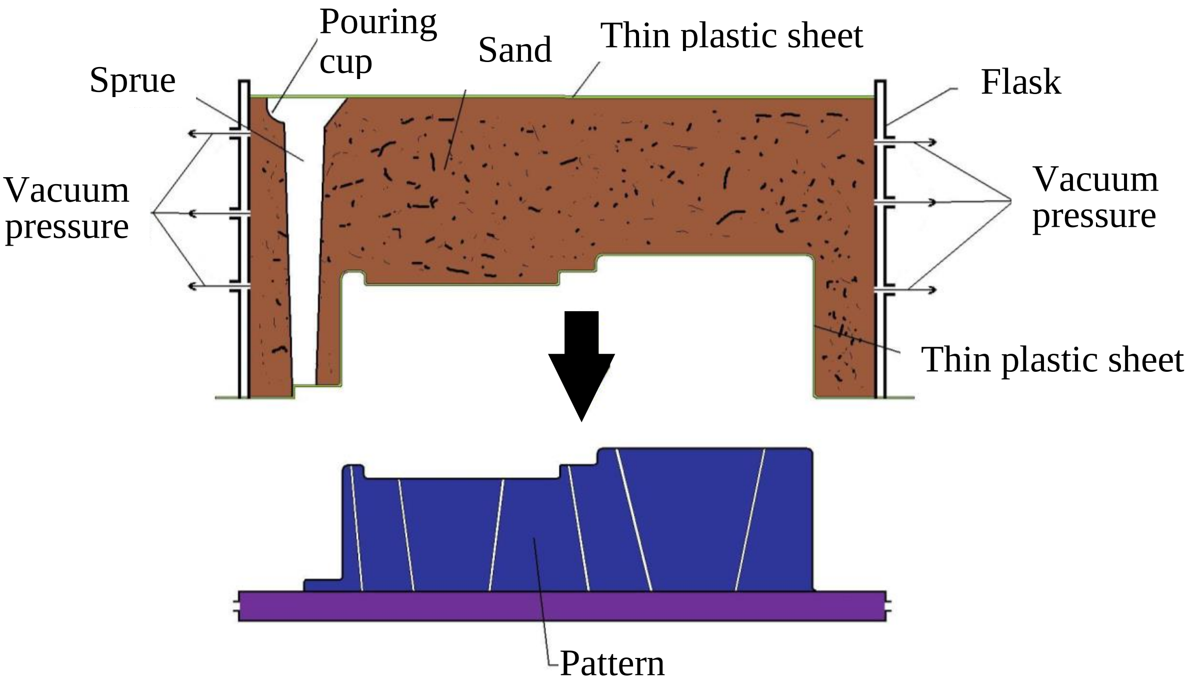


Figure 47 – Removing the pattern

The drag portion of the mold is manufactured in the same fashion. The two halves are then assembled for the pouring of the casting. Note that there are now 4 plastic films in use. One on each half of the internal casting cavity and one on each of the outer surfaces of the cope and drag.

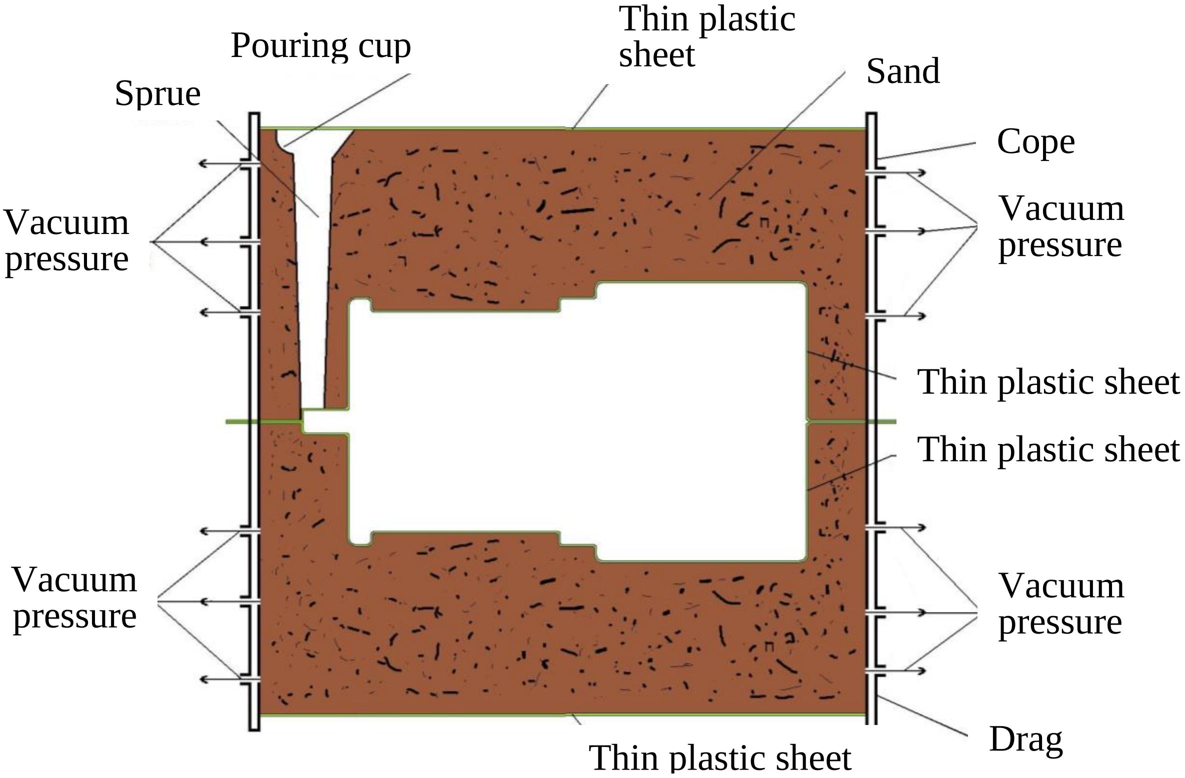


Figure 48 – The drag portion of the mold

During the pouring of the casting, the molten metal easily burns away the plastic.

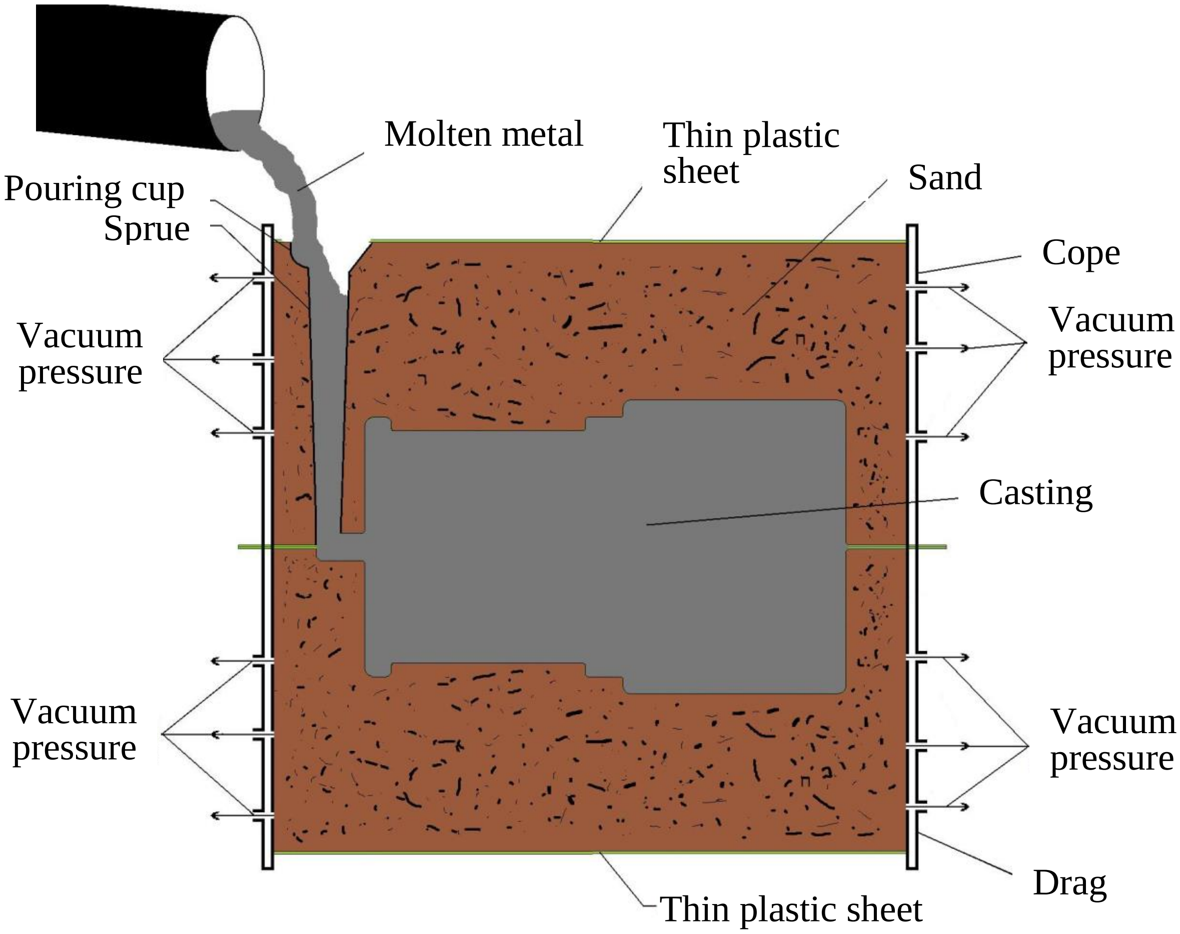


Figure 49 – Pouring of the casting

Properties and considerations of manufacturing by vacuum mold casting:

- In vacuum mold casting manufacture there is no need for special molding sands or binders.
- The pattern is covered tightly by a thin sheet of plastic.
- Sand recovery and reconditioning, a common problem in the metal casting industry, is very easy due to the lack of binders and other agents in the sand.
- The second flak is then placed on top of the sand, and a vacuum draws the sand so that the pattern can be tight and withdrawn. Both halves of the mold are made and assembled in this way.
- During pouring, the mold remains under a vacuum but the casting cavity does not.

- When the metal has solidified, the vacuum is turned off and the sand falls away, releasing the casting.
- When manufacturing parts by vacuum mold casting the sand mold contains no water, so moisture-related metal casting defects are eliminated.
- The size of risers can be significantly reduced for this metal casting process, making it more efficient in the use of material.
- Casting manufacture by vacuum molding is a relatively slow process.
- Vacuum molding produces casting with high-quality detail and dimensional accuracy.
- It is especially well suited for large, relatively flat castings.
- Vacuum mold casting is not well suited to automation.

Table 12 – Advantages and disadvantages of vacuum casting

Advantages	Disadvantages
Reduce porosity, improve mechanical properties and surface quality of die casting.	The mold used in the process has a short life.
Complex and intricate shapes can be easily manufactured with high precision.	Molds and tooling parts need to be regularly maintained.
Production of thin-walled products.	
Welding and heat treatment of products is possible.	High tooling and mold tools costs.
Suitable for low-volume production.	Long lead time feasible.
No requirement for expensive hard tool finishing.	Slow cycle times.
Diminishes air pockets and bubbles at early stages.	Not suitable for large-scale production.
Multiple components can be simultaneously manufactured, increasing the efficiency of production.	Potential hollowness issues.

The vacuum casting process is popular in various industries including rail trains, heavy-duty trucks, automobiles, construction equipment, hydraulics, logistics equipment, aerospace, electronics, agricultural equipment, marine, engine systems, etc. As a result, some components fabricated by this manufacturing process include structural chassis components and automotive body parts.

6.6. Expanded polystyrene casting

In the expanded polystyrene casting process, a sand mold is packed around a polystyrene pattern representing the metal casting to be manufactured. The pattern is not removed, and the molten metal is poured into the pattern which is vaporized from the heat of the metal. The liquid metal takes the place of the vaporized polystyrene and the casting solidifies in the sand mold.

The concept of molten metal vaporizing a foamed polystyrene pattern was first patented in 1958. In its original form, patterns were fabricated from an expandable polystyrene insulation board and surrounded with bonded sand after which the metal was poured. With certain improvements, this process is still in use today and is suited for large one- of- a- kind castings such as dies for stamping large automotive sections and large dimension, heavy- sectioned castings used by machine tool builders. Expanded polystyrene is suitable for use with both ferrous and nonferrous metals.

In the metal casting industry this process is known as the lost foam process, evaporative pattern casting, or the full mold process. A large variety of castings of different sizes and materials can be manufactured using this technique. Parts produced in the manufacturing industry using this process include crankshafts, cylinder heads, machine bases, manifolds, and engine blocks.

The process.

Expanded polystyrene casting process steps:

1. The pattern of polystyrene is coated with a refractory compound.
2. The foam pattern is placed in a mold box, and sand is compacted around the pattern.
3. Molten metal is poured into the portion of the pattern that forms the pouring cup and sprue. As the metal enters the mold, the polystyrene foam is vaporized ahead of the advancing liquid, thus allowing the resulting mold cavity to be filled.

The first step in the evaporative casting process is to manufacture the polystyrene pattern. For small production runs, a pattern may be cut from larger sections of polystyrene material and assembled. For large industrial manufacturing processes, the pattern will be molded. A die, often made from aluminum, is used for this process. Polystyrene beads are placed in the die and heated, they expand from the heat and the foam material takes the shape of the die.

Depending upon the complexity of the casting, several of these polystyrene sections may have to adhere together to form the pattern. In most cases the pattern is coated with a refractory compound, this will help create a good surface finish on the metal casting. In addition to the casting itself, the foam pattern will also include sprue, the pouring cup, the gating system and internal cores if needed. Mold does not have to be opened into cope and drag sections.

The pattern is then placed in a flask and molding sand is packed around it. The sand may or may not contain bonding agents, dependent upon the particular manufacturing procedure.

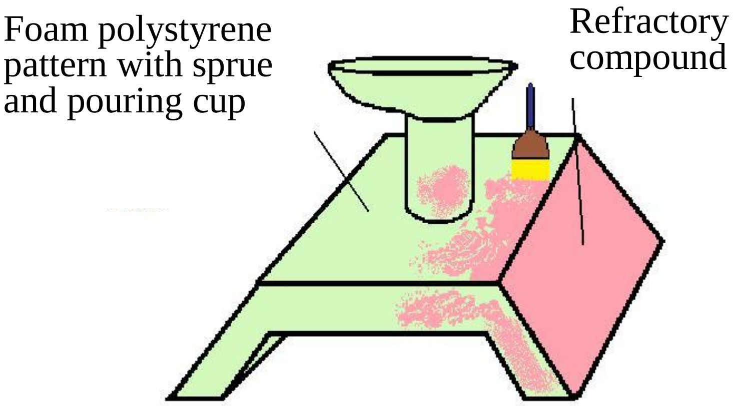


Figure 50 – The foam pattern

The molten metal is then poured into the mold without removing the pattern. The liquid metal vaporizes the polystyrene pattern, as it flows through the mold cavity. Any leftover product from the vaporized polystyrene material is absorbed into the molding sand.

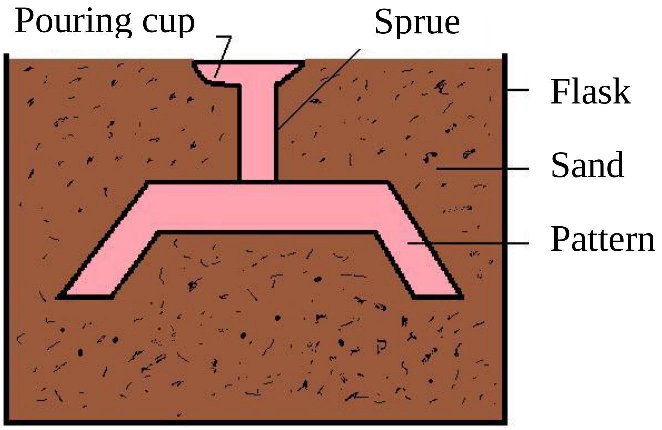


Figure 51 – Pattern is placed in a flask and molding sand

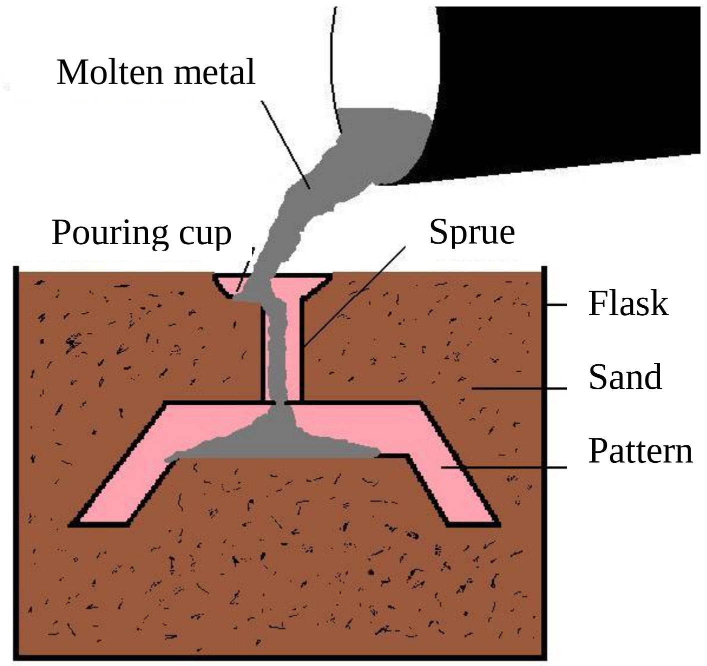


Figure 52 – Pouring of the expanded polystyrene casting

The molten metal is then allowed to harden within the sand mold. Once solidified, the casting is removed.

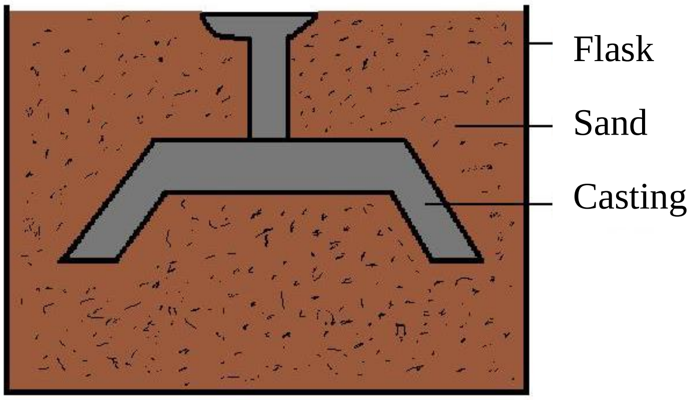


Figure 53 – Molten metal in the sand mold

Properties and considerations of manufacturing by expanded polystyrene casting:

- If a core is needed it is incorporated within the pattern. Therefore placing and securing a core in the mold cavity before the pouring of the metal casting is not a step in this manufacturing process.

- Flasks for this process are simple and not expensive. Also, the manufacturing process itself is easy since there is no parting line or removal of the pattern needed.
- In the manufacturing industry, patterns for expanded polystyrene metal casting will always include the full gating system.
- Due to the extra energy required to vaporize the polystyrene, there will be a large thermal gradient present at the metal-pattern interface as the casting is being poured.
- Very complex metal casting geometry can be produced using this process.
- A new pattern is needed for every casting, so the economics of the expanded polystyrene casting process depends largely on the cost of producing the patterns.
- This manufacturing process can be very efficient in the production of metal castings for large industrial runs. The main cost is to create the die to produce the foam polystyrene patterns. Once that is overcome, the process itself is very inexpensive.
- The process has been applied to mass-produce castings for automobile engines.
- This manufacturing process can be easily automated.
- Automated and integrated manufacturing systems are used to mold the polystyrene pattern and then feed them to the downstream casting operations.

Table 13 – Advantages and disadvantages of expanded polystyrene casting

Advantages	Disadvantages
Patterns need not be removed from the mold.	A new pattern is needed for every casting.
Simplifies and speeds mold-making, because two mold halves are not required as in a conventional green-sand mold.	The pattern coating process is time- consuming, and pattern handling requires great care.
The parts (cope and drag with proper parting line, cores, gating and riser system) are built into the pattern itself.	Economic justification of the process is highly dependent on the cost of producing patterns.

6.7. Investment casting

Investment casting is a manufacturing process in which a wax pattern is coated with a refractory ceramic material. Once the ceramic material is hardened its internal geometry takes the shape of the casting.

This manufacturing technique is also known as the lost wax process. Investment casting was developed over 5500 years ago and can trace its roots back to both ancient Egypt and China.

Investment casting usually refers to the casting scheme in which the mold is made of fusible material, covered with several layers of refractory material on the surface of the mold to make the shell, and then the mold is melted and discharged from the shell to obtain a mold without a parting surface, which can be filled with sand and poured after high-temperature roasting. Because the mold sample is a widely used wax material to manufacture, so often fusion casting is called “lost wax casting”.

The investment casting process initiates with the production of wax replicas or patterns of the required shape of castings. Every casting requires a pattern to be produced. Wax or polystyrene is made used as the injecting material. The assembly of a large number of patterns is made and attached to a wax sprue centrally. Metallic dies are used to prepare the patterns. The pattern is immersed in the refractory slurry which completely surrounds it and gets set at room temperature forming the mold. The mold is further heated, so that the pattern melts and flows out, leaving the required cavity behind. After heating, the mold gets further hardened and molten metal is poured while it is still hot. After the metal gets solidified within the ceramic mold, the mold is broken and it is taken out.

The types of alloys that can be produced by investment casting include carbon steel, alloy steel, heat-resistant alloys, stainless steel, precision alloys, permanent magnet alloys, bearing alloys, copper alloys, aluminum alloys, titanium alloys and ductile iron, etc.

Many of the advantages of the investment casting process can be achieved through other casting techniques if principles of thermal design and control are applied appropriately to existing processes that do not involve the shortcomings of investment castings.

Components made by investment casting are utilized to cast a wide variety of items, including high-quality and high-performance industrial parts of complex structures. The application of the precision investment casting (lost wax casting process) components covers a wide range of industries, they are included gears, cams, ratchets, turbine blades, machinery components and other parts of complex geometry.

The process.

The basic steps of the investment casting process are the following:

1. Preparing the heat-disposable wax, plastic or polystyrene patterns in a die.

2. Assembly of the prepared patterns onto a gating system

3. «Investing,» (covering) the pattern assembly with a refractory slurry which builds the shell.

4. Melting the pattern assembly (burning out the wax) by firing, for removing the traces of the pattern material

5. The metal in the molten state is poured into the formed mold.

6. Once the metal solidifies, the shell is removed (knocked out).

7. Fettling (cutting off) of the pouring basin and gates followed by finishing operations to get the desired dimensional tolerances and finish.

The first step in investment casting is to manufacture the wax pattern for the process. The pattern for this process may also be made from plastic; however, it is often made of wax since it will melt out easily and wax can be reused. Since the pattern is destroyed in the process, one will be needed for each casting to be made.

When producing parts in any quantity, a mold from which to manufacture patterns will be desired. Similar to the mold that may be employed in the expanded polystyrene casting process to produce foam polystyrene patterns, the mold to create wax patterns may be cast or machined. The size of this master die must be carefully calculated. It must take into consideration the shrinkage of wax, shrinkage of the ceramic material invested over the wax pattern and shrinkage of the metal casting. It may take some trial and error to get just the right size, therefore these molds can be expensive. Since the mold does not need to be opened, castings of very complex geometry can be manufactured. Several wax patterns may be combined for a single casting.

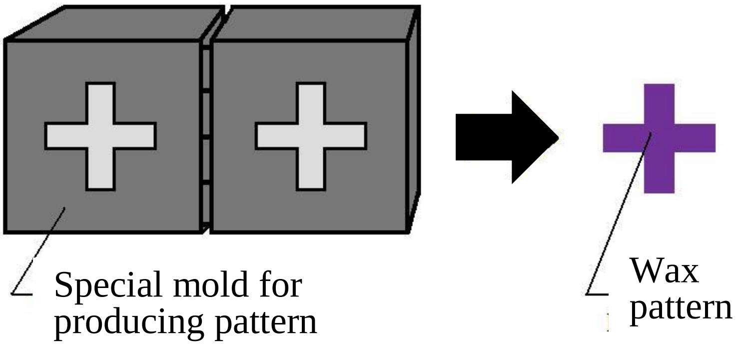


Figure 54 – Manufacture the pattern

Or as in often the case, many wax patterns may be connected and poured together producing many castings in a single process. This is done by attaching the wax patterns to a wax bar, the bar serves as a central sprue. A ceramic pouring cup is attached to the end of the bar. This arrangement is called a tree, denoting the similarity of casting patterns on the central runner beam to branches on a tree.

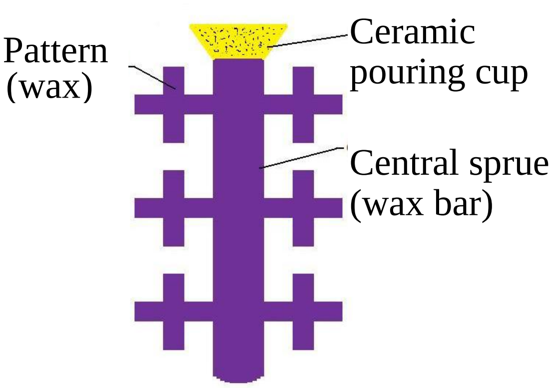


Figure 55 – Wax pattern tree for investment casting

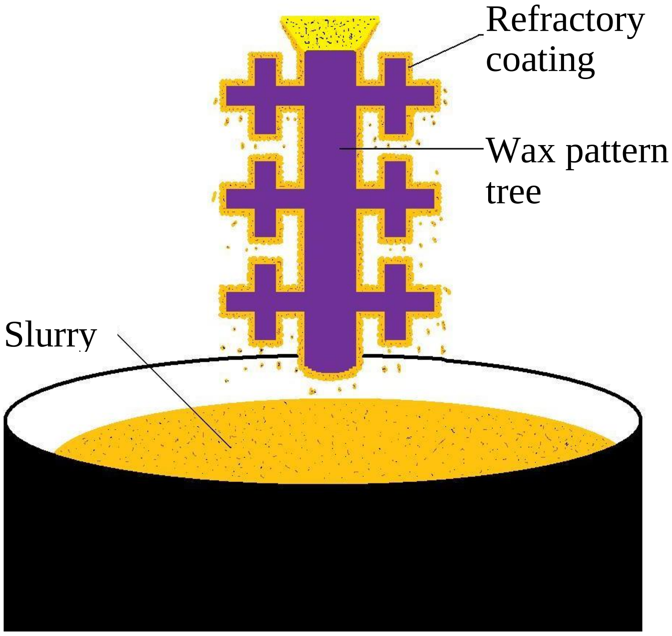


Figure 56 – Refractory slurry invested over wax pattern

The metal casting pattern is then dipped in a refractory slurry whose composition includes extremely fine-grained silica, water and binders. A ceramic layer is obtained over the surface of the pattern. The pattern is then repeatedly dipped into the slurry to increase the thickness of the ceramic coat. In some cases, the pattern may be placed in a flask and the ceramic slurry poured over it. Once the refractory coat over the pattern is thick enough, it is allowed to dry in air in order to harden.

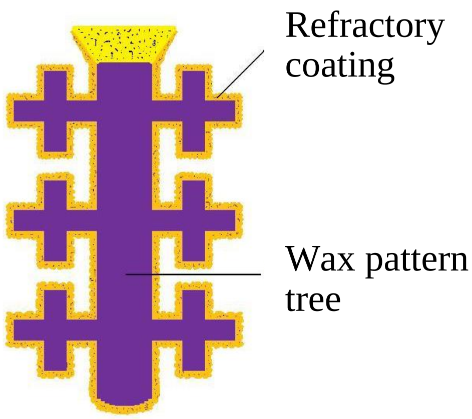


Figure 57 – Refractory slurry invested over wax pattern drying in air

The next step in this manufacturing process is the key to investment casting. The hardened ceramic mold is turned upside down and heated to a temperature of around 200F–375F (90°C–175°C). This causes the wax to flow out of the mold, leaving the cavity for the metal casting.

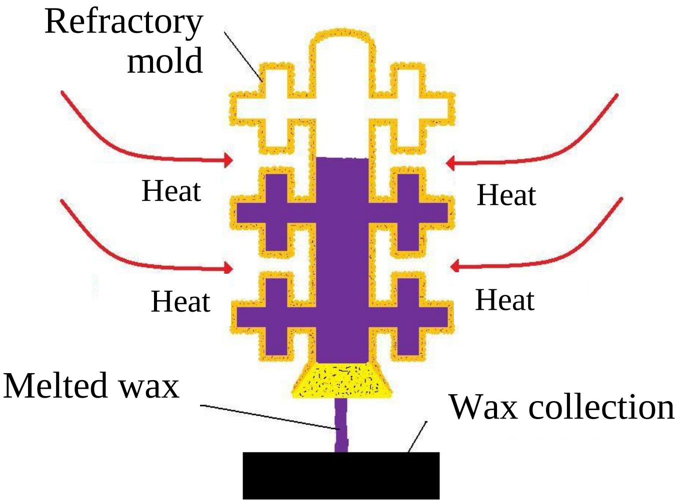


Figure 58 – Wax melted out of mold for investment casting

The ceramic mold is then heated to around 1000F–2000F (550°C–1100°C). This will further strengthen the mold, eliminate any leftover wax or contaminants and drive out water from the mold material. The metal casting is then poured while the mold is still hot. Pouring the casting while the mold is hot allows the liquid metal to flow easily through the mold cavity, filling detailed and thin sections. Pouring the metal casting in a hot mold also gives better dimensional accuracy, since the mold and casting will shrink together as they cool.

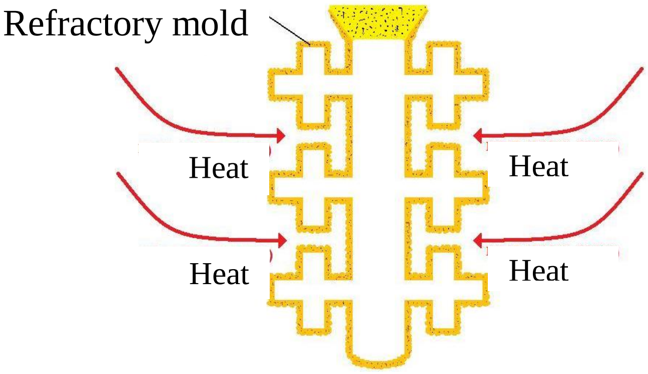


Figure 59 – Mold for investment casting heated before pouring

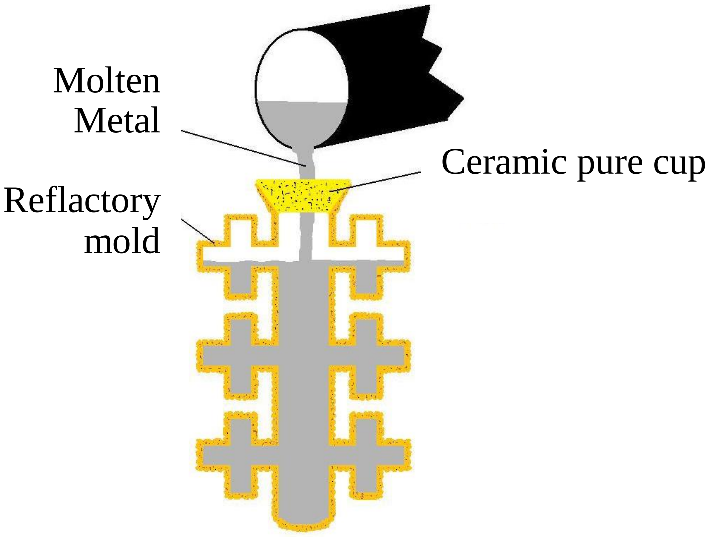


Figure 60 – Pouring of an investment casting

After pouring the molten metal into the mold, the casting is allowed to set as the solidification process takes place.

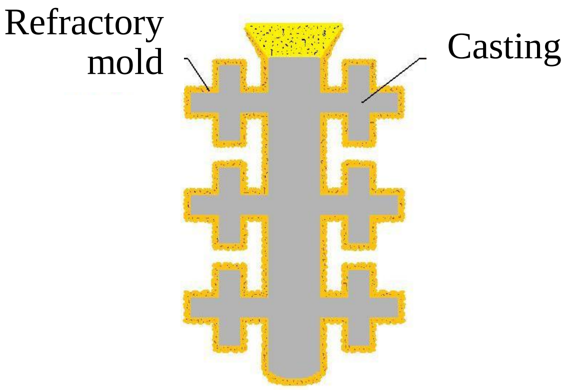


Figure 61 – Solidification of an investment casting

The final step in this manufacturing process involves breaking the ceramic mold from the investment casting and cutting the parts from the tree.

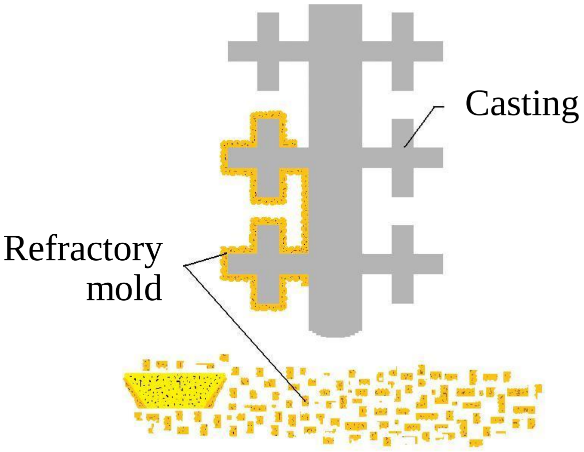


Figure 62 – Break up of the mold for investment casting

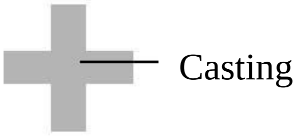


Figure 63 – Investment casting final product

Properties and considerations of manufacturing by investment casting:

- Investment casting is a manufacturing process that allows the casting of extremely complex parts, with good surface finish.
- Very thin sections can be produced by this process. Metal castings with sections ~ .015in (.4mm) have been manufactured using investment casting.
- Investment casting also allows for high dimensional accuracy. Tolerances as low as 0,003 in (0,076 mm) have been claimed.
- Practically any metal can be investment cast. Parts manufactured by this process are generally small, but parts weighing up to 75 lbs have been found suitable for this technique.
- Parts of the investment process may be automated.
- Investment casting is a complicated process and is relatively expensive.

Table 14 – Advantages and disadvantages of investment casting

Advantages	Disadvantages
Investment casting can improve the utilization rate of metal materials.	More segregation of alloy components during pouring under the forces of rotation.
Less material is required for the gate.	
Fine-grained structure at the outer surface of the casting free of gas and shrinkage cavities and porosity.	Contamination of the internal surface of castings with non-metallic inclusions.
A very smooth surface is obtained with no parting line.	It can be difficult to cast objects requiring cores.
High dimensional accuracy and close tolerance can be achieved. Generally up to CT4-6.	The size of the casting can not be too large process of complex casting cooling rate is slow.
Not limited by alloy materials.	Inaccurate internal diameter.
Due to breaking away of the shell mold, allows for castings with 90-degree angles.	New die requirement for the creation of wax patterns for each casting cycle.
Investment casting can cast hard-to-melt alloys such as stainless steel, thin steel, etc.	Higher manufacturing costs of molds.
Certain unmachinable parts can be cast to a preplanned shape.	Investment castings require very long production cycle times versus other casting processes.
Castings are free from usual defects.	
Many intricate forms with undercuts can be cast.	The process is the most complex and the casting cost is high.
Formation of hollow interiors in cylinders without cores.	Investment castings require very complex equipment versus other casting processes.
High production flexibility and adaptability.	The process is expensive, it may be used to replace die casting where short runs are involved.
Melt casting is suitable for both high-volume production and small-volume production or even single-piece production.	This process is practically infeasible for high-volume manufacturing, due to its high cost and long cycle times.

Multiple Choice Questions

6.1. The most widely used metal casting process in manufacturing is:
1) shell casting;
2) plaster mold casting;
3) vacuum casting;
4) sand casting;
5) investment casting.

6.2. Silica sand has which one of the following compositions?
1) Al_2O_3;
2) Na_2O;
3) SiO_2;
4) $FeSO_4$;
5) $Ca(OH)_2$.

6.3. What is a great advantage of sand in manufacturing applications?
1) that sand is inexpensive;
2) fine-grained;
3) flowability;
4) resistant to elevated temperatures;
5) resistance to chemically aggressive environments.

6.4. Usually sand used to manufacture a mold for the casting process is held together by:
1) the molding compound sintering method;
2) the molding compound crystallization method;
3) the mixture of water and plaster;
4) the mixture of water and clay;
5) the special organic mixture.

6.5. A typical mixture by volume could be:
1) 89% sand;
2) 76% sand;
3) 4% water;
4) 8% water;
5) 7% clay;

6.6. To keep the shape of the mold throughout the casting operation:
1) the mold must have a reliable case;

2) the mold must have physical integrity;
3) the mold must have corrosion resistance;
4) the mold must have resistance to high temperatures;
5) the mold must have impact strength.

6.7. In the sand casting manufacturing process, as a binding agent to adhere the molding sand together used:

1) the clay;
2) plaster;
3) organic resins, (such as phenolic resins);
4) inorganic bonding agents, (such as phosphate and sodium silicate);
5) special synthetic binding agents.

6.8. What are the general types of sand used in the manufacturing process of sand casting?

1) fine-grained and loose sand;
2) artificially crushed sand;
3) specially calibrated sand;
4) naturally bonded;
5) synthetic sand.

6.9. What are the disadvantages of naturally bonded sand for sand casting?

1) includes organic impurities that reduce the fusion temperature of the sand mixture;
2) contains inorganic impurities that contribute to the formation of slag in the casting;
3) lower the binding strength;
4) 4) reduce the impact viscosity of the sand mixture;
5) require a higher moisture content;
6) require the addition of plasticizers.

6.10. What are the advantages of synthetic sand for sand casting?

2) higher green strength;
3) lower content of organic and inorganic impurities;
4) more permeability;
5) greater refractory strength.

6.11. What is the key to controlling the properties of the casting's mold sand mixture?

1) controlling the content of the sand binder;

2) controlling the type and other additives in a sand mixture;
3) controlling of uniform concentration of sand binder and other additives in the sand mixture;
4) controlling the volumetric weight of the sand mixture;
5) controlling the impact viscosity of the sand mixture.

6.12. Moisture content affects the properties of the mixture such as:
1) liquidity;
2) gas permeability;
3) permeability;
4) plasticity;
5) strength.

6.13. Too much moisture in the mixture can cause:
1) loss of strength of the sand mixture;
2) increased fluidity of the sand mixture;
3) steam bubbles to be entrapped in the metal casting;
4) formation of incomplete casting;
5) decrease in the impact viscosity of the sand mixture.

6.15. The ability of the sand casting mixture to hold its geometric shape under the conditions of mechanical stress imposed during the sand casting process is:
1) the explanation of the accuracy of castings;
2) the explanation of mold reliability;
3) the explanation of mold durability;
4) the explanation of strength;
5) the explanation of coagulation of sand casting mixture.

6.16. The ability of the sand mold to permit the escape of air, gases, and steam during the sand casting process is:
1) ventilation;
2) conditioning;
3) permeability;
4) air outlet;
5) gas outlet.

6.17. The ability of the sand mixture to collapse under force is:
1) flowability;
2) fragility;

3) fatigue destruction;
4) collapsibility;
5) renewability.

6.18. Collapsibility of the mold will allow the metal casting during the solidification phase of the process:
1) to shrink freely;
2) to expand freely;
3) to crystallize evenly;
4) to uniformly recrystallize;
5) to shake out with the mold.

6.19. If the molding sand cannot collapse adequately for the casting's shrinkage, then:
1) compressive stresses will appear in the casting;
2) tensile stresses will appear in the casting;
3) hot tearing or cracking will develop in the casting;
4) fatigue failure will occur in the casting;
5) there will be a loss of strength in the sand mixture.

6.20. The ability of the sand mixture to flow over and fill the sand casting pattern during the impression-making phase of the manufacturing process is:
1) fragility;
2) permeability;
3) fluidity;
4) liquidity;
5) flowability.

6.21. During the pouring of the molten metal in sand casting manufacture, the sand mixture in the mold must not:
1) heat;
3) burn;
4) crack;
5) spill;
6) sinter.

6.22. The ability of the mold sand mixture to withstand levels of extreme temperature is:
1) refractory strength;

2) thermoregulation;
3) thermal insulation;
4) thermostatics.

6.23. The ability of the mold sand mixture to be reused to produce other sand castings in subsequent manufacturing operations is:
1) permeability;
2) cyclicality;
3) reusability;
4) reproducibility of the sand mixture;
5) versatility of the sand mixture.

6.24. Establish correspondence:

A	Small grain size
B	Large grain size

1	enhances mold strength.
2	increases mold strength.
3	is less permeable.
4	is more permeable.

1) A – 1; 3) B – 3;
2) A – 2; 4) B – 4.

6.25. Establish correspondence:

A	Sand casting molds made from grains of irregular shape
B	Sand casting molds made from rounder grains

1	tend to be stronger because of grain interlocking.
2	are more fragile due to insufficient adhesion of grains.
3	provide higher wear resistance of the casting surface.
4	provide a better surface finish.
5	have higher corrosion resistance.

1) A – 1;
2) A – 2;
3) B – 3;
4) B – 4;
5) B – 5.

6.26. If the sand is being reused from a previous sand casting manufacturing process, then:
1) sand mixture should be dried;
2) lumps should be crushed;
3) granules should be sieved;
4) all particles removed;
5) metal granules removed.

6.27. Establish correspondence:

A	A sand casting mold mixture with more collapsibility
B	A sand casting mixture with more strength

1	has less strength.
2	has less collapsibility.

1) A – 1;   3) B – 1;
2) A – 2;   4) B – 2.

6.28. If the sand is being reused from a previous sand casting manufacturing process, metal granules removed may be used:

1) electrostatic field;
2) gravitational field;
3) magnetic field;
4) centrifugal drums;
5) vibrating drums.

6.29. In industrial practice, all sand and constituents screened are used:

1) shakers;
2) gravitational slopes;
3) rotary screens;
4) vibrating screens;
5) electromagnetic sieves.

6.30. To mix the sand uniformly in industrial practice used:

1) intermittent rotary mixers;
2) continuous screw-mixers;
3) vertical centrifugal drums;
4) vibrating drums;
5) mulling machines.

6.31. A green sand mold is a mixture of:

1) sand;
2) clay;
3) plaster;
4) plasticizer;
5) water.

6.32. The term green refers to the fact that during the pouring of the casting the mold will contain:

1) binder;

2) adsorbents;
3) moisture;
4) composite material;
5) a special green additive.

6.33. Which properties of green sand molds have advantages?
1) good collapsibility and permeability;
2) better casting properties;
3) good reusability;
4) high impact strength;
5) low cost.

6.34. Which properties of green sand molds have advantages?
1) a sand casting mold mixture with more collapsibility has a greater ability to curdle;
2) the molding the sand cannot collapse adequately for the casting's shrinkage;
3) moisture in the sand can cause defects in some castings, dependent upon the type of metal used in the sand casting;
4) moisture in sand can cause defects geometry of the part to be cast;
5) large grain size of the sand mixture reduces the strength of the mold strength.

6.35. Dry sand molds are baked in an oven, (at 300F – 650F for 8–48 hours), prior to the sand casting operation, in order to:
1) dry the mold;
2) heat the mold to the temperature of the molten metal;
3) increase the refractory strength;
4) use heat treatment of structural elements of the mold;
5) strengthen the mold, and hardens its internal surfaces.

6.36. Dry sand molds are manufactured using binders rather:
1) than plaster;
2) than clay;
3) than organic resins;
4) than inorganic bonding agents;
5) than special synthetic binding agents.

6.37. Which properties of dry sand molds have advantages?
1) better conformity of the shape and mutual placement of the casting surfaces;

2) better dimensional accuracy of sand cast part than green sand molds;
3) better crystalline structure of the casting metal;
4) better surface finish of sand cast part than green sand molds;
5) shorter time of pouring the molten metal into the mold.

6.38. Which properties of dry sand molds have disadvantages?
1) more expensive manufacturing process than green sand production;
2) manufacturing production rate of castings is reduced due to drying time;
3) distortion of the mold is greater (during mold manufacture);
4) the metal casting is more susceptible to hot tearing because of the lower collapsibility of the mold;
5) unsufficient surface quality dry sand casting;
6) dry sand casting is generally limited to the manufacture of medium and large castings.

6.39. When sand casting a part by the skin-dried mold process a mold is employed with:
1) fine-grained sand;
2) dry sand mixture;
3) green sand;
4) naturally bonded sand;
5) synthetic sand.

6.40. What are the features of the process of casting into skin-dried molds?
1) low cost of the process;
2) the cast part dimensional and surface finish advantages of dry sand molds are partially achieved;
3) distortion of the mold is greater (during mold manufacture);
4) no large oven is needed;
5) special bonding materials must be added to the sand mixture to strengthen the mold cavity surface.

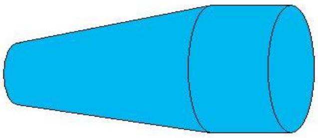
6.41. What is the advantage of cold setting processes of mold?
1) rapid hardening of the form;
2) uniform crystallization of the casting;
3) casting binders mixed with the sand, bond chemically at room temperature;
4) improved structure of the surface layer of the casting;

5) manufacturing production rate of castings is reduced due to drying time.

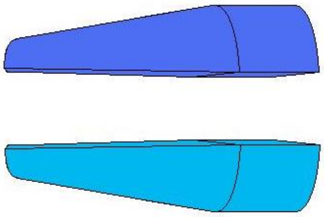
6.42. The setup of a sand mold in manufacturing involves:
1) using a pattern to create an impression of the part to be sand cast within the mold;
2) removal of the pattern;
3) placement of sprue channels;
4) placement of cores, (if needed);
5) creation of a system of ventilation holes;
6) creation of a gating system within the mold.

6.43. Solid pattern is:
1) a sample of the part on which the casting is made;
2) a pattern that takes into account the shrinkage of the casting during the casting process;
3) a pattern that takes into account the allowance for machining the casting;
4) a one-piece pattern representing the geometry of the casting;
5) a one-piece pattern representing the geometry of the main cavity of the mold.

6.44. What is shown in the figure?
1) the core;
2) the solid pattern;
3) the split pattern;
4) the ingate;
5) the down sprue.



6.45. The figure demonstrates:
1) two cores;
2) the solid pattern;
3) the split pattern;
4) two solid patterns;
5) the match plate pattern.



6.46. What are the features of setting up a sand mold when casting using a solid pattern?
1) solid pattern is an easy pattern to manufacture;
2) solid pattern has greater strength;

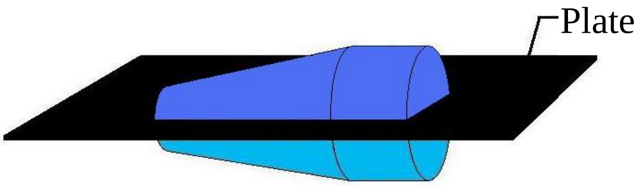
3) determining the parting line between cope and drag is more difficult for the foundry worker;
4) solid pattern reduces the time of filling the mold;
5) solid pattern accelerates the hardening of the mold.

6.47. A two-piece pattern representing the casting, divided at the parting line, similar to the split pattern is:

1) the match plate pattern;
2) the solid pattern;
3) the split pattern;
4) the forming pattern;
5) the cope and drag pattern.

6.48. What is shown in the figure?

1) two cores;
2) the solid pattern;
3) the split pattern;
4) the ingate;
5) the match plate pattern.

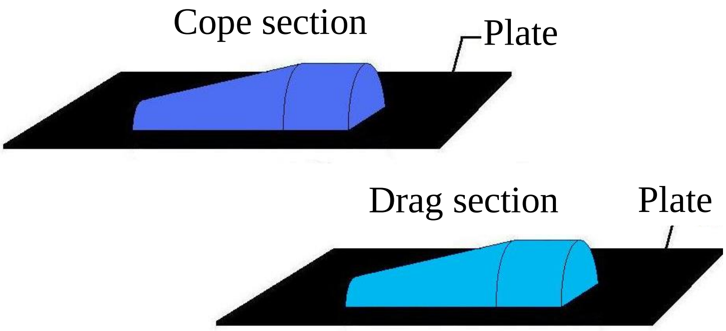


6.49. Enables the cope section of the mold, and the drag section of the mold to be created separately and later assembled before the pouring of the sand casting gives:

1) the match plate pattern;
2) the cope and drag pattern;
3) the split pattern;
4) the solid pattern;
5) the parting line.

6.50. The figure demonstrates:

1) the match plate pattern;
2) the cope and drag pattern;
3) the split pattern;
4) the solid pattern;
5) the parting line.



6.51. The internal geometry of the casting is forming:

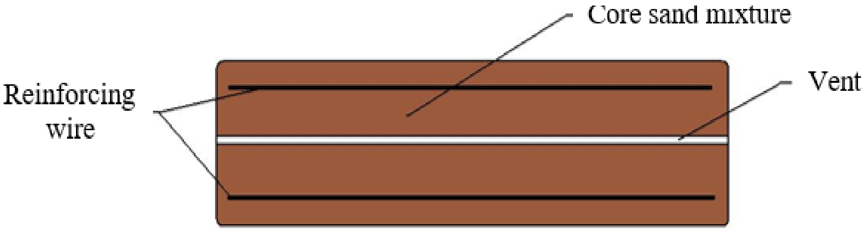
1) the top risers;
2) the cores;

3) the sprue;
4) the ingates;
5) the pattern.

6.52. Cores must:
1) be strong;
2) have elasticity;
3) be permeable;
4) be heat resistant;
5) have sufficient collapsibility.

6.53. The core may be manufactured with vents to:
1) weight loss;
2) additional pouring of molten metal into the mold;
3) improvement of thermal conductivity;
4) facilitate the removal of gases;
5) more accurate installation in the main cavity of the mold.

6.54. What is shown in the figure?
1) the core;
2) the riser;
3) the sprue;
4) the ingate;
5) the pattern.



6.55. The sand casting operation involves:
1) creation of mold and pattern;
2) heating the mold;
3) pouring the molten metal into the sand mold;
4) solidification of the casting within the mold;
5) heat-resistant metallographic analysis of casting inside the mold;
6) removal of the casting.

6.56. Specific interest in sand casting would be:
1) the effect and dissipation of heat through the particular sand mold mixture during the casting's solidification;
2) the effect of the flow of liquid metal on the integrity of the mold (mold sand mixture properties and binder issues);
3) the velocity of filling the main mold cavity with liquid metal;
4) accuracy of the shape and dimensions of the casting after

solidification in the mold;
5) the escape of gases through the mixture.

6.57. Sand usually has the ability:
1) mix well with various components;
2) sintered under the influence of high temperatures;
3) withstand extremely high-temperature levels;
4) allows the escape of gases quite well;
5) to compact and match the shape of the main cavity.

6.58. After the sand casting is removed from the sand mold, then:
1) it is slowly cooled in the air;
2) it is shaken out, all the sand is otherwise removed from the casting;
3) the geometric parameters of the casting are controlled;
4) the quality and the hardness of the casting surface are checked;
5) the gating system is cut off the part.

6.59. After removing the part from the sand mold then undergo further manufacturing processes such as:
1) heat treatment;
2) thermomechanical treatment;
3) machining, and/or metal forming;
4) metallographic analysis of the metal structure of the casting;
5) control of the shape, size and surface roughness of the casting**.**

6.60. Plaster mold casting is:
1) the preparatory process of preparing a sand-plaster mixture of molds for metal casting;
2) the final stage of preparing a plaster mold for metal casting;
3) production process of casting parts from the plaster;
4) a manufacturing process having a similar technique to sand casting;
5) technological process of shaping the high-precision castings.

6.61. What type of material is used to form the mold for the casting?
1) tropical plaster;
2) plaster of Paris;
3) white clay;
4) crushed chalk;
5) sand-gypsum molding mixture.

6.62. In the step of the manufacture of a plaster casting mold, the plaster of

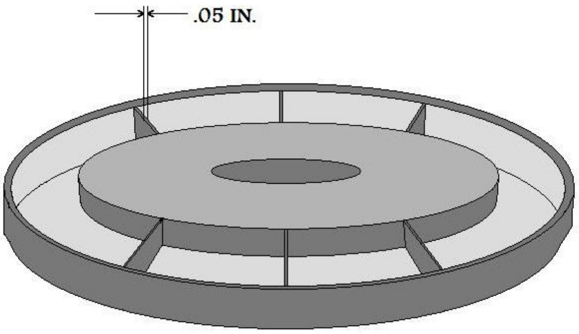
Paris and water are then mixed with various additives such as:
1) talc;
2) limestone;
3) silica flour;
4) organic glass;
5) silicon powder.

6.63. In the manufacturing of a plaster casting mold, the additives serve to:
1) control the porosity of the mixture;
2) control the setting time of the plaster;
3) increase the plasticity of the mixture;
4) improve the strength of the mixture;
5) increasing the operational resource of the plaster casting mold.

6.64. The pattern used for the plaster casting mold should be made from:
1) plastic;
2) ceramics;
3) wood;
4) metal;
5) plaster.

6.65. After striping the pattern, the mold must be baked for several hours:
1) to remove air;
2) to remove the moisture;
3) to heat the mold before pouring the molten metal;
4) to carry out heat treatment;
5) to become hard enough.

6.66. In what molds is the casting of high detail and cross-section depicted in the figure cast?
1) the sand casting mold;
2) the green sand mold;
3) the ceramic casting mold;
4) the plaster casting mold.



6.67. When baking the plaster casting mold just the right amount of water should be left in the mold material because:
1) too much moisture in the mold can cause metal casting defects;
2) too much moisture in the mold can cause defects the plaster casting

mold to bake;
3) if the mold is too dehydrated, it will lose adequate strength;
4) if the mold is too dehydrated, it will lose its fluidity;
5) if the mold is too dehydrated, it will lose its plasticity.

6.68. The fluid plaster slurry flows readily over the pattern, making an impression of:
1) high concentration;
2) great detail;
3) quick mold filling;
4) surface finish;
5) accurate dimensions and surface shape.

6.69. Due to the low thermal conductivity of the plaster mold material, the casting will solidify slowly:
1) creating a more uniform grain structure;
2) creating a fine-grain structure;
3) creating a large-grained grain structure;
4) reducing the shrinkage of the casting;
5) reducing internal stresses in the casting during hardening;
6) mitigating casting warping.

6.70. The qualities of the plaster mold enable the process to manufacture parts with:
1) high surface hardness;
2) excellent surface finish;
3) thin sections;
4) large dimensions and weight;
5) high geometric accuracy.

6.71. Plaster casting mold used in industry to manufacture castings made from based alloys, such as:
1) aluminum;
2) magnesium;
3) potassium;
4) zinc;
5) copper;
6) tin.

6.72. What are the disadvantages of plaster mold casting?

1) the cost of making a plaster mold is quite high;
2) the ephemerality of the plaster mold due to the low strength of the mixture;
3) manufacturing production rates are relatively slow, due to the long preparation time of the mold;
4) the plaster mold is not permeable, which severely limits the escape of gases from the casting;
5) the plaster mold is fragile, which significantly reduces shock loads.

6.73. What methods are used in order to overcome the problem of the lack of permeability of the plaster mold?
1) metal casting can be poured in an overheated state;
2 metal casting can be poured into a preheated mold;
3) metal casting can be poured into a mold with pre-made ventilation channels;
4) the metal casting may be poured in a vacuum;
5) pressure may be used to evacuate the mold cavity before pouring.

6.74. A special technique called the Antioch process may be used for:
1) ensuring the permeability of the plaster mold for metal casting;
2) achieving the required strength of the plaster mold for metal casting;
3) improvement of the setting of the mixture of the plaster;
4) prevention of defects of the gypsum mold during sintering;
5) increasing the durability of the gypsum mold.

6.75. What is the composition of the formation mixture in the Antioch process?
1) 75% of ordinary plaster;
2) 50% plaster of Paris;
3) 50% sand;
4) 25% green sand;
5) water.

6.76. To create the mold for the metal casting, ceramic casting uses:
1) earthenware ceramics for a mold material;
2) glass ceramics for a mold material;
3) refractory ceramics for a mold material;
4) silicon carbide for a mold material;
5) stoneware ceramics for a mold material.

6.77. What components are create a ceramic slurry?

1) grain zircon ($ZrSiO_4$);
2) bonding agents;
3) fused silica;
4) aluminum oxide;
5) magnesium oxide;
6) water.

6.78. The firing in ceramic mold casting will burn off any unwanted material and make the mold:

1) solid and porous;
2) plastic and flexible;
3) hardened and rigid;
4) continuous and smooth.

6.79. A network of microscopic cracks in the mold material gives the ceramic mold:

1) collapsibility;
2) good permeability;
3) excellent plasticity;
4) good strength;
5) excellent durability.

6.80. In ceramic mold casting, like in other expendable mold processes, the ceramic mold:

1) is cracked in the removal of the metal casting;
2) is crumbled in the removal of the metal casting;
3) is destroyed in the removal of the metal casting;
4) is stretched in the removal of the metal casting.

6.81. What stage is not included in the ceramic mold casting process?

1) refractory;
2) pattern-making;
3) ejection;
4) stripping.

6.82. What does the refractory stage in the ceramic mold casting process include?

1) a small percentage of gelling agent is added to the binder and mixed with the refractory powder to produce a creamy slurry;

2) composing of specially blended groups of refractory powders;
3) the liquid medium is visually based on ethyl silicate and is specially produced to proprietary formulations;
4) the slurry is poured over a pattern, made of metal, plaster or plastic.

6.83. What does the mixing stage in the ceramic mold casting process include?

1) the slurry is poured over a pattern, made of metal, plaster, plastic, etc;
2) is composed of a variety of specially blended groups of refractory powders;
3) the liquid medium is visually based on ethyl silicate and is specially produced for proprietary formulations;
4) a small percentage of gelling agent is added to the binder and mixed with the refractory powder to produce a creamy slurry;
5) the mold, immune to thermal shock, is placed in a high-temperature oven until all vestiges of moisture are driven off.

6.84. What does the pattern-making stage in the ceramic mold casting process include?

1) is composed of a variety of specially blended groups of refractory powders;
2) the slurry is poured over a pattern, made of metal, plaster, plastic, etc;
3) a small percentage of gelling agent is added to the binder and mixed with the refractory powder to produce a creamy slurry;
4) the liquid medium is visually based on ethyl silicate and is specially produced for proprietary formulations.

6.85. What does the stripping stage in the ceramic mold casting process include?

1) the gelled refractory mass is stripped from the pattern by hand or by a mechanical stripping mechanism;
2) the mold is ignited, it burns until all volatiles are consumed and it sets up the microcrazed structure;
3) core and drag mold pieces are assembled along with any necessary cores, and poured;
4) the mold, immune to thermal shock, is placed in a high-temperature oven until all vestiges of moisture are driven off.

6.86. What does the burn-off stage in the ceramic mold casting process include?

1) core and drag mold pieces are assembled along with any necessary cores, and poured;
2) the mold, immune to thermal shock, is placed in a high temperature oven until all vestiges of moisture are driven off;
3) the gelled refractory mass is stripped from the pattern by hand or by a mechanical stripping mechanism;
4) the mold is ignited, it burns until all volatiles are consumed and it sets up the microcrazed structure.

6.87. What does the baking stage in the ceramic mold casting process include?

1) the mold, immune to thermal shock, is placed in a high-temperature oven until all vestiges of moisture are driven off;
2) core and drag mold pieces are assembled along with any necessary cores, and poured;
3) the mold is ignited, it burns until all volatiles are consumed and it sets up the microcrazed structure;
4) the gelled refractory mass is stripped from the pattern by hand or by a mechanical stripping mechanism.

6.88. What does the casting stage in the ceramic mold casting process include?

1) the gelled refractory mass is stripped from the pattern by hand or by a mechanical stripping mechanism;
2) the mold, immune to thermal shock, is placed in a high-temperature oven until all vestiges of moisture are driven off;
3) core and drag mold pieces are assembled along with any necessary cores, and poured;
4) the mold is ignited, it burns until all volatiles are consumed and it sets up the microcrazed structure.

6.89. Manufacturing by ceramic mold casting can produce parts with:

1) thin sections;
2) intricate shapes;
3) excellent surface finish;
4) high dimensional accuracy;
5) large dimensional tolerances.

6.90. Due to this heat tolerance, the ceramic casting process can be used to manufacture:

1) high melting point metal casting materials;
2) nonferrous casting materials;
3) ferrous casting materials;
4) casting materials, which include brass and tin alloys;
5) corrosion-resistant alloys.

6.91. What are the advantages of ceramic mold casting?

1) excellent surface finish;
2) it is a very expensive process;
3) close dimensional tolerances;
4) creating castings with fine detail;
5) creating castings of very smooth surfaces.

6.92. What are the disadvantages of ceramic mold casting?

1) thin cross-sections;
2) it is a very expensive process;
3) close dimensional tolerances;
4) it is only cost-effective for small to medium-sized production runs;
5) only ferrous and high-temperature non-ferrous are most commonly cast with these processes.

6.93. Shell mold casting or shell molding is a metal casting process in the manufacturing industry in which:

1) the mold is a thick hardened shell of sand and resin binder, backed up by some other material;
2) the molten metal is poured into the mold cavity under pressure in order to eliminate bubbles and air pockets;
3) the mold is a thin hardened shell of sand and a thermosetting resin binder, backed up by some other material;
4) the molten metal is poured into the mold cavity inside a vacuum chamber in order to eliminate bubbles and air pockets.

6.94. What are the benefits of shell casting as compared to sand casting?

1) lower labor requirements;
2) creating castings of very smooth surfaces;
3) higher productivity rate;
4) it is only cost-effective for small to medium-sized production runs;
5) better dimensional accuracy.

6.95. In shell casting the molten metal is poured into:
1) a permanent mold;
2) an expendable mold;
3) vacuum mold;
4) non-expendable mold;
5) ceramic shell mold.

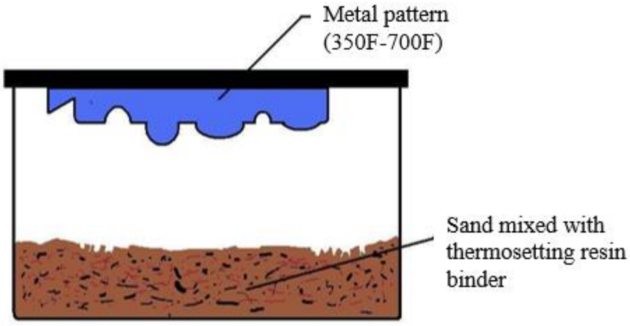
6.96. Shell casting is used for:
1) small to medium parts that require high precision;
2) medium to small parts that require high precision and thin wall thickness of the parts;
3) small to medium parts that require low precision;
4) medium to small parts that require high rough casting dimensional accuracy.

6.97. In shell mold casting, the mold is a thin-walled shell created by applying:
1) a sand-resin mixture inside a pattern;
2) a clay-resin mixture around a pattern;
3) a sand-resin mixture around a pattern;
4) a plaster-resin mixture inside a pattern;

6.98. A reusable pattern in shell mold casting allows for:
1) higher production rates;
2) enable complex geometries to be cast;
3) thin cross-sections to be cast;
4) enable thin walls to be cast;
5) able high rough casting dimensional accuracy is obtained.

6.99. Shell mold casting requires the use of:
1) sand-resin mixture;
2) metal pattern and oven;
3) core box and molten metal;
4) dump box and molten metal.

6.100. The figure demonstrates:
1) creation of the pattern;
2) pouring the molten metal;
3) creation of the shell mold;
4) assembly mold;
5) the completed shell mold.



6.101. What does the pattern creation stage in the shell mold casting process include?

1) the molten metal is poured from a ladle into the gating system and fills the mold cavity;
2) after the molten metal has cooled, the mold can be broken and the casting removed;
3) the molten metal is allowed to cool and solidify into the shape of the final casting;
4) a two-piece metal pattern is created in the shape of the desired part, typically from iron or steel;
5) each pattern half is heated and coated with a lubricant and then they are clamped to a dump box with a mixture of sand and a resin binder.

6.102. What does the mold creation stage in the shell mold casting process include?

1) each pattern half is heated and coated with a lubricant and then they are clamped to a dump box with a mixture of sand and a resin binder;
2) the molten metal is poured from a ladle into the gating system and fills the mold cavity;
3) the molten metal is allowed to cool and solidify into the shape of the final casting;
4) a two-piece metal pattern is created in the shape of the desired part, typically from iron or steel;
5) after the molten metal has cooled, the mold can be broken and the casting removed.

6.103. What does the mold assembly stage in the shell mold casting process include?

1) after the molten metal has cooled, the mold can be broken and the casting removed;
2) the molten metal is poured from a ladle into the gating system and fills the mold cavity;
3) the two shell halves are joined together and securely clamped to form the complete shell mold;
4) the molten metal is allowed to cool and solidify into the shape of the final casting;
5) a two-piece metal pattern is created in the shape of the desired part, typically from iron or steel.

6.104. What does the pouring stage in the shell mold casting process include?

1) the molten metal is allowed to cool and solidify into the shape of the final casting;
2) a two-piece metal pattern is created in the shape of the desired part, typically from iron or steel;
3) the molten metal is poured from a ladle into the gating system and fills the mold cavity;
4) after the molten metal has cooled, the mold can be broken and the casting removed;
5) each pattern half is heated and coated with a lubricant and then they are clamped to a dump box with a mixture of sand and a resin binder.

6.105. What does the cooling stage in the shell mold casting process include?

1) the molten metal is poured from a ladle into the gating system and fills the mold cavity;
2) after the molten metal has cooled, the mold can be broken and the casting removed;
3) a two-piece metal pattern is created in the shape of the desired part, typically from iron or steel;
4) each pattern half is heated and coated with a lubricant and then they are clamped to a dump box with a mixture of sand and a resin binder;
5) the molten metal is allowed to cool and solidify into the shape of the final casting.

6.106. What does the mold assembly stage in the shell mold casting process include?

1) a two-piece metal pattern is created in the shape of the desired part, typically from iron or steel;
2) after the molten metal has cooled, the mold can be broken and the casting removed;
3) each pattern half is heated and coated with a lubricant and then they are clamped to a dump box with a mixture of sand and a resin binder;
4) the molten metal is poured from a ladle into the gating system and fills the mold cavity;
5) the molten metal is allowed to cool and solidify into the shape of the final casting.

6.107. What does the casting removal stage in the shell mold casting process include?

1) the mold can be broken and the casting removed;

2) a two-piece metal pattern is created in the shape of the desired part, typically from iron or steel;
3) a two-piece metal pattern is created in the shape of the desired part, typically from iron or steel;
4) the molten metal is poured from a ladle into the gating system and fills the mold cavity;
5) each pattern half is heated and coated with a lubricant and then they are clamped to a dump box with a mixture of sand and a resin binder.

6.108. The desired thickness of the shell is dependent upon:
1) the mold accuracy requirements for the particular metal casting application;
2) the mold dimensions for the specific metal casting application;
3) the strength requirements of the mold for the particular metal casting application;
4) the length of time the sand mixture is in contact with the metal casting pattern;
5) the dimensional requirements of the mold for the particular metal casting application.

6.109. The main advantage of shell molding is that:
1) a metallic pattern is used;
2) the molds are stronger;
3) thin sections can be easily obtained;
4) highly complex sections can be easily obtained;
5) no further machining is required.

6.110. What are the advantages of shell mold casting?
1) high rough casting dimensional accuracy is obtained;
2) this process needs to use metal patterns (iron patterns);
3) less manpower and molding skill requirements;
4) not suitable for small-scale production;
5) shell casting is an easily automated process.

6.111. What are the disadvantages of shell mold casting?
1) casting of thick wall thickness and complex parts;
2) more permeable process so the chances of gas defect increase;
3) this process can be performed by semi-skilled labor;
4) limitations on size and weight;
5) high rough casting dimensional accuracy is obtained.

6.112. Vacuum casting is the type of casting, where:
1) sand mold is packed around a polystyrene pattern representing the metal casting to be manufactured;
2) the molten metal is poured into the mold cavity under pressure in order to eliminate bubbles and air pockets;
3) sand mold is packed around a polystyrene pattern representing the metal casting to be manufactured;
4) the molten metal is poured into the mold cavity inside a vacuum chamber in order to eliminate bubbles and air pockets;
5) the molten metal is poured into a mold which is clamped shut until the material cools and solidifies into the desired part shape.

6.113. The vacuum evacuation of the die cavity reduces:
1) the entrapment of gases within the cavity during the injection;
2) the entrapment of air within the cavity during the metal injection;
3) the time of molten metal solidification in order to eliminate air pockets;
4) the entrapment of gases within the cavity during the metal molting;
5) the entrapment of air within the cavity during the metal molting.

6.114. What materials are used in vacuum casting?
1) various grades of steel;
2) aluminum and copper-base alloys;
3) grey and ductile iron;
4) ductile and malleable iron;
5) magnesium alloys.

6.115. Which of the following problems arises in casting that can be solved by having vacuum casting?
1) overheating;
2) interruption in progressive solidification;
3) air in the cavity;
4) difficulty in cooling casting.

6.116. Which of the following helps in reducing the oxidation of the material in vacuum casting?
1) mold thickness;
2) mold material;
3) tight tolerances;
4) mold coating.

6.117. What are the ways to minimize turbulence, oxidation and porosity in vacuum casting?

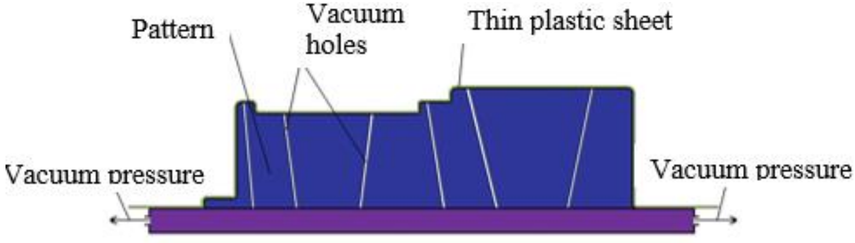
1) to use a special pattern;
2) to extract air from the mold before the metal flows in;
3) to fill quickly from the bottom of the mold;
4) to extract gases from the mold before the metal flows in;
5) to fill slowly from the bottom of the mold.

6.118. What does the special pattern in vacuum casting look like?

1) thin plastic sheet is placed over the casting pattern;
2) match-plate;
3) core with tiny holes to enable a vacuum suction;
4) drag pattern with tiny holes to enable a vacuum suction.

6.119. What is shown in the figure?

1) special flask;
2)special pattern;
3) special holes;
4) special sprue;
5) pouring cup.



6.120. What does the special flask in vacuum casting look like?

1) flask with holes to utilize vacuum pressure;
2) flask filled with sand mixture;
3) flask with a central hole to utilize gases;
4) flask placed over the casting pattern.

6.121. In vacuum mold casting manufacture there is no need for:

1) special molding binders;
2) special flask;
3) special molding sands;
4) special pattern;
5) special mold or core.

6.122. In vacuum casting the pattern is covered tightly by:

1) a thin sheet of plastic;
2) water agents;
3) a thick sheet of plastic;
4) a plastic film on the top of the pattern;
5) a thin layer of polystyrene.

6.123. What are the main advantages of vacuum casting?

1) suitable for low-volume production;
2) complex and intricate shapes can be easily manufactured with high precision;
3) welding and heat treatment of products is possible;
4) slow cycle times;
5) multiple components can be simultaneously manufactured, increasing the efficiency of production.

6.124. What are the disadvantages of vacuum casting?

1) no requirement for expensive hard tool finishing;
2) molds and tooling parts need to be regularly maintained;
3) diminishes air pockets and bubbles at early stages;
4) the mold used in the process has a short life;
5) vacuum casting is not well suited to automation.

6.125. The expanded polystyrene casting process is a process, where:

1) sand mold is packed around a polystyrene pattern representing the metal casting to be manufactured; sand mold is packed around a polystyrene pattern representing the metal casting to be manufactured;
2) a wax pattern is coated with a refractory ceramic material;
3) the molten metal is poured into a mold which is clamped shut until the material cools and solidifies into the desired part shape;
4) the molten metal is poured into the mold cavity under pressure in order to eliminate bubbles and air pockets;
5) the molten non-ferrous alloy is poured into a metal mold consisting of two or more parts which can be opened to extract the part.

6.126. What are the main stages of the expanded polystyrene casting process?

1) sand mold is packed inside a polystyrene pattern;
2) the molten metal is poured into the pattern which is vaporized from the heat of the metal;
3) the liquid metal takes the place of the vaporized polystyrene;
4) the casting solidifies in the sand mold.

6.127. Expanded polystyrene casting is suitable for use:

1) in manufacturing large one- of- a- kind castings such as dies for stamping of large automotive sections;

2) in manufacturing of heavy- sectioned castings used by machine tool builders;
3) castings with both ferrous and nonferrous metals;
4) in manufacturing large one- of- a- kind castings of large dimensions;
5) in manufacturing small castings with closed dimensions.

6.128. What are the main steps of the expanded polystyrene casting process?
1) preparation of pattern;
2) heating of pattern;
3) placing of foam pattern;
4) heating of casting material;
5) pouring the molten metal into the mold.
6) casting.

6.129. What does the pattern preparation stage in the expanded polystyrene casting process include?
1) the polystyrene foam is vaporized ahead of the advancing liquid, thus allowing the resulting mold cavity to be filled and solid;
2) pattern of polystyrene is coated with a refractory compound;
3) the molten metal is poured into the portion of the pattern that forms the pouring cup and sprue;
4) foam pattern is placed in a mold box, and sand is compacted around the pattern.

6.130. What does the foam pattern placing stage in expanded polystyrene casting process include?
1) foam pattern is placed in a mold box, and sand is compacted around the pattern;
2) pattern of polystyrene is coated with a refractory compound;
3) the polystyrene foam is vaporized ahead of the advancing liquid, thus allowing the resulting mold cavity to be filled and solid;
4) the molten metal is poured into the portion of the pattern that forms the pouring cup and sprue.

6.131. What does the pouring stage in expanded polystyrene casting process include?
1) the polystyrene foam is vaporized ahead of the advancing liquid, thus allowing the resulting mold cavity to be filled and solid;
2) foam pattern is placed in a mold box, and sand is compacted around the pattern;

3) the molten metal is poured into the portion of the pattern that forms the pouring cup and sprue;
4) pattern of polystyrene is coated with a refractory compound.

6.132. What does the casting stage in expanded polystyrene casting process include?
1) the polystyrene foam is vaporized ahead of the advancing liquid, thus allowing the resulting mold cavity to be filled and solid;
2) pattern of polystyrene is coated with a refractory compound;
3) the molten metal is poured into the portion of the pattern that forms the pouring cup and sprue;
4) foam pattern is placed in a mold box, and sand is compacted around the pattern.

6.133. The foam pattern in expanded polystyrene casting includes:
1) sprue;
2) pouring cup;
3) internal risers;
4) gating system;
5) internal cores.

6.134. What are the features of the expanded polystyrene casting process?
1) for large production runs, a pattern may be cut from smaller sections of polystyrene material and assembled;
2) for large industrial manufacturing processes, the pattern will be molded;
3) a die, made from aluminum cast iron, is used for this process;
4) for small production runs, a pattern may be cut from larger sections of polystyrene material and assembled;
5) polystyrene beads are placed in the die and heated, they expand from the heat and the foam material takes the shape of the die.

6.135. In the manufacturing industry, patterns for expanded polystyrene metal casting will always include:
1) the full gating system;
2) step of placing and securing a core in the mold cavity before the pouring of the metal casting;
3) the full set of cores;
4) step of removal of the pattern;
5) the full set of risers.

6.136. Due to the extra energy required to vaporize the polystyrene, there will be:

1) a small thermal gradient is present at the metal-pattern interface as the casting is being poured;
2) a large temperature rate is present at the metal-pattern interface as the casting is being poured;
3) a large thermal gradient is present at the metal-pattern interface as the casting is being poured;
4) a small velocity rate is present at the metal-pattern interface as the casting is being poured.

6.137. Expanded polystyrene metal casting process:

1) not limited by alloy materials;
2) can improve the utilization rate of metal materials;
3) can produce very complex metal casting geometry;
4) certain unmachinable parts can be cast into preplanned shapes.

6.138. The efficiency of the expanded polystyrene casting process depends largely on:

1) casting dimensions and tolerances;
2) industrial runs;
3) complexity of castings;
4) cost of casting materials;
5) cost of producing the foam polystyrene patterns.

6.139. For production the foam polystyrene patterns are used:

1) compute simulation for polystyrene casting processes;
2) automated manufacturing systems;
3) compute design for polystyrene patterns;
4) integrated manufacturing systems.

6.140. What are the main advantages of expanded polystyrene casting?

1) very complex metal casting geometry can be produced;
2) simplifies and speeds mold-making, because two mold halves are not required as in a conventional green-sand mold;
3) pattern coating process is time- consuming, and pattern handling requires great care;
4) the parts (cope and drag with proper parting line, cores, gating and riser system) are built into the pattern itself;
5) a new pattern is needed for every casting.

6.141. What are the main disadvantages of expanded polystyrene casting?

1) economic justification of the process is highly dependent on the cost of producing patterns;
2) the parts (cope and drag with proper parting line, cores, gating and riser system) are built into the pattern itself;
3) a new pattern is needed for every casting;
4) very small metal casting can be produced using this process;
5) pattern coating process is time- consuming, and pattern handling requires great care.

6.142. Investment casting is a manufacturing process in which:

1) a wax pattern is coated with a refractory ceramic material;
2) the molten metal is poured into the mold cavity under pressure in order to eliminate bubbles and air pockets;
3) the molten non-ferrous alloy is poured into a metal mold consisting of two or more parts which can be opened to extract the part;
4) the molten metal is poured into a mold which is clamped shut until the material cools and solidifies into the desired part shape;
5) the molten metal is not allowed to completely solidify in the mold.

6.143. What is a typical scheme of investment casting?

1) the mold is made of fusible material;
2) the mold is covered with several layers of refractory material on the surface of the mold to make the shell;
3) the mold is melted and discharged from the shell;
4) the molten metal is poured after high-temperature roasting;
5) the mold is obtained without a parting surface, which can be filled with sand.

6.144. Investment casting is called «lost wax casting» because:

1) the mold sample is covered by wax material;
2) the pattern is widely used wax material to manufacture;
3) the pattern and core are covered by wax material;
4) the mold sample is a widely used wax material to manufacture.

6.145. The investment casting process initiates with:

1) the production of wax replicas of the required shape of casting;
2) choosing the injecting materials, such as wax or polystyrene;
3) one pattern is made and attached to a wax sprue centrally;
4) the production of wax patterns of the required shape of casting;

5) the assembly of a large number of patterns is made and attached to a wax sprue centrally.

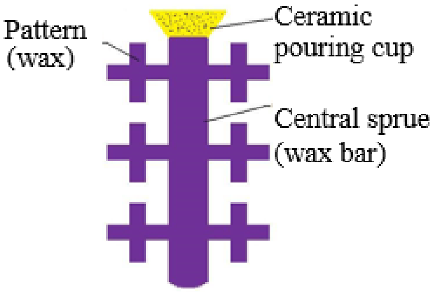
6.146. What dies are used to prepare the pattern?

1) ceramic dies;
2) aluminum dies,
3) metallic dies;
4) polystyrene dies.

6.147. The types of alloys that can be produced by investment casting include:

1) carbon steel and alloy steel;
2) heat-resistant alloys, titanium alloys and precision alloys;
3) stainless steel and ductile iron;
4) permanent magnet alloys, aluminum alloys and copper alloys;
5) magnesium alloys.

6.148. What is shown in the figure?



1) wax pattern tree for investment casting;
2) refractory coating;
3) heat-disposable wax;
4) mold for investment casting;
5) wax sprue.

6.149. What does the preparing pattern stage include in investment casting?

1) investing the pattern assembly with a refractory slurry which builds the shell;
2) preparing the heat-disposable wax, plastic or polystyrene patterns in a die;
3) assembly of the heat-disposable wax and polystyrene patterns in a die;
4) assembly of the prepared patterns onto a gating system.

6.150. What does the assembly stage include in investment casting?

1) preparing the heat-disposable wax, plastic or polystyrene patterns in a die;
2) investing the pattern assembly with a refractory slurry which builds the shell;
3) assembly of the heat-disposable wax, plastic or polystyrene patterns in a die;

4) assembly of the prepared patterns into a gating system;
5) the metal in the molten state is poured into the formed mold.

6.151. What does the covering pattern stage include in investment casting?
1) investing the pattern assembly with a refractory slurry which builds the shell;
2) cutting off the pouring basin and gates followed by finishing operations to get the desired dimensional tolerances;
3) the metal in the molten state is poured into the formed mold;
4) preparing the heat-disposable wax, plastic or polystyrene patterns in a die;
5) the pouring basin and gates followed by finishing operations to get the desired dimensional tolerances.

6.152. What does the melting stage include in investment casting?
1) cutting off the pouring basin and gates followed by finishing operations to get the desired dimensional tolerances;
2) assembly of the prepared patterns into a gating system;
3) melting the pattern assembly (burning out the wax) by firing, for removing the traces of the pattern material;
4) the pouring basin and gates followed by finishing operations to get the desired dimensional tolerances;
5) assembly the heat-disposable wax, plastic or polystyrene patterns in a die.

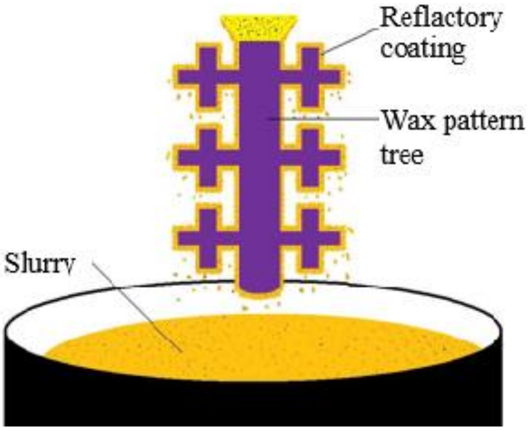
6.153. What does the pouring stage include in investment casting?
1) cutting off the pouring basin and gates followed by finishing operations to get the desired dimensional tolerances;
2) the pouring basin and gates followed by finishing operations to get the desired dimensional tolerances;
3) the metal in the molten state is poured into the formed mold;
4) once the metal is poured, the shell is removed (knocked out).
5) assembly of the prepared patterns into a gating system.

6.154. What does the solidification stage include in investment casting?
1) assembly of the heat-disposable wax, plastic or polystyrene patterns in a die;
2) melting the pattern assembly (burning out the wax) by firing, for removing the traces of the pattern material;

3) cutting off the pouring basin and gates followed by finishing operations to get the desired dimensional tolerances;
4) assembly of the prepared patterns into a gating system;
5) solidification, once the metal solidifies, the shell is removed (knocked out).

6.155. What does the fettling stage include in investment casting?
1) assembly of the heat-disposable wax, plastic or polystyrene patterns in a die;
2) cutting off the pouring basin and gates followed by finishing operations to get the desired dimensional tolerances;
3) melting the pattern assembly (burning out the wax) by firing, for removing the traces of the pattern material;
4) solidification, once the metal solidifies, the shell is removed (knocked out);
5) assembly of the prepared patterns into a gating system.

6.156. What is shown in the figure?
1) refractory slurry invested over wax pattern drying in the air;
2) wax melted out of the mold for investment casting;
3) refractory slurry invested over wax pattern;
4) solidification of an investment casting.



6.157. What materials for patterns are used in investment casting?
1) wax;
2) non-ferrous alloys;
3) plastic;
4) ceramics.
5) aluminum alloys.

6.158. What are the advantages of using wax for preparing patterns?
1) can be reused;
2) can be easily destroyed;
3) easy melting;
4) it has good elasticity;
5) it has excellent viscosity.

6.159. The mold to create wax patterns may be:

1) cast;
2) forged;
3) machined;
4) stamped.

6.160. The size of the master die in investment casting must be carefully calculated, taking into consideration:

1) strengthening of pattern;
2) shrinkage of wax;
3) shrinkage of the ceramic material invested over the wax pattern;
4) porosity of metal casting;
5) shrinkage of the metal casting.

6.161. In investment casting since the mold does not need to be opened:

1) castings of the thin walls can be manufactured;
2) several wax patterns may be combined for a single casting;
3) castings of the thick walls can be manufactured;
4) castings of very complex geometry can be manufactured;
5) very smooth surface is obtained with no parting line.

6.162. Heating of the ceramic mold to around 1000F–2000F during investment casting allows:

1) further strengthen the mold;
2) eliminate any leftover wax or contaminants;
3) drive out gases from the mold material;
4) drive out water from the mold material.

6.163. Pouring the casting while the mold is hot allows:

1) to fill detailed and thin sections;
2) to give better dimensional accuracy;
3) the liquid metal to flow easily through the mold cavity;
4) the mold and casting will shrink together as they cool.

6.164. What are the features of investment casting?

1) formation of hollow interiors in cylinders without cores;
2) parts manufactured by this process are generally small, but parts weighing up to 75 lbs have been found suitable for this technique;
3) certain unmachinable parts can be cast to a preplanned shape;

4) less material required for the gate;
5) parts of the investment process may be automated.

6.165. Investment casting is used for:
1) shapes that are made by difficulty using complex patterns in sand casting;
2) mass production;
3) shapes that are very complex and intricate and can't be cast by any other method;
4) hard-to-melt alloys such as stainless steel, thin steel, etc.;
5) many intricate forms with undercuts.

6.166. Which of the following casting methods utilizes wax pattern?
1) shell molding;
2) plaster mold casting;
3) slush casting;
4) investment casting;
5) ceramic mold casting.

6.167. What are the main advantages of investment casting?
1) higher manufacturing costs of molds;
2) low production flexibility and adaptability;
3) castings are free from usual defects;
4) require very short production cycle times versus other casting processes;
5) many intricate forms with undercuts can be cast;
6) melt casting is suitable for both high-volume production and small-volume production or even single-piece production.

6.168. What are the main disadvantages of investment casting?
1) new die requirement for the creation of wax patterns for each casting cycle;
2) limited by alloy materials;
3) the process is expensive, it may be used to replace die casting where short runs are involved;
4) investment castings require very long production cycle times versus other casting processes;
5) melt casting is suitable for both high-volume production and small-volume production or even single-piece production.

7. PERMANENT MOLD CASTING

7.1. Basic permanent mold casting

Basic permanent mold casting is a generic term used to describe all permanent mold casting processes. The main similarity of this group is the employment of a permanent mold that can be used repeatedly for multiple metal castings. The mold also called a die, is commonly made of steel or iron, but other metals or ceramics can be used.

Permanent mold casting is a metal casting process that shares similarities to both sand casting and die casting. As in sand casting, molten metal is poured into a mold which is clamped shut until the material cools and solidifies into the desired part shape. However, sand casting uses an expendable mold which is destroyed after each cycle. Permanent mold casting, like die casting, uses a metal mold (die) that is typically made from steel or cast iron and can be reused for several thousand cycles. Because the molten metal is poured into the die and not forcibly injected, permanent mold casting is often referred to as gravity die casting.

Also known simply as permanent molding, permanent mold casting is characterized by the use of a reusable or “permanent” mold. Rather than being disposed of, the molds can be reused. It’s not uncommon for manufacturing companies to reuse permanent molds hundreds of times.

Permanent mold casting is a process for producing a large number of castings using a single reusable mold. The casting process simply involves pouring molten metal into a mold where it cools and solidifies. The mold is then opened, the casting removed, and the mold is reused. The mold is made from a high-temperature metallic material, such as cast iron or hot work die steel, which can withstand the repeated heating and cooling involved with large-volume production.

Permanent mold casting produces metal with better dimensional tolerance, superior surface finish, and higher and more uniform mechanical properties when compared with metal solidified using sand casting , which is another popular casting process. Permanent mold castings have relatively high strength, toughness and ductility owing to the mold walls rapidly removing heat from the liquid metal. This generates a fast solidification rate which produces a fine-grain structure in the cast metal.

Permanent mold casting is typically used for the high-volume production of small, simple metal parts with uniform wall thickness. Non-ferrous metals are typically used in this process, such as aluminum alloys, magnesium alloys, and copper alloys. However, irons and steels can also be cast using graphite molds. In order to make the mold last, permanent molds are often made of sturdy metals like copper and steel alloy.

Common permanent mold parts include gears and gear housings, pipe fittings, cylinder blocks, cylinder heads, pistons, connecting rods, parts for aircraft and rockets, gear blanks and other automotive and aircraft components such as pistons, impellers, and wheels.

The process.

The permanent mold casting process consists of the following steps:

1. Mold preparation. First, the mold is pre-heated to around 300–500°F (150–260°C) to allow better metal flow and reduce defects. This pre-heating allows for a better metal flow. While also reducing defects caused during the casting process.Then, a ceramic coating is applied to the mold cavity surfaces to facilitate part removal and increase the mold lifetime.

2. Mold assembly. After the mold has been pre-heated, a ceramic coating s applied to the mold cavities. The coating allows for easier part removal and prolongs the mold’s lifecycle. The mold consists of at least two parts – the two mold halves and any cores used to form complex features. Such cores are typically made from iron or steel, but expendable sand cores are sometimes used. In this step, the cores are inserted and the mold halves are clamped together.

3. Pouring. The molten metal is poured at a slow rate from a ladle into the mold through a sprue at the top of the mold. The metal flows through a runner system and enters the mold cavity.

4. Cooling. The molten metal is allowed to cool and solidify in the mold.

5. Mold opening. After the molten metal has cooled solidified, the two mold halves are opened and the casting is removed.

6. Trimming. During cooling, the metal in the runner system and sprue solidify attached to the casting. This excess material is now cut away.

Using these basic steps, other variations on permanent mold casting have been developed to accommodate specific applications. Examples of these variations include the following:

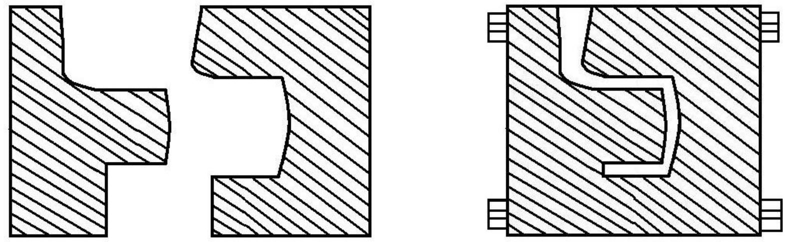
- Slush casting. As in permanent mold casting, the molten metal is poured into the mold and begins to solidify at the cavity surface. When the amount of solidified material is equal to the desired wall thickness, the remaining slush (material that has yet to completely solidify) is poured out of the mold. As a result, slush casting is used to produce hollow parts without the use of cores.

- Low pressure permanent mold casting. Instead of being poured, the molten metal is forced into the mold by low pressure air (< 1 bar). The application of pressure allows the mold to remain filled and reduces shrinkage during cooling. Also, finer details and thinner walls can be molded.
- Vacuum permanent mold casting. Similar to low pressure casting, but vacuum pressure is used to fill the mold. As a result, finer details and thin walls can be molded and the mechanical properties of the castings are improved.
- Gravity mold casting. As the name suggests, gravity mold casting uses gravity to inject the mold cavity with the raw material. The mold is first preheated to a temperature of up to 400 degrees Fahrenheit. Next, the mold cavity is treated with a non-sticking solution. The heated or molten raw material is then poured into the mold cavity, essentially using gravity to fill it.

Thus, when planning to manufacture using a permanent mold manufacturing process the first step is to create the mold. The sections of the mold are most likely machined from two separate metal blocks. These parts are manufactured precisely. They are created so that they fit together and may be opened and closed easily and accurately. The gating system as well as the part geometry is machined into the casting mold.

A significant amount of resources need to be utilized in the production of the mold, making the setup more expensive for permanent mold manufacturing runs.

However, once created, a permanent mold may be used tens of thousands of times before its mold life is up. Due to the continuous repetition of high forces and temperatures, all molds will eventually decay to the point where they can no longer effectively manufacture quality metal castings.



Two halves of a basic permanent mold (cross-sectional)

Basic permanent mold assembled (cross-sectional)

Figure 64 – Basic permanent mold

The number of castings produced by that particular mold before it had to be replaced is termed mold life. Many factors affect mold life such as the mold operating temperature, mold material and casting metal.

Before pouring the metal casting, the internal surfaces of the permanent mold are sprayed with a slurry consisting of refractory materials suspended in the liquid. This coating serves as a thermal gradient, helping to control the heat flow and acting as a lubricant for easier removal of the cast part. In addition, applying the refractory coat as a regular part of the manufacturing process will increase the mold life of the valuable mold.

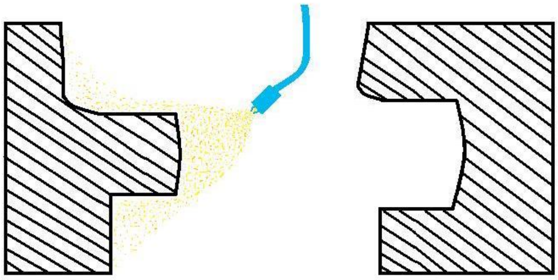


Figure 65 – Basic permanent mold being sprayed with refractory slurry prior to the casting operation

The two parts of the mold must be closed and held together with force, using some sort of mechanical means. Most likely, the mold will be heated prior to the pouring of the metal casting. A possible temperature that a permanent metal casting mold may be heated to before pouring could be around 350F (175^0 C). The heating of the mold will facilitate the smoother flow of the liquid metal through the mold's gating system and casting cavity.

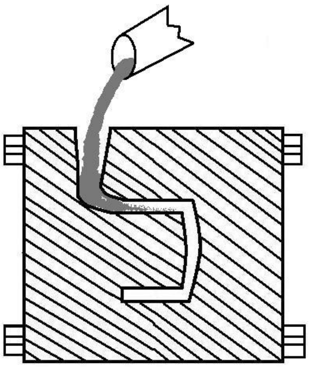


Figure 66 – Pouring of basic permanent mold (gravity-fed process)

Pouring in a heated mold will also reduce the thermal shock encountered by the mold due to the high-temperature gradient between the molten metal and the mold. This will act to increase mold life. Once securely closed and heated, the permanent mold is ready for the pouring of the cast part. After pouring, the metal casting solidifies within the mold.

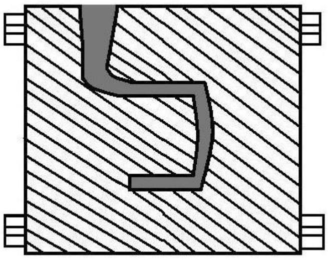


Figure 67 – Solidification of casting in basic permanent mold

In manufacturing practice, the metal cast part is usually removed before much cooling occurs, to prevent the solid metal casting from contracting too much in the mold. This is done to prevent cracking the casting since the permanent mold does not collapse. The removal of the part is accomplished by way of ejector pins built into the mold.

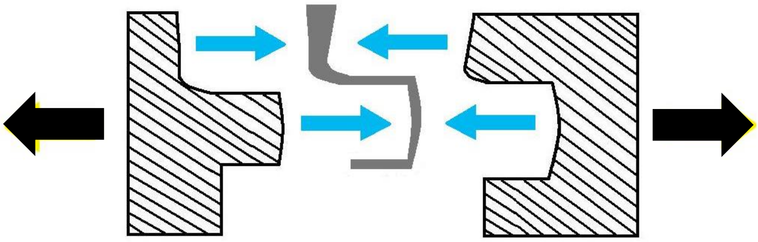


Figure 68 – Basic permanent mold is open and solidified casting is ejected

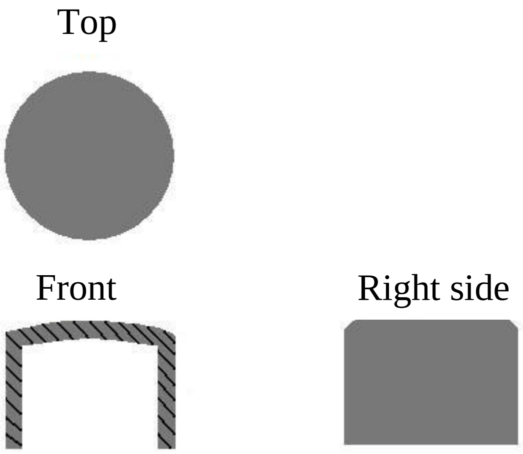


Figure 69 – Views of metal casting produced (piston)

Semi-permanent mold casting.

Semi-permanent mold is a casting process that makes aluminum alloy castings with reusable metal molds and sand cores to shape internal passage in casting. Molten aluminum alloy is poured into a metal mold consisting of two or more parts which can be opened to extract the part.

Molds are typically arranged in two halves – the sand cores being put into place before the two halves are placed together. The molten metal flows into the mold cavity and surrounds the sand core while filling the mold cavity. When the casting is removed from the mold the sand core is removed from the casting leaving an internal passage in the casting. The reusable metal molds are used time and again, but the sand cores have to be replaced each time the product is cast, hence the term semi-permanent molding.

Cores are often employed in a permanent mold metal casting process. These cores are likely made of the same material as the mold and are also permanent. The geometry of these cores has to allow for the removal of the casting or the cores need to be able to collapse by some mechanical means. Sand cores have a lot lfewer limitations and can be used in conjunction with permanent molds. Sand cores are placed within the permanent mold prior to pouring the metal casting. They can be positioned inside the mold to create hollow cavities in the casting. Solidification of the part takes place under the weight of the liquid metal riser, which is the last part of the casting to solidify, to compensate for shrinkage.

The sand cores are not permanent, like the mold and must be broken up and replaced with every casting. Sand cores, however, allow for more freedom in the manufacture of internal geometry. In the manufacturing industry using a disposable core with a permanent mold is called semi-permanent mold casting.

Semi-permanent molding affords a very high precision quality to casting at a reduced price compared to the sand casting processes.

Properties and considerations of manufacturing by basic permanent mold casting:

- Generally this manufacturing process is only suited for materials with lower melting temperatures, such as zinc, copper, magnesium and aluminum alloys.
- Cast iron parts are also manufactured by this process but the high melting temperature of cast iron is hard on the mold.

- Steels may be cast in permanent molds made of graphite or some special refractory material.
- The mold may be cooled by water or heat fins to help with the dissipation of heat during the metal casting process.
- Due to the need to open and close the mold to remove the workpiece, part geometry is limited.
- If the semi-permanent casting method is used, internal part geometry may be complex.
- Due to the nature of the mold, the metal casting will solidify rapidly. This will result in a smaller grain structure, producing a casting with superior mechanical properties.
- More uniform properties throughout the material of the cast part may also be observed with permanent mold casting.
- Closer dimensional accuracy as well as excellent surface finish of the part, is another advantage of permanent mold casting over most expendable metal casting processes.
- In industrial manufacture permanent mold casting results in a lower percentage of rejects than many expendable mold processes.
- There is a limitation on the size of cast parts manufactured by this process.
- The initial setup cost is high, making permanent mold casting unsuitable for small production runs.
- Permanent mold casting, which is an unexpendable casting process, can be highly automated. Automation increases permanent mold throughput and process control, and parts are often processed with minimum human intervention until cleaning or machining operations.
- This manufacturing process is useful in industry for high volume runs. When set up, it can be extremely economical with a high rate of production.

Design aspects of permanent mold casting:

- permanent molds are made of carbon steels, grey cast irons, graphite (for casting steels and cast irons) or bronze;
- since the metallic mold of a permanent casting expands when it is filled with molten metal and then both the casting and the mold shrink during cooling the shrinkage allowances taken in the permanent mold design are smaller than those in the sand casting;
- external cooling (by water or air) may be used for creating desired solidification direction and reducing shrinkage defects and internal stresses;

- parts of 0.4 lb (0.1 kg) to 150 lb (70 kg) may be cast;
- the section thickness of permanent mold casting may vary in the range of 0.1” – 2” (2.5–50 mm);
- the dimensional tolerances are 0.015–0.06” (0.4–1.5 mm) depending on the casting section thickness;
- allowances of 0.01–0.03” (0.25–0.75 mm) are taken for the dimensions crossing the parting line of the mold;
- the draft angle is commonly 1–3%;
- permanent cores are commonly used for permanent mold castings, however, if a casting has a cavity’s shape not allowing a withdrawal of the core it is made of chemically bonded sand or other materials used for the preparation of expendable cores, new consumable cores are added after each pour.

Table 15 – Advantages and disadvantages of permanent mold casting

Advantages	Disadvantages
1	2
This process produces a fine-grained casting with an excellent surface finish and superior mechanical properties.	Limited size range – parts which must have a high draft to remove them from the mold are not practical.
Small cored holes may be produced as compared to sand casting.	Only non-ferrous metals may be cast by this process.
Close dimensional tolerance can be obtained.	The complicated shape can not be produced.
Inserts can be readily cast in place.	Higher tooling cost.
Suitable for very high volume production of quality castings.	Low thermal resistance.
	Greater risk of shrinkage cracks.
Directional solidification for optimal distribution of microstructure and mechanical properties inside the part.	Material quality: in general, only good quality material is used for permanent mold casting due to the use of molding sand.
Produces dense, regular castings by high dimensional precision.	High productivity is not possible.
	High cost of molds.
Produce a very good surface finish of the order of 4 microns.	Only suitable for large-scale production.

Continue Table 15

1	2
Rapid production rate with low scrap loss.	The elevated cost of tooling requires a higher quantity of castings.
The process lends itself to the production of highly accurate and complex parts.	Low capital investment – an entire set-up does not need to be bought for permanent mold casting.
Increases repeatability of casting.	
It’s possible to create hollow models that would be difficult or impossible to achieve in any other casting process.	At low volume, it is difficult to overcome the high initial tooling cost and compete based on casting cost. Metal dies are more expensive than patterns for sand casting or investment casting so the process is not economical for short runs.
This process is economical for large-scale production as the labor involved in the mold preparation is reduced.	
The use of expendable cores in semi-permanent mold casting permits great design flexibility for castings.	Less competitive with sand casting when three or more sand cores are required.
	Large parts cannot be cast.
This process produces less porosity.	A method is limited to the production of the little casting of easy exterior design, while difficult castings, such as engine blocks and heads are now usual.
Lower investment is required for equipment when compared to low pressure and high pressure die casting.	
Casting has high compressive strength.	Since castings are filled with liquid metal under only the pressure of gravity, castings sections tend to be thicker in permanent mold casting than in the low pressure and high pressure die casting processes.
Reasonable piece costs resulting from the high production rates achieved with metal molds compared to sand and investment casting.	
The metal used can be easily melted later on for recycling purposes, rather than having the mold broken and the prototype wasted when it is completed with plaster.	The high cost of the reusable mold, and the casting process is usually viable only when high-volume production can offset the cost.

7.2. Vacuum permanent mold casting

Vacuum permanent mold casting is a permanent mold casting process employed in the manufacturing industry that uses the force caused by an applied vacuum pressure to draw molten metal into and through the mold's gating system and casting cavity. This process has a similar name to vacuum mold casting discussed in the expendable mold process section; however, these are two completely different manufacturing processes and should not be confused with each other.

Vacuum casting is similar to low pressure casting except that a vacuum is created within the mold cavity and the metal is pulled rather than pushed into the mold. Similar to low pressure, excellent mechanical properties and high production rates are the norm with this process due to the low mold temperature. In addition, this process achieves similar casting yield results as low pressure. However, this process is usually associated with smaller castings and requires specialized, complex mold designs to induce the vacuum properly.

In the case of vacuum and low pressure, many innovations to the processes have allowed metal casters to combine both vacuum and pressure during casting to better control mold fill. This is the key with the more advanced permanent mold casting manufacturing – controlling the flow of metal into the mold to ensure as tranquil a mold fill as possible in as short of a casting cycle as possible. The faster and less turbulent, the higher quality casting at a lower cost.

The process.

A permanent mold containing the part geometry and the gating system is created, (usually accurately machined), similar to the molds employed in the other permanent mold processes. The mold in vacuum mold casting is much like the mold in the pressure casting manufacturing process, in that the gating system is designed so that the flow of molten material starts at the bottom and flows upwards.

Figure 70 – Permanent mold for vacuum casting

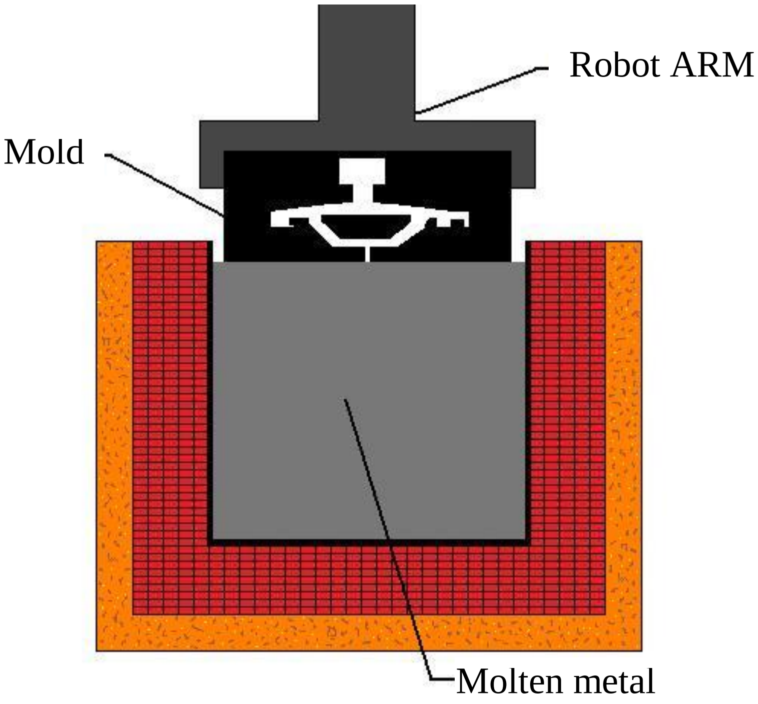


Figure 71 – The first stage of vacuum permanent mold casting

The mold is mounted on a moving head. The mold is suspended over a supply of liquid metal for casting by some mechanical device, possibly a robot ARM. The head is lowered into molten metal in an induction furnace so that the lower face of the mold is submerged.

A vacuum force is applied to the top of the mold. The reduced pressure within the mold causes the molten metal to be drawn up through the gating system and casting cavity.

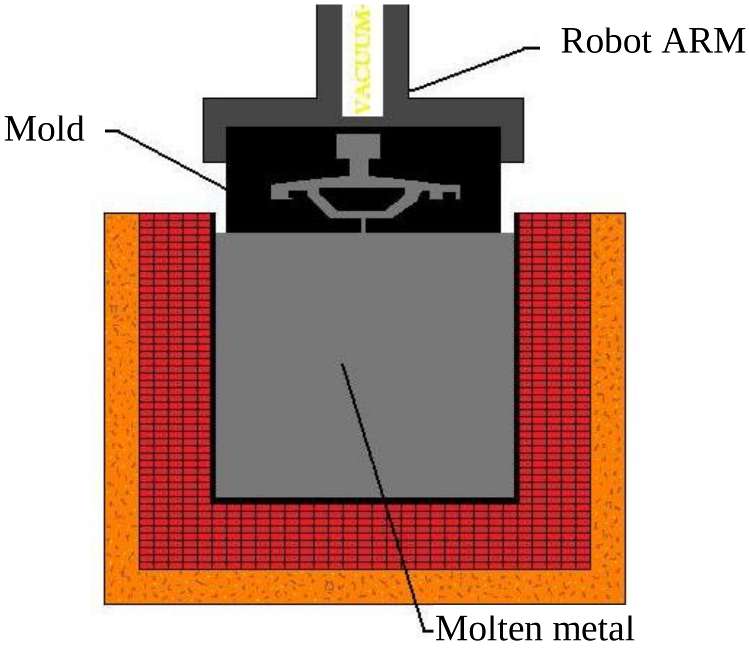


Figure 72 – The second stage of vacuum permanent mold casting

As the casting solidifies, the mold is withdrawn from its position over the molten metal and opened to release the casting.

Properties and considerations of manufacturing by vacuum permanent mold casting:

- This manufacturing process can produce metal castings with close dimensional accuracy, good surface finish, and superior mechanical properties.
- Castings with thin-walled sections may be manufactured using this technique.
- This process is very much like pressure casting in the way the mold is filled, but since vacuum force is used instead of air pressure, gas-related defects are reduced.
- Set up cost to make this manufacturing process more suitable for high-volume production, instead of small batch manufacture.

Table 16 – Advantages and disadvantages of vacuum permanent mold casting

Advantages	Disadvantages
Wide selection of alloys including heat treatable and non-heat treatable alloys.	Pressure forming is one example of a complex feature that necessitates additional tooling and is a challenge for mass manufacturing.
Better mechanical properties of castings.	
Reduced air porosity, greater strength.	The mold used in the process has a short life.
Thin wall castings can be made in large structures: designs using a minimum wall thickness well below 2 mm.	The mold utilized for the job needs to be cleaned frequently. If not, the resulting pieces will have signs of mark-offs.
The yields are high since no risers are used.	Potential hollowness issues.
Vacuum permanent mold casting is a process of higher productivity.	High mold costs. High tooling price.
This process is relatively inexpensive and can be automated.	Slow cycle time. Small tooling time.

7.3. Slush casting

Slush casting is a traditional method of the permanent mold casting process, where the molten metal is not allowed to completely solidify in the mold. When the desired thickness is obtained, the remaining molten metal is poured out. The slush casting method is an effective technique to cast hollow items like decorative pieces, components, ornaments, etc.

Slush casting is a variation of permanent mold casting that is used to produce hollow parts. In this method neither the strength of the part nor its internal geometry can be controlled accurately.

A slush casting is produced by pouring the liquid material into an open-top permanent mold, after the desired wall thickness is obtained, the mold is inverted therefore, not yet solidified molten metal is drained out. This is useful for making shell-like ornamental objects from low melting point metals such as zinc, tin or lead alloys. Low-melting point metals such as lead, zinc, and tin are used. The exterior appearance is important, but the strength and interior geometry of the casting are minor considerations.

The slush-cast alloy is a high-purity purpose-engineered product manufactured by eastern alloys. Eastern alloys is a world-class manufacturer of zinc-based alloys for the die casting, foundry and steel coating industries. This alloy was developed to provide a high-fluidity casting material capable of producing a good surface definition when cast in a metal permanent mold or rubber mold. It contains approximately 5% aluminum and 95% zinc giving it a very short freezing range and good fluidity.

The process.

Slush casting process step-by-step explained with seven casting operations:

1. Melting ingots in the furnace. Low-temperature, non-ferrous metal ingots are desirable for this casting process. Metal is heated above the melting point keeping it ready for pouring operation.
2. Inspection and pre-heating of permanent mold. Mold must be first opened and inspected for any abnormalities and defects in mold. The mold cavity is coated with die lubricant to improve the surface finish and reduces the final casting. Permanent mold is pre-heated to the desired temperature, before pouring molten metal.
3. Pouring operation. Care must be taken that molten metal is free from dross, slag and other impurities before pouring molten metal. Molten

metal is poured till the cavity is full with the help of a ladle. This casting only has one gate which is used for pouring metal in and draining metal out remaining metal. This casting process is a variation of gravity die casting when it comes to pouring the liquid metal into the mold cavity.

4. Solidification operation. After the molten metal is poured into the mold, the metal is not allowed to solidify completely in the mold. In this process, only the layer of thin thickness is allowed to solidify around the mold and the rest molten metal is drained out. Metal starts solidifying at the surface of the mold wall first and then slowly starts solidifying inwards. During the solidification molten metal gats into a slushy state. The slushy state is the state where molten metal is between a solid and a liquid state. The thickness of the casting depends on how long the metal is in contact with the mold wall. The more time metal is in contact with the wall more the thickness of casting will be.

5. Draining out excess metal. Once the desired thickness is achieved non-solidified metal is drained out. Metal that is drained out is unwanted metal which has no significant importance. This drained metal is reused making this process a very economical process.

6. Ejecting casting from mold operation. This is the final stage of slush casting where mold is opened, and hollow casting is ejected out of the permanent mold. As permanent mold is used here, the process is repeated multiple times for mass production by reusing the mold.

7. Secondary manufacturing operation. After the casting is taken out, the edges are trimmed and shaved. Other coating elements are coated to polish the surface and to avoid long-term corrosion of the casting.

Besides that, slush casting has the following characteristics, that need to be taken into account when using it:

- all permanent molding principles apply to the slush casting process;
- the casting produced is hollow and has lower weight as compared to a casting produced by sand casting;
- controlling internal geometry is difficult;
- a high-quality smooth exterior surface can be achieved;
- a mechanism to invert the hollow mold is necessary to drain excess molten out;
- strength, toughness, hardness and other mechanical properties are difficult to achieve;
- the interior of slush casting has a rough texture because with passing time, the temperature of draining metal starts dropping and the metal starts solidifying internally giving a rough texture to the casting;

– the manufacturing process is straightforward compared to the sand casting process and is very cost-effective,

– the difference between slush casting and slush molding is that slush casting is mostly associated with metal products while slush molding is associated with liquid materials such as resin, silicon, thermosetting plastic and rubber;

– the current usage of the metal slush casting process is in many industries, slush casting is widely employed and used in mechanical and electrical industries to produce hollow castings.

When producing a cast part using the slush casting method, a permanent mold is employed and set up (see basic permanent mold casting). The mold is clamped together and prepared for pouring.

Figure 73 – Mold for slush casting ready to be poured

After pouring the mold will set, as solidification begins to take place.

Figure 74 – Mold for slush casting immediately after pouring

The main principle of this casting process relies on the fact that when a metal casting hardens in a mold, it will solidify from the mold wall towards the inside of the casting. In other words a metal skin forms first, (as the external geometry of the part). This skin thickens as more of the metal casting's material converts to a solid state.

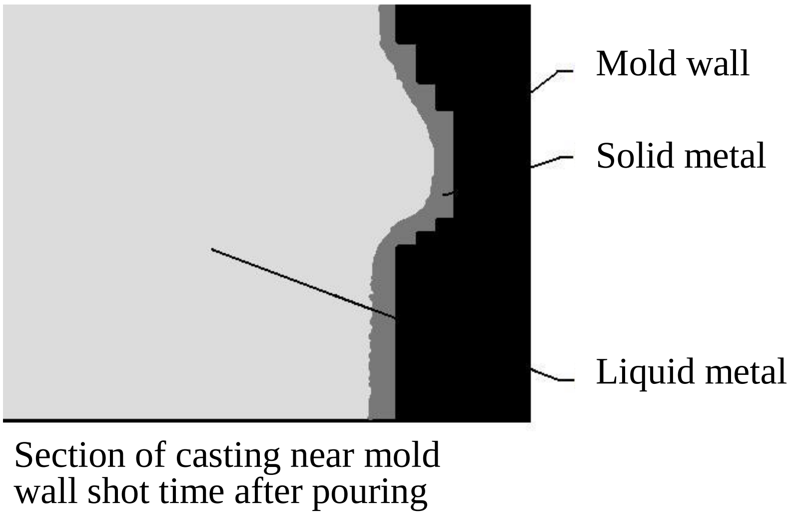


Figure 75 – Solidification can be used to start at interface between molten metal and mold surfaces

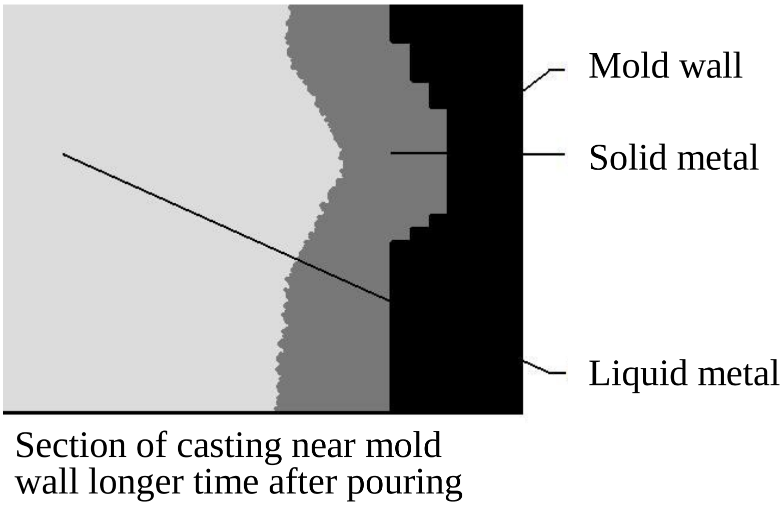


Figure 76 – Solidification process from mold-casting interface towards inner regions of the material thickness of this solid section increases with time

Figure 77 – Mold for slush casting gross sectional view of inside of casting a certain amount of time (T_1) after pouring

Figure 78 – Mold for slush casting gross sectional view of inside of casting a certain amount of time (T_2) after pouring also note ($T_2 > T_1$)

Figure 79 – Mold for slush casting gross sectional view of inside of casting a certain amount of time (T_3) after pouring also note ($T_3 > T_2$)

In slush mold casting, during the solidification of the material, when the solid-liquid boundary has reached a certain point, the mold is turned over and the remaining liquid metal from the casting is poured out.

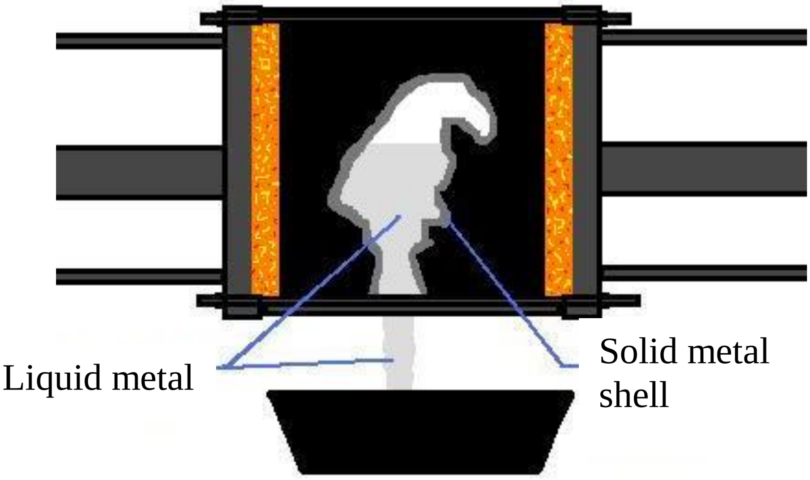


Figure 80 – The liquid metal from the interior of the casting is poured out before the entire mass of molten material can harden leaving only the solidified outer shell

This will leave only the solidified skin with the exterior geometry of the metal cast part and a hollow interior. The longer the metal casting was allowed to solidify before pouring out the excess metal, the greater the casting's wall thickness will be.

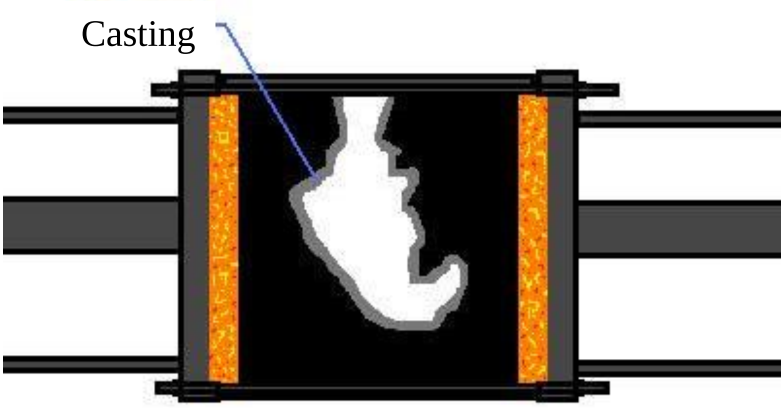


Figure 81 – Metal in solidified outer shell is all that remains in mold

The cast part is then removed from the die and allowed to cool.

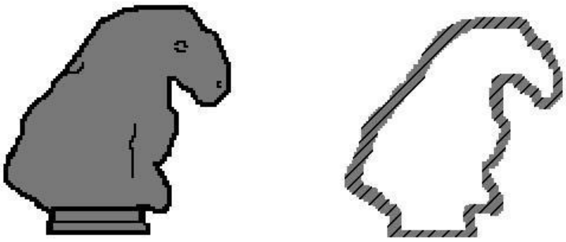


Figure 82 – Final product of the slush casting process (shown with section view)

Properties and considerations of manufacturing by slush casting:

- Slush casting is a type of permanent mold casting, therefore many of the basic principles of a permanent mold process will apply.
- Slush casting is mainly suited to lower melting point materials, zinc, tin, or aluminum alloys are commonly slush cast in manufacturing industry.
- With this process it needs to have a mechanical means of turning over the mold in order to pour out the molten metal from the cast part.
- When manufacturing by slush casting it is difficult to accurately control the metal casting's strength and other mechanical properties.
- The casting's internal geometry cannot be effectively controlled with this process.

- The hollow metal castings manufactured by this process are lighter than solid parts and save on material.
- Good surface finish and accurate exterior geometry are possible with the slush casting manufacturing process.

Table 17 – Advantages and disadvantages of slush casting

Advantages	Disadvantages
Slush casting is used to produce hollow parts without the use of cores.	Suitable for only low-temperature pure metals such as lead, zinc, tin, cadmium and magnesium.
The desired thickness can be achieved by pouring out the leftover molten metal.	Difficulty in controlling the thickness of the hollow casting, uniform thickness cannot be produced.
A variety of exquisitely designed casting can be cast for decorative and ornamental purposes.	Large-size components cannot be manufactured due to problems in inverting the mold and draining out molten metal.
Best for pure and low-temperature metals.	There is no control over the internal geometry of casting.
Tooling cost is low making it an inexpensive process.	The labor-intensive process is if the metal is poured manually.
This is a higher-yield casting process.	There are limitations on how strong a casting can be made.
Both symmetrical and asymmetrical casting can be produced with high control over the external surfaces.	It is a slow and time-consuming process if not done under automation.
The mold used here has only one gate, it does not have a sprue, runner or rise.	The interior of the casting is rough in texture and inaccurate.
Solidification time is less in the slush casting process for thinner castings.	Casting made by the slush casting process cannot sustain high-stress conditions.
Suitable for small to medium size production.	Suitable for casting with thin thickness only.
If the process is automated high-volume casting can be made.	External appearance is of primary importance only.

7.4. Die casting

Die casting is a permanent mold manufacturing process that was developed in the early 1900s. In 1849 Sturges made the hand manually operated die casting machine used in printing, making it more accurate, creative, and persistent when making different complex shapes. Later in 1855, Otto Mergenthaler made the linotype machine known for its better efficiency and is an important part of the publishing industry.

The demand for die casting machines grew in the 19th century due to their advantages. Consequently, die casting became popular in many industries. During this period, there was technological advancement. For example, aluminum replaced tin and lead due to their higher quality. Also, the original process of low pressure injection die casting changed to high pressure casting methods.

According to Grand View Research, the die casting industry today currently accounts for 50% of the global shares due to low-cost production rates and consistency.

The process is called die casting due to its using dies. The dies are the steel mold made majorly by CNC machining into which the liquid metal is injected. It has two halves: the fixed half, which is stationary and attached to the casting machine and the movable ejector half.

Die casting manufacture is characteristic in that it uses large amounts of pressure to force molten metal through the mold. Since so much pressure is used to ensure the flow of metal through the mold, metal castings with great surface detail, dimensional accuracy, and extremely thin walls can be produced. Wall thickness within castings can be manufactured as small as .02in (.5mm). The size of industrial metal castings created using this process vary from extremely small to around 50 lbs.

The die casting process is applicable in creating different parts and components that are truly unique and highly functional. There are several main areas of application of this process: manufacture of consumer and industrial products, manufacture of automotive products and manufacture of aerospace parts.

Die casting is suitable for making consumer products such as sink faucets, compressor pistons, connector rods, heat sinks, etc. The process is used in making gear, cylinders, small engines, gladhands, transfer cases and more specific parts applicable in the automotive industry. Die casting is a cost-effective solution to produce light but superior metal components that meet the high-quality standards of the aerospace industry.

Typical parts made in industry by die casting include tools, carburetors, machine components, various housings, and motors.

The process.

The standard die casting process involves injecting molten metal into a die mold under high pressure. The process cycle for die casting consists of five main stages, which are explained below. The total cycle time is very short, typically between 2 seconds and 1 minute. Below are the intricate die casting process steps:

1. Clamping. The first step is the preparation and clamping of the two halves of the die. Each die half is first cleaned from the previous injection and then lubricated to facilitate the ejection of the next part. The lubrication time increases with part size, as well as the number of cavities and side cores. Also, lubrication may not be required after each cycle, but after 2 or 3 cycles, depending on the material.

After lubrication, the two die halves, which are attached inside the die casting machine, are closed and securely clamped together. Sufficient force must be applied to the die to keep it securely closed while the metal is injected. The time required to close and clamp the die is dependent upon the machine – larger machines (those with greater clamping forces) will require more time. This time can be estimated from the dry cycle time of the machine.

2. Injection. The molten metal, which is maintained at a set temperature in the furnace, is next transferred into a chamber where it can be injected into the die. The method of transferring the molten metal is dependent upon the type of die casting machine, whether a hot chamber or cold chamber machine is being used.

The difference in this equipment will be detailed in the next section. Once transferred, the molten metal is injected at high pressure into the die. Typical injection pressure ranges from 1,000 to 20,000 psi. This pressure holds the molten metal in the dies during solidification. The amount of metal that is injected into the die is referred to as the shot.

The injection time is the time required for the molten metal to fill all of the channels and cavities in the die. This time is very short, typically less than 0.1 seconds, in order to prevent early solidification of any one part of the metal. The proper injection time can be determined by the thermodynamic properties of the material, as well as the wall thickness of the casting. A greater wall thickness will require a longer injection time. In the case where a cold chamber die casting machine is being used, the injection time must also include the time to manually ladle the molten metal into the shot chamber.

3. Cooling. The molten metal that is injected into the die will begin to cool and solidify once it enters the die cavity. When the entire cavity is filled and the molten metal solidifies, the final shape of the casting is formed. The die can not be opened until the cooling time has elapsed and the casting is solidified.

The cooling time can be estimated from several thermodynamic properties of the metal, the maximum wall thickness of the casting, and the complexity of the die. A greater wall thickness will require a longer cooling time. The geometric complexity of the die also requires a longer cooling time because of the additional resistance to the flow of heat.

4. Ejection. After the predetermined cooling time has passed, the die halves can be opened and an ejection mechanism can push the casting out of the die cavity. The time to open the die can be estimated from the dry cycle time of the machine and the ejection time is determined by the size of the casting's envelope and should include time for the casting to fall free of the die. The ejection mechanism must apply some force to eject the part because during cooling the part shrinks and adheres to the die. Once the casting is ejected, the die can be clamped shut for the next injection.

5. Trimming. During cooling, the material in the channels of the die will solidify attached to the casting. This excess material, along with any flash that has occurred, must be trimmed from the casting either manually via cutting or sawing or using a trimming press. The time required to trim the excess material can be estimated from the size of the castings envelope. The scrap material that results from this trimming is either discarded or can be reused in the die casting process. Recycled material may need to be reconditioned to the proper chemical composition before it can be combined with non-recycled metal and reused in the die casting process.

Die casting alloys.

Most alloys used in die casting are non-ferrous with strong mechanical properties. The non-ferrous moiety is responsible for the low melting point in agreement with the strong mechanical properties. The type of properties needed depends on the material being worked on. Consequently, there is no limitation when choosing a material. However, below are several popular alloys for die casting:

1. Aluminum alloys. They have unique properties, making them applicable in making a wide range of products. On the one hand, aluminum alloy 380.0 is the most common material in die casting due to its unique properties. Other alloys include Aluminum Alloys 360, 390, and 413. The use of aluminum alloys is explained by their following characteristics:

- high operating temperatures;
- outstanding corrosion resistance;
- lightweight;
- very good strength and hardness;
- good stiffness and strength-to-weight ratio;
- excellent EMI and RFI shielding properties;
- excellent thermal conductivity;
- high electrical conductivity;
- good finishing characteristics;
- full recyclability;
- withstand the highest operating temperatures of all the diecast alloys;
- corrosion-resistance;
- it retains high dimensional stability with thin walls.

2. Zinc Alloys. These alloys have incredible strength, toughness, firmness, performance, and cost-effectiveness. As a result, they are an important part of the die casting process, with properties rivaling and exceeding other alloys such as aluminum, magnesium, and bronze.

There are many alloys of zinc which are used in die casting. However, the common die casting zinc materials are Zamak #2, #3, #5, #7, ZA8 and ZA27, known for the following properties:

- improved castability;
- shortened cycle time;
- extended die life;
- ideal mechanical qualities.

3. Magnesium alloys. Magnesium is another material used for die casting. It has many alloys, but the most common one is the AZ91D, known for its toughness, durability, lightweight and good castability. It is 75% lighter than steel and 33% lighter than aluminum without a loss in strength. Most enthusiasts prefer magnesium as it is better for complex casting with tight tolerances and it has better corrosion resistance.

4. Other alloys. Suitable for making die casting parts include bronze, brass, lead, and tin. Tin is the first material used in die casting due to its high fluidity. It has a low melting point, and it leaves little or no wear on the molds.

Bronze (white bronze) is the right die cast material used in the jewelry industry. It has a similar color to white gold and stainless steel alloys but is suitable for die casting due to its low melting point.

The mold.

Like in all permanent mold manufacturing processes, the first step in die casting is the production of the mold. The mold must be accurately created as two halves that can be opened and closed for removal of the metal casting, similar to the basic permanent mold casting process.

The mold for die casting is commonly machined from steel and contains all the components of the gating system. Multi-cavity die is employed in the manufacturing industry to produce several castings with each cycle. Unit dies which are a combination of smaller dies are also used to manufacture metal castings in the foundryindustry.

In a die casting production setup, the mold, (or die), is designed so that its mass is far greater than that of the casting. Typically the mold will have 1000 times the mass of the metal casting.

So, a 2-pound part will require a mold weighing a ton! Due to the extreme pressures and the continuous exposure to thermal gradients from the molten metal, wearing the die can be a problem. However, in a well-maintained manufacturing process, a die can last hundreds of thousands of cycles before needing to be replaced.

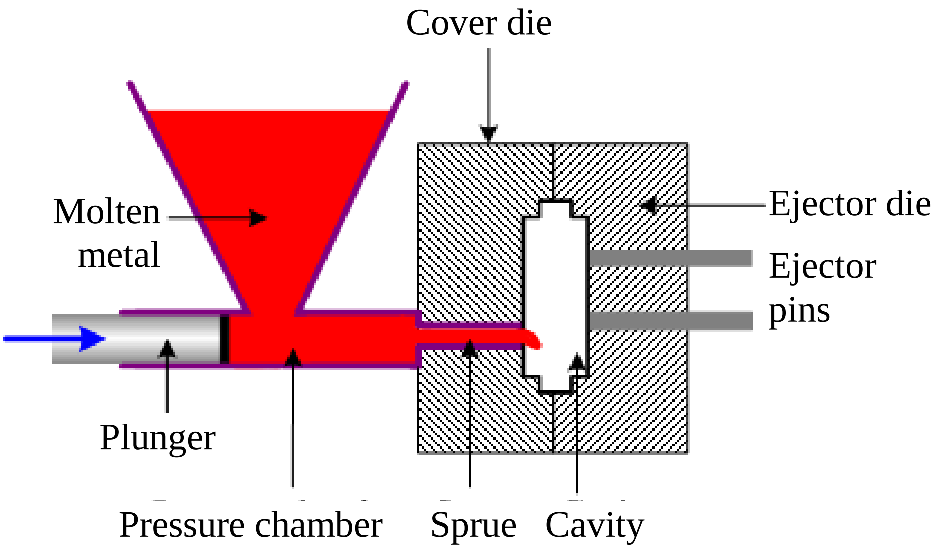


Figure 83 – Die casting process

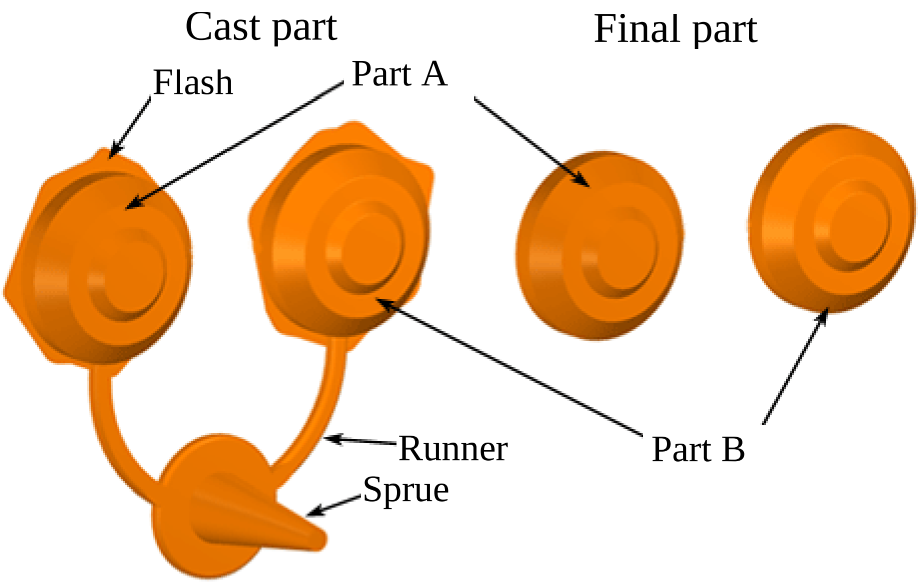


Figure 84 – Die casting part

Die casting machines.

In addition to the opening and closing of the mold to prepare for and remove castings, it is very important there must be enough force that can be applied to hold the two halves of the mold together during the injection of the molten metal. The flow of molten metal under such pressures will create a tremendous force acting to separate the die halves during the process. Die casting machines are large and strong, designed to hold the mold together against such forces.

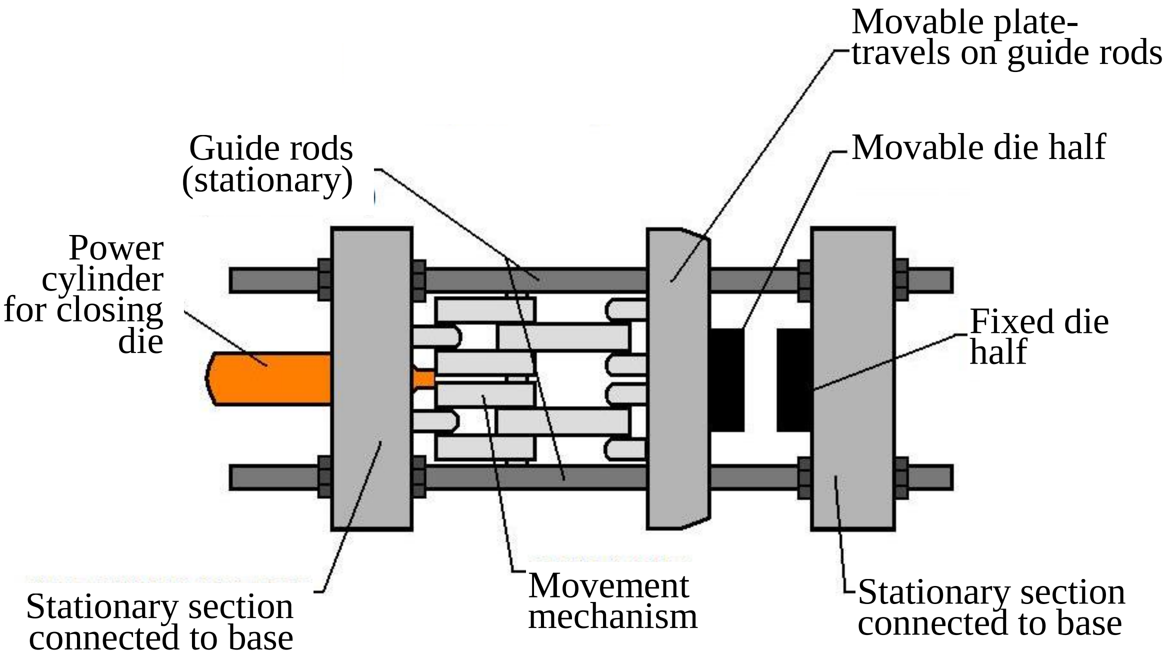


Figure 85 – Cold chamber die casting machine (top view)

In the manufacturing industry, die casting machines are rated on the force with which they can hold the mold closed. Clamping forces for these machines vary from around 25 to 3000 tons.

Injection of molten metal.

In industrial manufacture the process of die casting falls into two basic categories, hot chamber die casting and cold chamber die casting. Each process will be discussed specifically in more detail later. Although these processes vary from each other, both employ a piston or plunger to force the molten metal to travel in the desired direction.

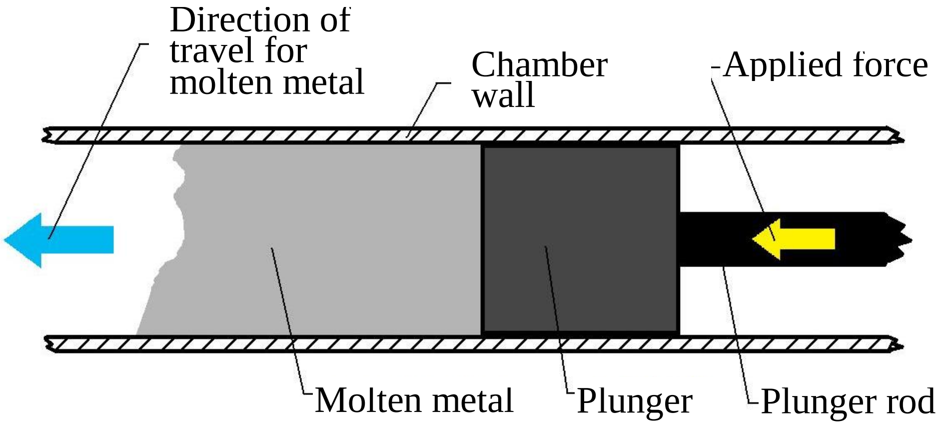


Figure 86 – Basic principle of die casting

The pressure at which the metal is forced to flow into the mold in die casting manufacture is on the order of 1000psi to 50000psi (7MPa to 350MPa). This pressure is accountable for the tremendously intricate surface detail and thin walls that are often observed in metal castings manufactured by this technique.

Once the mold has been filled with molten metal, the pressure is maintained until the casting has hardened. The mold is then opened and the casting is removed. Ejector pins built into the mold assist in the removal of the metal casting. In most manufacturing operations, the internal surfaces of the mold are sprayed with a lubricant before every cycle. The lubricant will assist in cooling down the dies as well as preventing the metal casting from sticking to the mold.

After the casting has been removed and the lubricant applied to the mold surfaces, the die is clamped together again then the cycle will repeat itself. Cycle times will differ depending on the details of each specific die casting manufacturing technique. In some instances, very high rates of production have been achieved using this metal casting process.

Insert molding.

With the die casting process, shafts, bolts, bushings and other parts can be inserted into the mold and metal casting may be formed around these parts. This is called insert molding, once solidified these parts become one with the casting. To help with the integration of the part into the casting, the part may be grooved or knurled providing a stronger contact surface between the part and the molten metal.

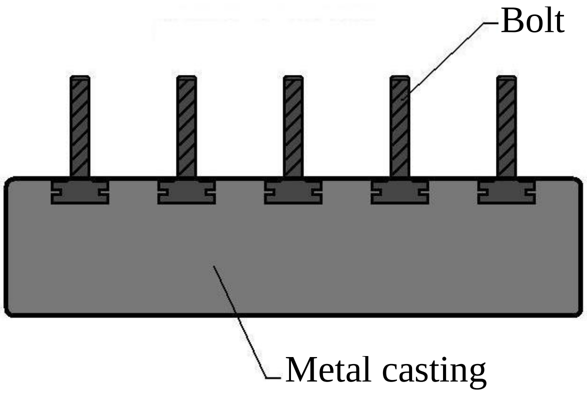


Figure 87 – Grooved bolts cast into a part

Properties and considerations of manufacturing by die casting:

- Metal castings with close tolerances, tremendous surface detail, and thin intricate walls can be manufactured using this process.
- Due to the rapid cooling at the die walls smaller grain structures are formed, resulting in manufactured metal castings with superior mechanical properties. This is especially true of the thinner sections of the casting.
- When manufacturing by this process, it is of concern to keep the mold cool. Die may have special passages built into them that water is cycled through in order to keep down thermal extremes.
- Due to the high pressures, a thin flash of metal is usually squeezed out at the parting line. This flash has to be trimmed later from the casting.
- Since the mold is not permeable, adequate vents need to be provided for the elimination of gases during the metal casting process. These vents are usually placed along the parting line between the die.
- High production rates are possible in die casting manufacture.
- Ejector pins will usually leave small round marks on the metal casting. These can be observed on the surfaces of manufactured parts.
- The need to open and close the mold limits some of the shapes and geometries that may be cast using this manufacturing process.
- Equipment costs for die casting are generally high.

- Die casting manufacture can be highly automated, making labor cost low.
- Die casting is similar to most other permanent mold casting processes in that high set-up cost, and high productivity make it suitable for larger batch manufacture and not small production runs.

Design aspects of die casting.

- Since the metallic mold of a die casting expands when it is filled with a molten metal and then both the casting and the mold shrink during cooling the shrinkage allowances taken in the die mold design are smaller than those in the sand casting.
- Parts of 0.05 lb (20 g) to 75 lb (34 kg) may be cast.
- The section thickness of permanent mold casting may vary in the range of 0.02” – 0.5” (0.5–12 mm).
- The dimensional tolerances are 0.01–0.03” (0.25–0.75 mm) depending on the casting section thickness.
- Allowances of 0.004–0.01” (0.1–0.25 mm) are taken for the dimensions crossing the parting line of the mold.
- The draft angle is commonly about 1%.
- Lower (as compared to other casting methods) radii of the part corners may be achieved by the die casting process.
- Changes in the section thickness should be as gradual as possible.
- The parting line should not cross critical dimensions.
- Water-cooled dies may be used for obtaining faster solidification at a desired direction.
- The dies are fabricated from tool and die steels. The die life is determined by the ability of the material to withstand wear caused by the molten alloys and fatigue caused by multiple heating and expansion.
- The cores are made of refractory ceramic materials. Sand-based cores are not applicable due to their insufficient strength under pressure applied in die casting.

Die casting can have significant advantages over other manufacturing processes, which often lead to major cost savings, not only in the part price itself but also in the overall cost of production. During casting a part, it is possible to create complex net shapes, including external threads and complex internal features with minimal draft angles – minimizing secondary operations. It is possible also to combine multiple parts into a single part, eliminating assembly operations and lowering labor costs, with the added benefits of simplified stock control and greater component consistency. Other benefits and limitations are shown in Table 18.

Table 18 – Advantages and disadvantages of die casting

Advantages	Disadvantages
Variable wall thicknesses.	Microporosity in the die casting products is a common problem because of faster solidification, trapped air and vaporized die lubricants.
Tighter tolerances.	
Fewer steps from raw material to finished part.	
High accuracy in part dimensions.	
Smooth surface finish for minimum mechanical finishing.	Undercuts cannot be found in simple two-piece dies.
Long tool life, especially for zinc and magnesium.	Not suitable for metals with high melting points.
Reduction in material scrap.	Hollow shapes are not readily cast because of the high metal pressure.
Manufacture of multiple parts without the need for assembly.	
Much thinner wall sections can be produced which can’t be produced by other casting.	Limited sizes of the products can be produced based on the availability of the equipment.
Ability to make many intricate parts such as hole opening slot trademark number etc.	High melting temperature alloys are practically not die-casted.
Good mechanical properties of castings.	Flash is present except for very small zinc die casting.
Die casting can create complex parts.	Large parts can not be cast.
One mold can be repeatedly used for the same production.	Some gases may be entrapped in the form of porosity.
Recyclable choice of material.	Poor control over mechanical properties.
Fast production cycle times.	
Ability to cast inserts such as pins studs shafts, fasteners etc.	The extra quantity of material required during the process.
Varieties of alloys can be used as per design requirements. For example, zinc can be used for intricate forms and plasticity and aluminum for higher structural strength, rigidity and light weight.	Usually support non-ferrous metals only.
	Not suitable for low volume production.
	High die cost.
	Large capital investment.
Lowering labor costs.	Low die life.
Die casting can be fully automated.	Long lead time.

7.4.1. Hot chamber die casting

Hot chamber die casting is one of the two main techniques in the manufacturing process of die casting. This section will primarily discuss the specific details of the hot chamber process and contrast the differences between hot chamber die casting and cold chamber die casting, which is the other branch of die casting manufacture. The hot chamber process is sometimes known as the hot die or gooseneck casting process.

Hot chamber die casting is usually used for metals with a low-melting point, such as zinc, magnesium, tin, lead, and other low melting alloys. Zinc is one of the easier metals to cast and is very economical for small parts. Tin are lead are both commonly used as it is extremely corrosion-resistant and offers finished items that have high dimensional accuracy.

The process.

A similar characteristic of the hot chamber die casting process is the use of high pressure to force molten metal through a mold called a die. Many of the superior qualities of castings manufactured by die casting, (such as great surface detail), can be attributed to the use of pressure to ensure the flow of metal through the die. In hot chamber die casting manufacture, the supply of molten metal is attached to the die casting machine and is an integral part of the casting apparatus for this manufacturing operation.

The hot chamber die casting process has four main steps as follows:

1. Injection. A hot chamber is filled with molten metal. At this point, a plunger is raised, and the metal fills the mold.

2. Sealing of the chamber. The plunger begins to move downward. This forces the metal into the cavity of the mold and seals it off once it is filled.

3. Cooling. Once the mold has been sealed off, it is cooled and the metal solidifies, taking the shape of the mold.

4. Ejection. After the metal has solidified, the die opens and the casting (the cooled metal) is ejected, preparing the mold for the next object to be made.

The metal is heated directly inside the casting machine instead of going to a separate furnace. Having this built-in furnace is the defining characteristic of hot chamber die-casting. This built-in furnace helps heat the metal to a molten state and it uses a hydraulic-powered piston to force the molten metal into the die. Here, the molten will be formed into its final shape in as little as 15–20 minutes.

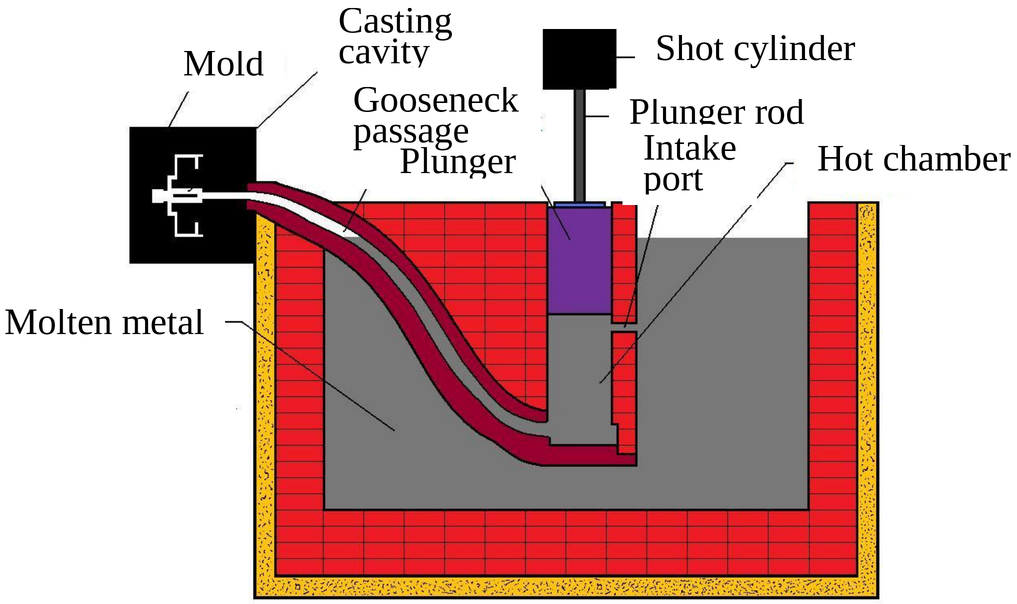


Figure 88 – Hot chamber die casting (first step)

The shot cylinder provides the power for the injection stroke. It is located above the supply of molten metal. The plunger rod goes from the shot cylinder down to the plunger, which is in contact with the molten material. At the start of a casting cycle, the plunger is at the top of a chamber (the hot chamber). Intake ports allow this chamber to fill with liquid metal. As the cycle begins, the power cylinder forces the plunger downward. The plunger travels past the ports, cutting off the flow of liquid metal to the hot chamber. Now there should be the correct amount of molten material in the chamber for the «shot» that will be used to fill the mold and produce the casting.

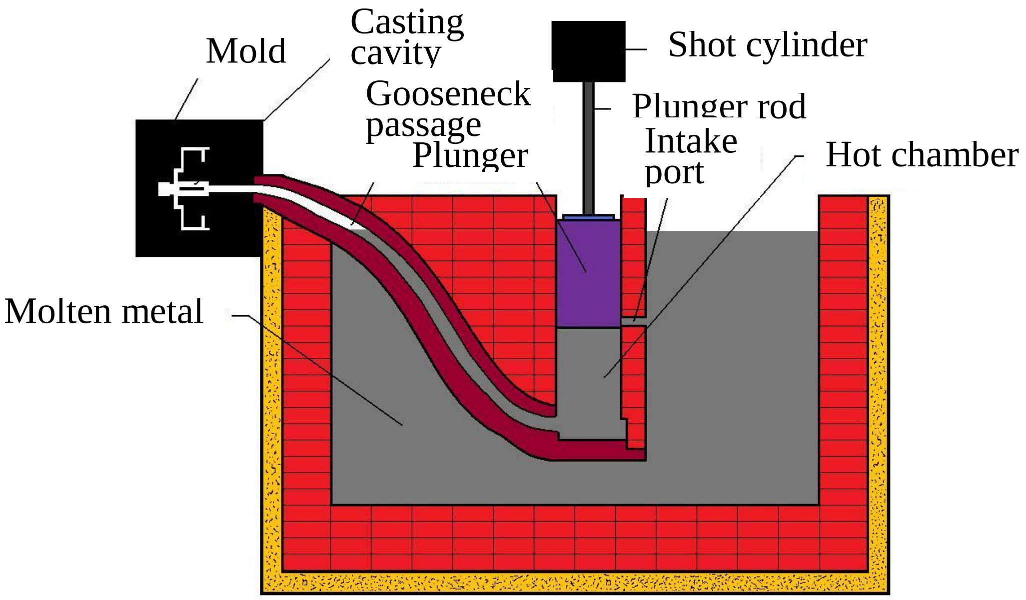


Figure 89 – Hot chamber die casting (second step)

At this point the plunger travels further downward, forcing the molten metal into the die. The pressure exerted on the liquid metal to fill the die in hot chamber die casting manufacture usually varies from about 700psi to 5000psi (5MPa to 35 MPa). The pressure is held long enough for the casting to solidify.

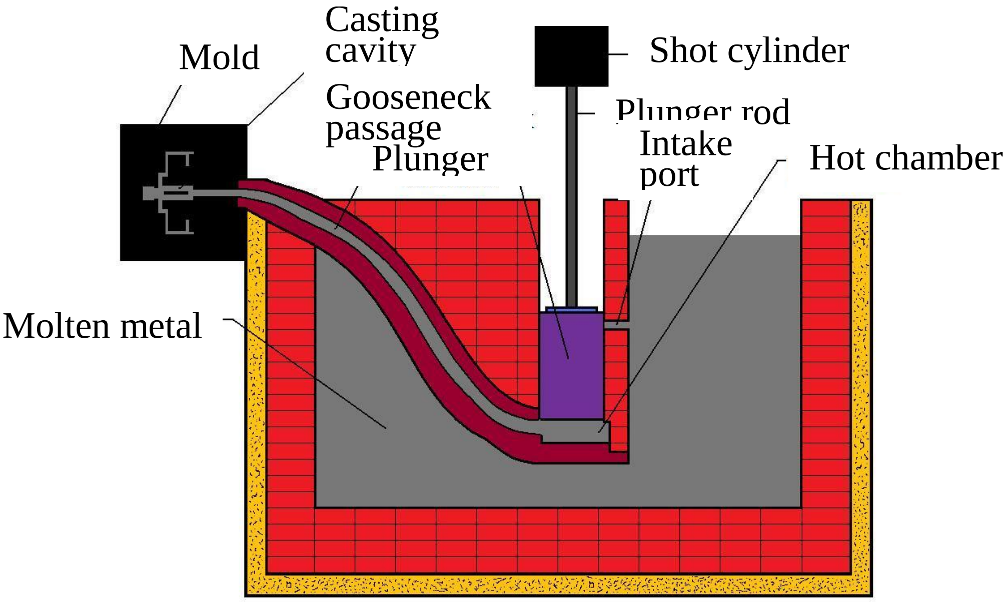


Figure 90 – Hot chamber die casting (third step)

In preparation for the next cycle of casting manufacture, the plunger travels back upward in the hot chamber exposing the intake ports again and allowing the chamber to refill with molten material.

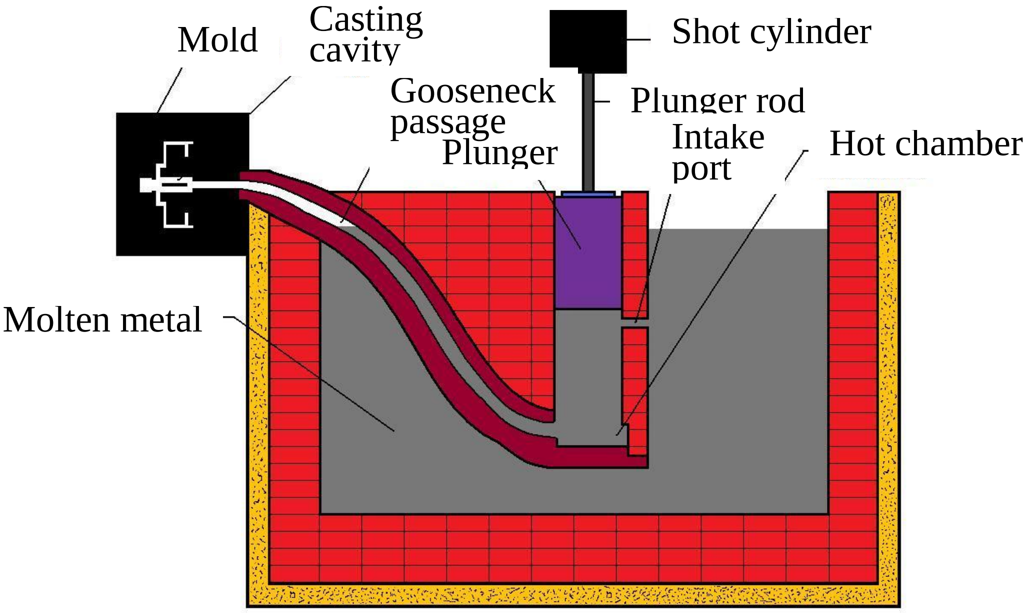


Figure 91 – Hot chamber die casting (fourth step)

Continuous submersion in a high enough temperature material will cause thermal related-damage to these components rendering them inoperative. For this reason usually, only lower melting point alloys of lead, tin, and zinc are used to manufacture metal castings with the hot chamber die casting process.

The hot chamber die casting machine is complex equipment with multiple components.

1. Furnace. The most important element of this machine is its built-in furnace. The furnace has a combustion chamber to burn fuel and produce extreme temperatures to melt the raw materials. In hot chamber casting, the furnace is in close vicinity of the die, as shown above.

2. Gooseneck. This is an essential component that is unique to hot chamber casting setups. The gooseneck links the injection mechanism to the feed line through which the molten metal travels into the die. It is submerged in the molten metal pool. As a result, it must have a high thermal resistance. Consequently, it is ideal to manufacture it from high-quality cast or forged steel. It contains a cylindrical lining that houses the hot chamber and the plunger, which are part of the hydraulic injection mechanism. Furthermore, most goosenecks are replaceable as their quality still deteriorates over an extended period under intense working conditions.

3. Nozzle. The nozzle regulates the flow of the molten metal through the gooseneck into the die. It acts as a gateway for the metal to enter the mold in a smooth, well-directed manner. Also, any extra raw material at the end of the casting cycle travels back into the furnace through the nozzle.

4. Hydraulic plunger/piston. This component transports the molten metal into the die and maintains it at high pressure. The plunger traverses up and down through the hot chamber. Its power source is an oil or gas hydraulic cylinder.

5. Die. Finally, the die/mold itself. It contains the cavity and ejector pins to eject the part. Moreover, it might house additional components like cores, depending on the part geometry. The die in the hot chamber die casting process is the same as other casting methods.

Hot chamber die casting machine.

The different components that make up the machine are:

- Injection mechanism. This consists of a furnace to melt the metal and a chamber to store the molten metal. It is attached to the machine by a gooseneck (a metal tube to feed the metal to the machine).
- Die. This is the mold that is to be filled with the metal. This will give the product its shape.

- Piston and plunger. The piston rises to let the metal into the die. The plunger then seals up the port and the die fills with metal. It holds this position until the metal solidifies.
- Ejector pins. After the metal has become solid, the die opens, the plunger allows any leftover molten metal to return to the chamber, and the ejector pins remove the object from the die.

Hot chamber machines are used for alloys with low melting temperatures. The temperatures required to melt other alloys would damage the pump, which is in direct contact with the molten metal. The metal is contained in an open holding pot which is placed into a furnace, where it is melted to the necessary temperature. The molten metal then flows into a shot chamber through an inlet and a plunger, powered by hydraulic pressure, forces the molten metal through a gooseneck channel and into the die. After the molten metal has been injected into the die cavity, the plunger remains down, holding the pressure while the casting solidifies.

After solidification, the hydraulic system retracts the plunger and the part can be ejected by the clamping unit. Prior to the injection of the molten metal, this unit closes and clamps the two halves of the die.

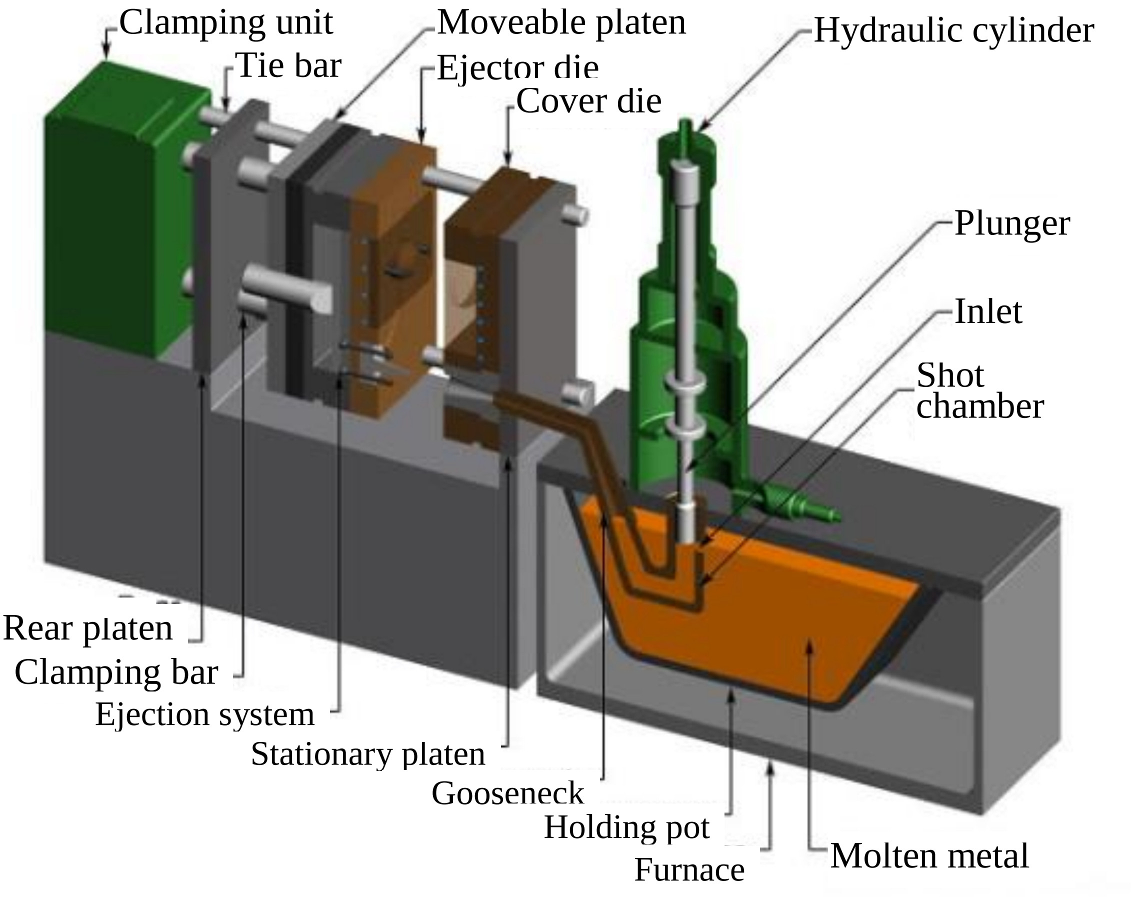


Figure 92 – Hot chamber die casting machine – Opened

When the die is attached to the die casting machine, each half is fixed to a large plate, called a platen. The front half of the die, called the cover die, is mounted to a stationary platen and aligns with the gooseneck channel.

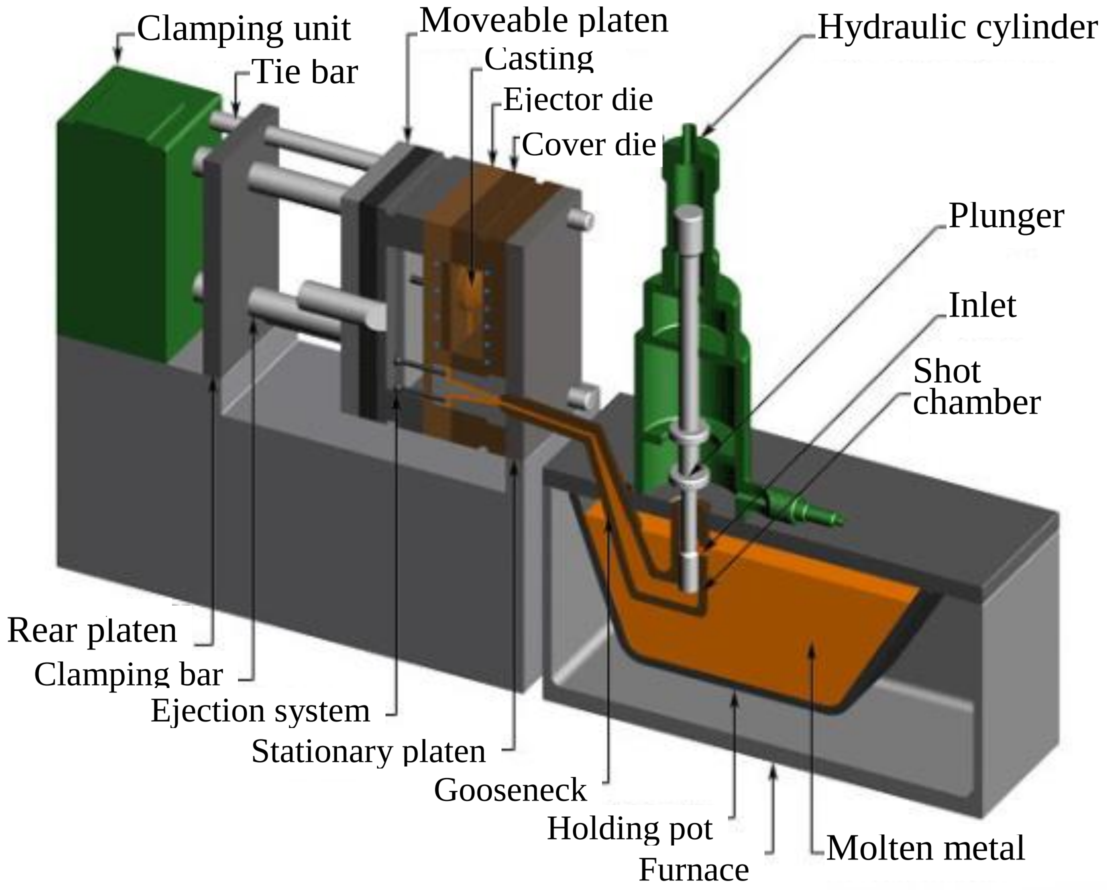


Figure 93 – Hot chamber die casting machine – Closed

The rear half of the die, called the ejector die, is mounted to a movable platen, which slides along the tie bars. The hydraulically powered clamping unit actuates clamping bars that push this platen towards the cover die and exert enough pressure to keep it closed while the molten metal is injected. Following the solidification of the metal inside the die cavity, the clamping unit releases the die halves and simultaneously causes the ejection system to push the casting out of the open cavity. The die can then be closed for the next injection.

Hot chamber die casting products include engine and transmission components, gears, sink faucets and their parts, and connector housings.

This casting process has the advantage of a very high rate of productivity (Table 19). During industrial manufacture by it, one of the main disadvantages is that the setup requires that critical parts of the mechanical apparatus, (such as the plunger), must be continuously submersed in molten material.

Table 19 – Advantages and disadvantages of hot chamber die casting

Advantages	Disadvantages
Suitable for complex thin-walled parts (> 0.05).	This process is only used successfully for casting low-melting metals such as tin alloys, zinc alloys, and magnesium alloys.
High dimensional precision and high process stability.	
Lightweight, high stability.	
Smooth surface and edges.	Hot chamber die casting parts have high porosity.
High thermal conductivity.	
Reduced porosity using the alloys, which do not damage or erode the machines when subjected to high temperature and pressure.	Hot chamber die-casting requires a high-pressure range that isn't always suitable for making every product.
It can create metal components with a more intricate design.	It offers limited metal fluidity due to variance in alloy malleability, limiting the final product's shape and/or complexity.
Excellent processing performance.	
The die can be used multiple times because of its lower melting points.	
A variety of surface treatments are possible.	Hot chamber die casting is more difficult for castings with complex recesses.
Lesser metal wastage.	
Compared to other die casting processing, it produces less metal scrap.	Ejector marks and tiny amounts of flash at the die separating line may remain.
Longer die casting die life due to lower melting points.	Low metal fluidity hence limited the product's complexity
Corrosion and weather resistance.	Heat treatment issues.
Less waste and defects.	The high-pressure range required.
The low unit price for larger series.	The high initial start-up cost required for setting up the die-casting equipment.
Low cycle time, automatic run.	
Reduce relatively high tool costs through optimized tooling structure on demand.	Cost-effective only for the high-volume production batch.
Hot chamber die casting has a faster production circle.	It is not suitable for small-batch production.
Die design efficiencies = waste reduction.	It needs a higher cost on equipment start-up.

7.4.2. Cold chamber die casting

Cold chamber die casting is the second of the two major branches of the die casting manufacturing process. This section will discuss cold chamber die casting specifically and contrast it with the hot chamber process discussed previously.

The cold chamber die casting process operates under high pressure. This can result in parts that are denser and have higher mechanical characteristics. Higher pressure also makes it possible for the parts to have thin walls, which increases the strength of the parts.

Compared to other manufacturing methods, the cold chamber die casting is a powerful, economical process that can produce a wide variety of forms and components. Long-lasting parts can be produced using the cold chamber die casting method, and they can be crafted to match the surrounding part’s aesthetic.

Cold chamber die casting machines are preferred systems for processing light metals with high melting points to serial-casting parts. They are very popular in the production of aluminum parts. Consistently high precision can be guaranteed even in large series with materials with thin wall thicknesses. The particularly complex structure and structural parts, like automotive engine blocks or door elements, are also producible with the cold chamber die casting-process.

The process.

Cold chamber die casting is a permanent mold metal casting process. A reusable mold, gating system and all is employed. It is most likely machined precisely from two steel blocks. Large robust machines are used to exert the great clamping force necessary to hold the two halves of the mold together against the tremendous pressures exerted during the manufacturing process.

The operating cycle of cold chamber die casting is the following:

1. Die is closed and molten metal is ladled into the cold chamber cylinder;
2. Plunger pushes molten metal into the die cavity; the metal is held under high pressure until it solidifies;
3. Die opens and the plunger follows to push the solidified slug from the cylinder, if there are cores, they are retracted away;
4. Ejector pins push casting off the ejector die and the plunger returns to the original position.

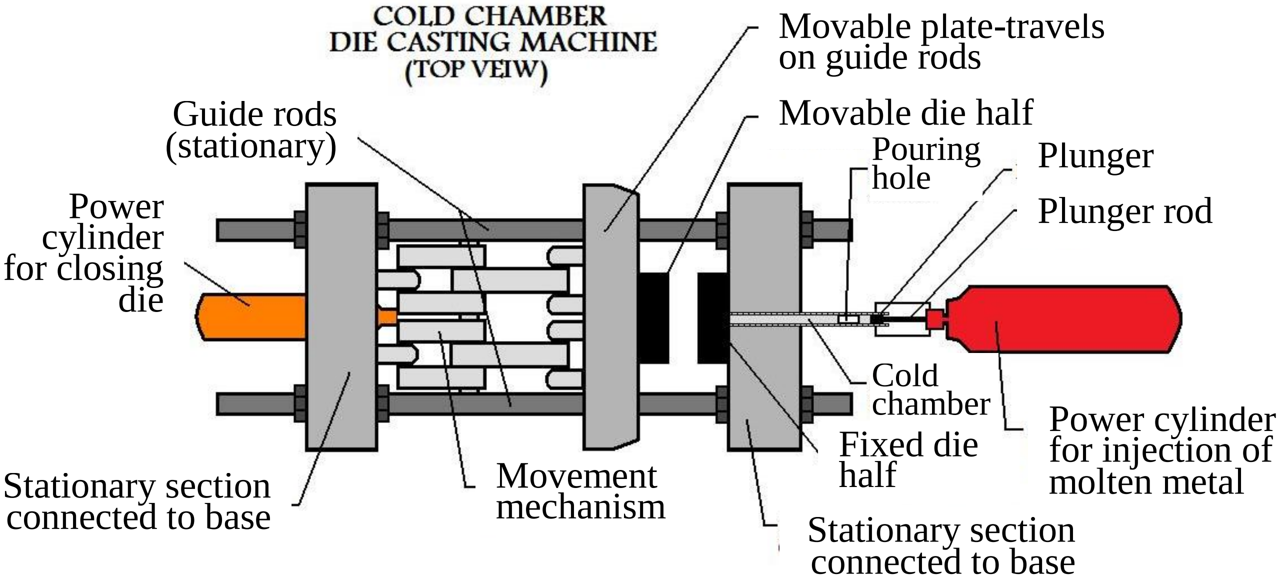


Figure 94 – Cold chamber die casting machine (top view)

A metal shot chamber (cold chamber), is located at the entrance of the mold. A piston is connected to this chamber, which in turn is connected to a power cylinder.

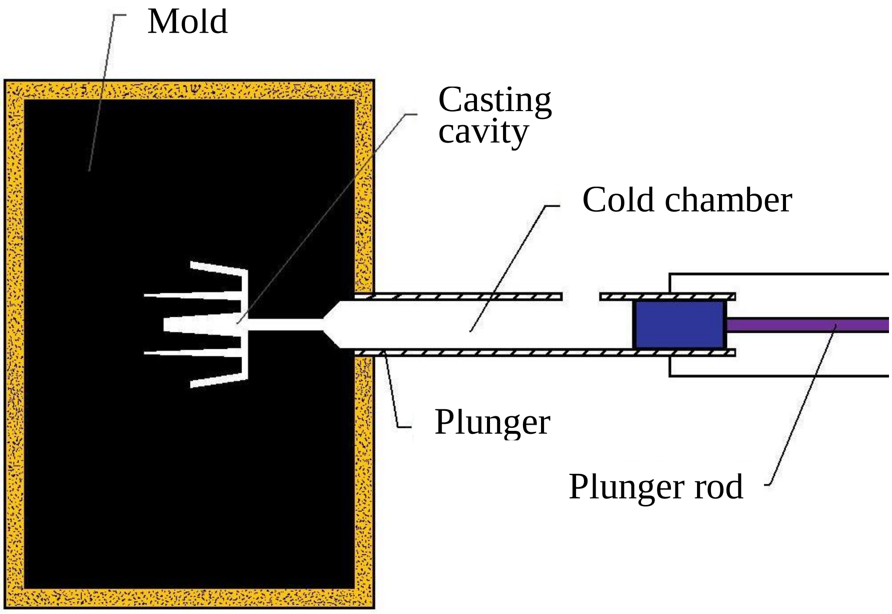


Figure 95 – Cold chamber die casting (first step)

At the start of the manufacturing cycle, the correct amount of molten material for a single shot is poured into the shot chamber from an external source holding the material for the metal casting.

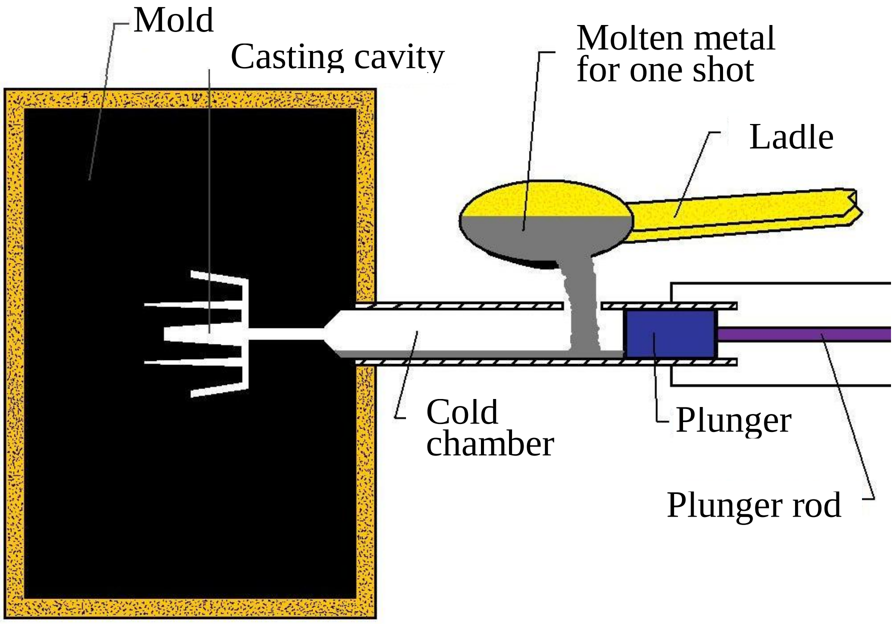


Figure 96 – Cold chamber die casting
(second step)

The power cylinder forces the piston forward in the chamber, cutting off the intake port. The power cylinder moving the piston forward forces the molten material into the casting mold with great pressure.

Pressure causes the liquid metal to fill in even thin sections of the metal casting and press the mold walls for great surface detail. The pressure is maintained sometime after the injection phase of die casting manufacture.

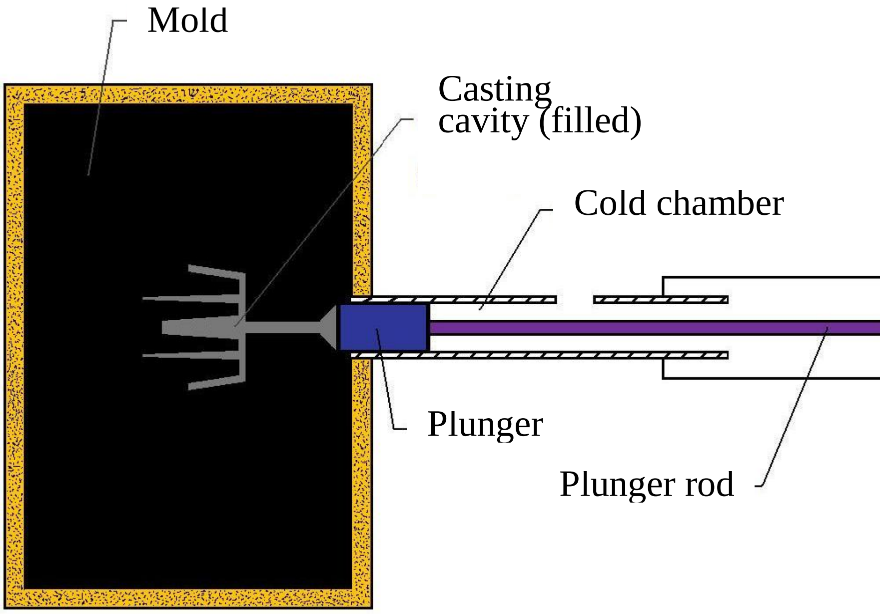


Figure 97 – Cold chamber die casting
(third step)

Once the metal casting begins to solidify, the pressure is released. Then the mold is opened and the casting is removed by way of ejector pins. The mold is sprayed with lubricant before closing again, and the piston is withdrawn in the shot chamber for the next cycle of production.

Cold chamber die casting machine.

Cold chamber machines are used for alloys with high melting temperatures that can not be cast in hot chamber machines because they would damage the pumping system. Such alloys include aluminum, brass, and magnesium. The molten metal is still contained in an open holding pot which is placed into a furnace, where it is melted to the necessary temperature. However, this holding pot is kept separate from the die casting machine and the molten metal is ladled from the pot for each casting, rather than being pumped. The metal is poured from the ladle into the shot chamber through a pouring hole. The injection system in a cold chamber machine functions similarly to that of a hot chamber machine, however it is usually oriented horizontally and does not include a gooseneck channel.

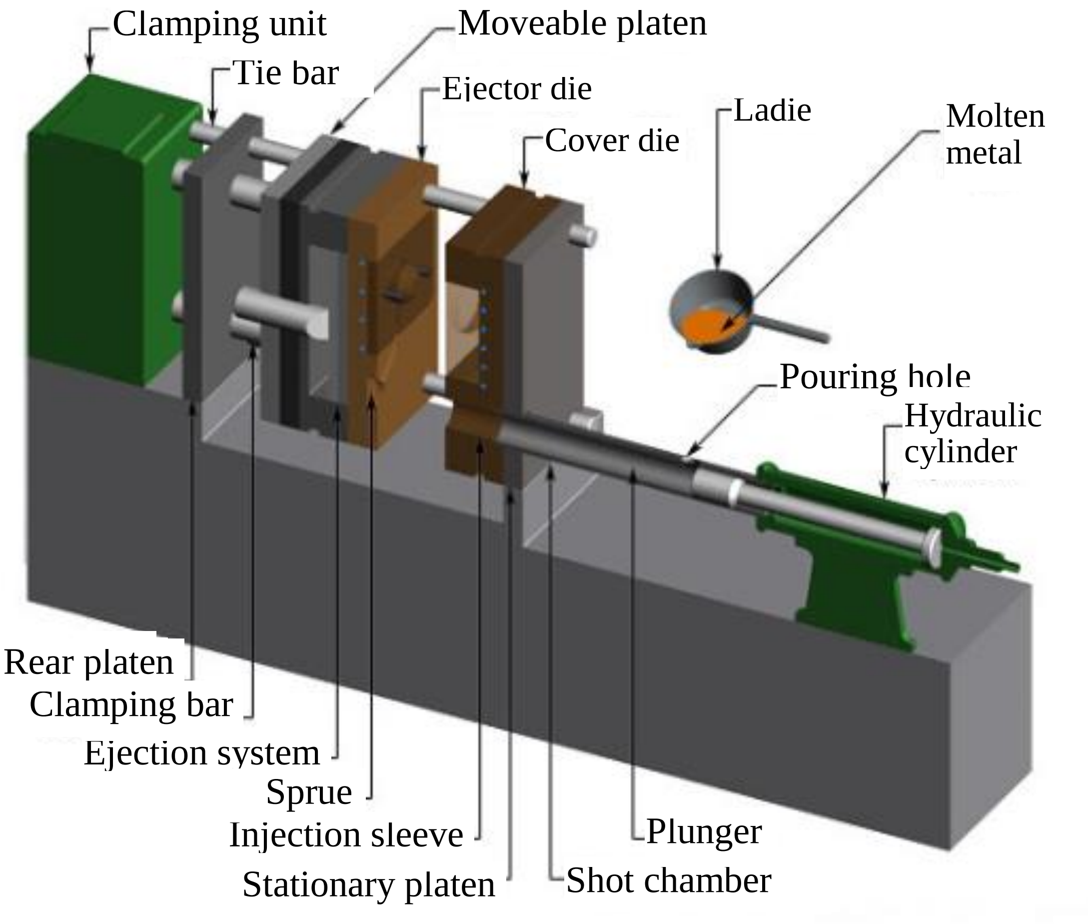


Figure 98 – Cold chamber die casting machine – Opened

A plunger, powered by hydraulic pressure, forces the molten metal through the shot chamber and into the injection sleeve in the die. The typical injection pressures for a cold chamber die casting machine are between 2000 and 20000 psi. After the molten metal has been injected into the die cavity, the plunger remains forward, holding the pressure while the casting solidifies. After solidification, the hydraulic system retracts the plunger and the part can be ejected by the clamping unit. The clamping unit and mounting of the dies is identical to the hot chamber machine.

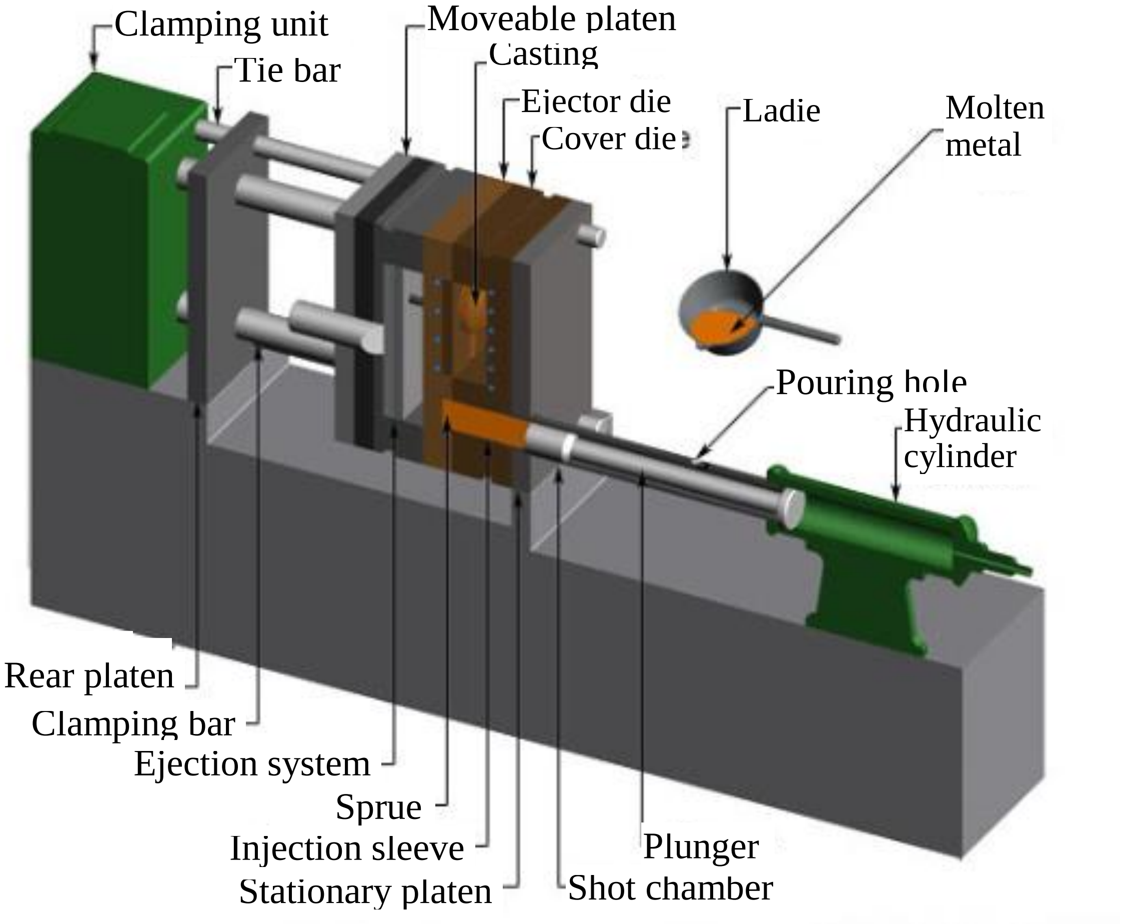


Figure 99 – Cold chamber die casting machine - Closed

Cold chamber die casting for manufacture.

The main difference between cold-chamber die casting and hot-chamber die casting manufacture is that in the cold-chamber process the molten metal for the casting is introduced to the shot chamber from an external source, while in the hot chamber process the source of molten material is attached to the machine. In the hot-chamber process, certain machine apparatus is always in contact with molten metal. For this reason, higher melting point materials will create a problem for the machinery in a hot-chamber metal casting setup. Since the liquid metal is brought in from an outside source, the die casting machinery can stay much cooler in a cold-chamber process.

Consequently, higher melting point alloys of aluminum, brass, copper, and aluminum-zinc are often metal cast in the manufacturing industry using cold chamber die casting. It is very possible to manufacture castings from lower melting point alloys using the cold-chamber method.

The cold chamber die casting is a process that is ideal for metals with higher melting points and corrosive properties, such as aluminum, brass, magnesium and copper alloys. Although zinc can be cast with a hot-chamber machine, there are some zinc alloys with a large percentage of Aluminum. It causes the melting temperature to increase and may require a cold-chamber machine instead. Any other metal with a high enough temperature will require a cold chamber die casting machine as well.

When considering industrial metal casting manufacture, however, the advantages of production by the hot-chamber process usually make it the more suitable choice for lower melting point alloys.

In the cold chamber die casting process, material must be brought in for every shot or cycle of production. This slows down the production rate for metal casting manufacture. Where in the hot chamber process, castings can be constantly output. Cold chamber die casting should still be considered a high-production manufacturing process.

In comparison with the hot die casting process, the cold die casting process requires the application of more pressure. The pressure at which the molten metal is forced into and fills the die cavity in cold chamber metal casting manufacture typically outranks the pressure used to fill the die in hot chamber metal casting by about an order of magnitude. Pressures of 3000psi to 50000psi (20MPa to 350MPa) may be used in the manufacturing industry to fill the mold cavities with molten material during cold chamber die casting manufacture.

High quantities and short cycle times develop their greatest efficiency in automation as widely as possible. Belonging to the cold chamber die casting machines peripheral advices are therefore available in both manual and automated form. Thus, dosing furnaces, spraying machines, removal robots and trimming presses can be installed to automatically operate casting cells.

Castings manufactured by cold chamber die casting have all the advantages characteristic of the die casting process, such as intricate detail, thin walls, and superior mechanical properties. The significant initial investment into this manufacturing process makes it suitable for high-production applications.

Table 20 – Advantages and disadvantages of cold chamber die casting

Advantages	Disadvantages
This method produces lighter castings with thin walls, which makes them stronger.	Wall thickness needs thinner than 8 mm.
Large-size parts can be produced.	Easy have shrinkage porosity inside of parts.
Dimensional stability.	
Diversified surface treatment.	Can not run heat treatment.
Wide range of applications.	Generally limited to metals with low metal points.
High strength, not too difficult technically and cheap.	
Components made using this technique are more durable than parts made by other processes.	Part geometry must allow removal from the die cavity.
Due to high pressure and temperature conditions, the method separates the molten metal from injector chemicals that cause corrosion, producing a corrosive-free metal.	Molten metal can cool significantly if it sits in the chamber too long and causes defects.
Complex shapes can be produced in a cold chamber with higher selectivity than many other mass manufacturing procedures.	Slower production cycles, often due to metal needing to be ladled into the chamber.
The cold chamber method also allows for low cost-effective production of non-ferrous metal parts compared to other methods.	The melted metal in the cold chamber is barer to oxidation and other contaminants chiefly if the production floor does not have strict quality control.
The cold chamber process c to make higher-density cast parts.	
Injector comanponents in cold chamber casting machines enjoy a longer machine life.	Compared to hot chamber die casting, it necessitates an additional step.
The parts produced with a cold chamber can be of different surface finishes, they can be textured or smooth.	Take up more space and more manual operation.
It is a cost-effective process considering the high-density elements it produces.	Requires a high degree of skill in operation and maintenance.

Difference between hot chamber and cold chamber die casting.

Cold chamber die casting and hot chamber die casting are variations of the high pressure die casting process. So, the process of both hot and cold chamber casting is quite similar. However, their scope of application is different from one another.

The main differences between the two methods are:

- The metal melts inside the pot of the furnace of the machine in the hot chamber. But in the cold chamber, the metal melts in a furnace separate from the machine.
- There is no need for any ladle in the hot chamber casting process. But in order to put the liquid metal in the shot chamber, a ladle is necessary for cold chamber casting.
- The liquid metal goes into the cavity via the gooseneck in the hot chamber process. But the liquid metal goes through the shot chamber in the cold chamber method.
- The hot chamber process doesn’t allow the cast of metal alloys that have high melting points. The maximum temperature of alloys that can be safely die cast in a hot chamber machine is around 450°C, which includes alloys of zinc, magnesium, lead, etc. On the contrary, cold chamber equipment deals with non-ferrous alloys of high temperature. It usually handles metal alloys with a temperature at or above 600°C, including alloys of aluminum, copper, brass, etc.
- Hot chamber machines offer noticeably higher casting cycles than cold chamber machines. Despite both of the equipment working quite similarly, cold chamber casting has a longer cycle due to the manual handling of molten metal.
- Hot chamber and cold chamber machines are constructed using the same materials. Hot chamber casting utilizes low melting point alloys, which have less impact on the die. So, it lasts longer. On the contrary, the die condition for cold chamber machines degrades faster as the melted metal has a higher temperature.
- Product size of the hot chamber process is small parts. The cold chamber process can cast bigger part, max weight can achieve 70kg per parts.

The similarities between the two casting processes are as follows:

- There are some similar components in both processes. For example, both machines have one fixed and one movable die.
- An external force is necessary for both processes to push the molten metal into the cavity.

7.5. Pressure die casting

Pressure die casting is a fast and reliable process for producing large quantities of parts that meet close dimensional tolerances. It is the most common type of die casting and involves injecting molten metal under high pressure into steel molds (tools). This solidifies rapidly (milliseconds to seconds) and is automatically extracted from the tool.

There are three main types of pressure die casting: gravity, low pressure and high pressure die casting.

Low pressure casting uses a crucible to fill a mold at a pressure of 0.7 bar to make rotationally symmetrical parts such as car wheels.

High pressure die casting is a metalworking process in which molten metal or metal alloy is injected into a mold at high pressure and speed.

Gravity die casting is a technique that involves pouring molten metal directly from a ladle into a semi-solid or solid mold.

Pressure die casting manufacturers have the equipment and expertise to produce high-quality parts using the pressure die casting process. They may also have in-house design and engineering capabilities to assist customers with the design and development of their parts. In addition, pressure die casting manufacturers may offer additional services, such as assembly, finishing, and packaging, to help customers take their products from concept to completion.

Pressure casting, also known in the manufacturing industry as pressure pouring, is another variation of permanent mold casting. Instead of pouring the molten metal into the casting and allowing gravity to be the force that distributes the liquid material through the mold, pressure casting uses air pressure to force the metal through the gating system and the metal casting's cavity. This process can be used to cast high-quality manufactured parts. Often steel castings are cast in graphite molds using this process. For example, in industry, steel railroad car wheels are cast with this method.

Pressure die casting manufacturers can be found in a variety of industries, including automotive, aerospace, consumer products, and more. They may serve many customers, from large multinational corporations to small businesses, and produce various parts and components for multiple applications.

Pressure die casting can produce more complex products requiring greater precision and fewer defects; it gives a better surface finish and achieves closer tolerances.

The economics of pressure die casting is well suited to producing large numbers of complex parts, mainly when replacement units must provide for in-service equipment.

The process.

This is a permanent mold process and the manufacture of the mold in pressure casting is standard in most regards, see basic permanent mold casting. Two blocks are machined extremely accurately, so they can open and close precisely for the removal of metal parts. The casting's gating system is machined into the mold. The gating system is set up so that the molten material flows into the mold from the bottom instead of the top, (like in gravity-fed processes).

The mold is set up above the supply of liquid metal to be used for the casting. A refractory tube goes from the entrance of the gating system down into the molten material. During manufacture by this process, the chamber that the liquid material is in is kept air tight. When the mold is prepared and ready for the pouring of the metal casting, air pressure is applied to the chamber.

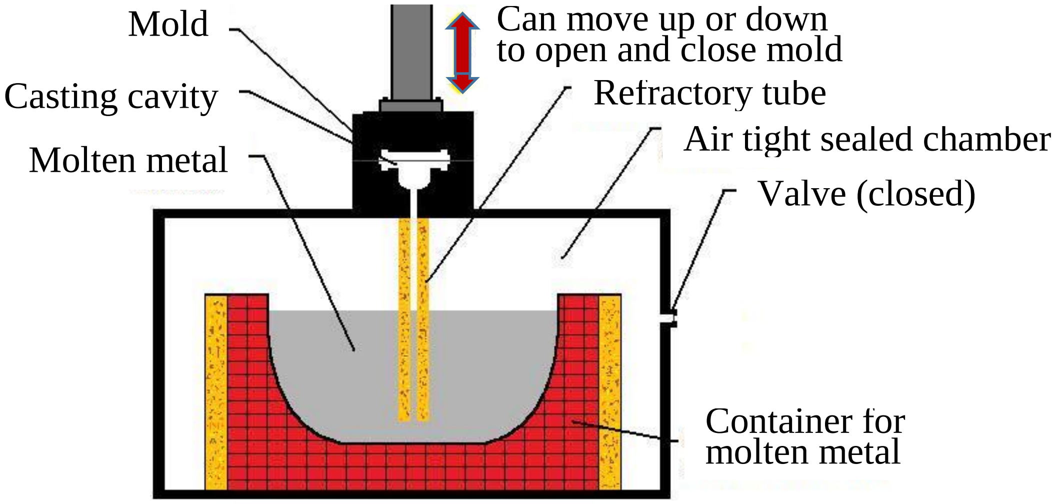


Figure 100 – Pressure die casting mold is in place and operation is ready to begin

This creates pressure on the surface of the liquid, that in turn forces molten material up the refractory tube and throughout the mold.

The pressure used in pressure casting is usually low, 15 lbs/in^2 could be typical for industrial manufacture using this process.

The air pressure is maintained until the metal casting has hardened within the mold. Once the cast part has solidified, the mold is opened and the part is removed.

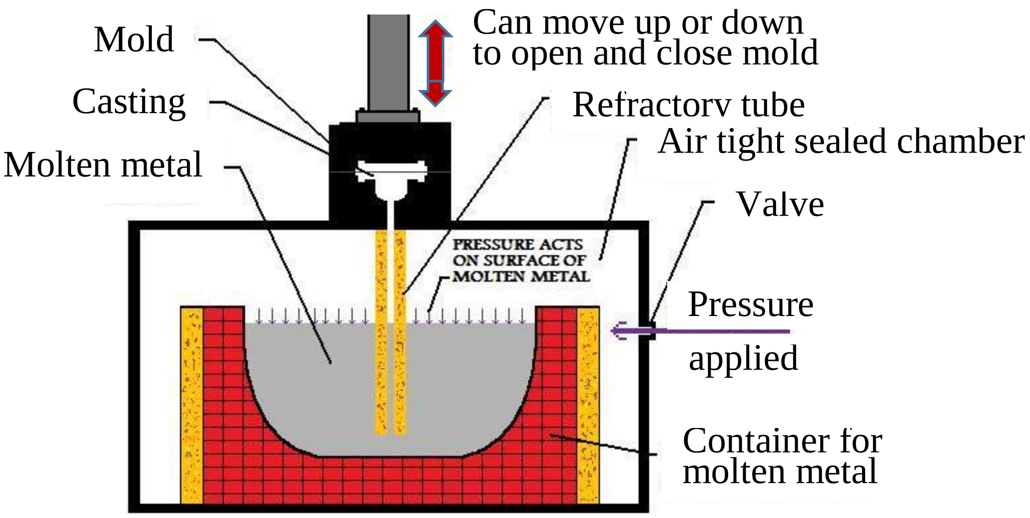


Figure 101 – Pressure is applied to the air-tight chamber from some source through the valve

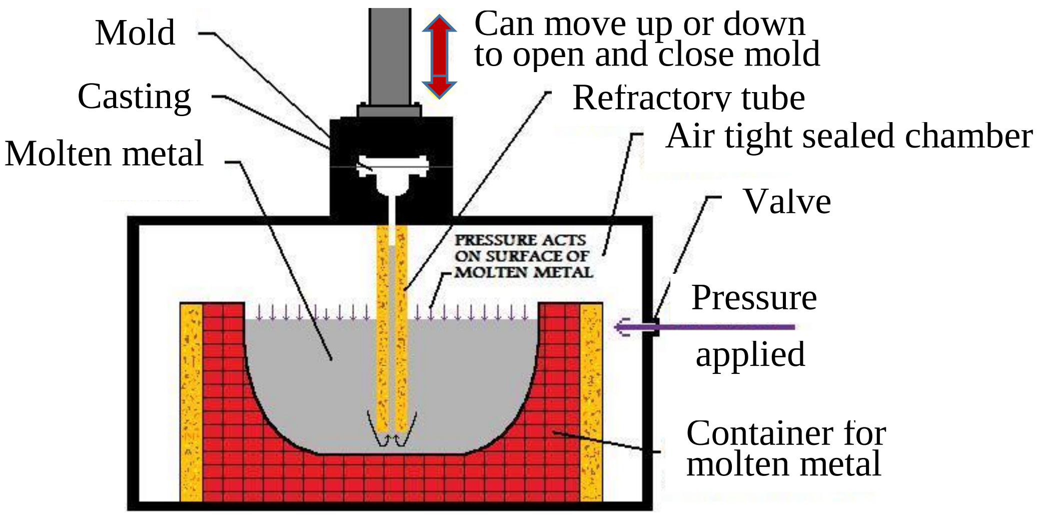


Figure 102 – Pressure difference between chamber and mold forces mental to flow up the refractory tube

Properties and considerations of manufacturing by pressure die casting:

- Pressure casting manufacture can be used to produce metal castings with superior mechanical properties, good surface finish, and close dimensional accuracy.
- Like in other permanent mold methods, the mold needs to be able to open and close for the removal of the workpiece. Therefore, very complicated casting geometry is limited.

Since the refractory tube is submersed in molten material, the metal metal drawn for the casting comes from well below the surface. This metal

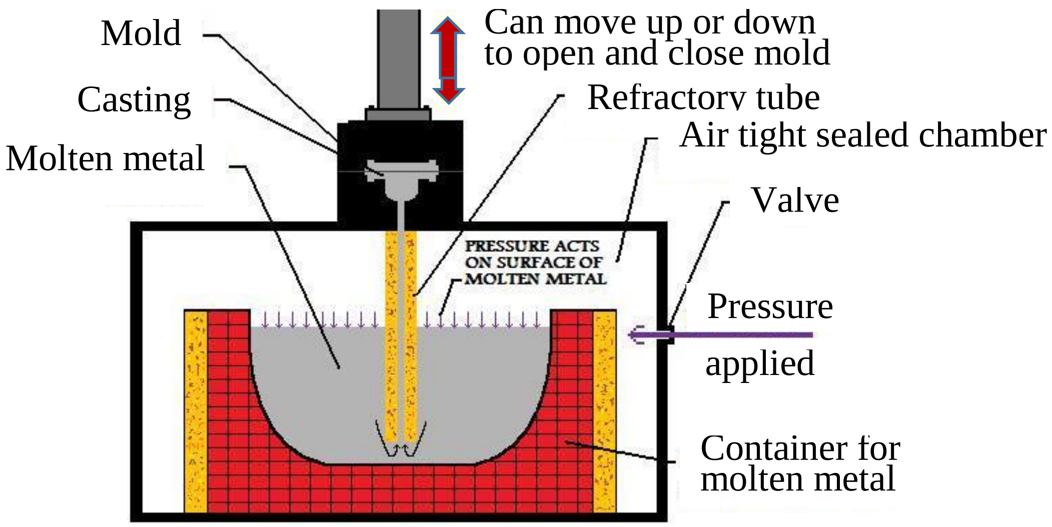


Figure 103 – The force of the pressure causes the molten metal to fill the mold pressure is applied during the solidification of the casting

has had less exposure to the environment than the material at the top. Gas trapped in the metal, as well as oxidation effects, are greatly reduced.

- The high setup cost makes pressure casting not efficient for small runs, but an excellent productivity rate makes it suitable for large batch manufacture.

Pressure die casting is also relatively inflexible compared to gravity die casting. Because it requires molten metal to be forced into the mold under pressure rather than being allowed to flow naturally and fill any voids that might exist in the mold cavity by its weight as gravity does.

The pressure die casting process results in castings with precise dimensional control and a good surface finish. Pressure die castings have thin walls, thanks to which they have less weight than sand castings and investment castings, as well as other metal casting methods. Additionally, they are economical to produce because they typically can be created before they need to be replaced.

Pressure die castings offer dimensional control, good surface finish, thin walls, and/or reduced weight, all of which reduce the cost per part.

Pressure die casting produces castings requiring a high degree of finish, particularly where relatively thin sections are involved. The technique is widely used to create car parts such as wheels, cylinder heads, and aerospace and automotive engine components. Other applications include kitchen equipment such as pressure cookers, cabinets for electronics applications, pump parts, and hydraulic components.

Table 21 – Advantages and disadvantages of pressure die casting

Advantages	Disadvantages
Pressure die casting can produce parts with superior mechanical properties.	The process is mainly suitable for high-fluidity metal parts.
The parts have a good finish and tight dimensional tolerance/accuracy.	Requires complex and expensive equipment.
It is easier to control the dimensions of the final product depending on the amount of pressure.	Limitation by the casting machine capacity.
Pressure die casting is a perfect choice for casting metals with thin walls and lightweight.	Heat treatment is difficult and porosity is common.
The final product is in its “purest form”. That is, the final product is free from oxidation effects with no gas trapped within the metals.	The entire process is only suitable for large-scale metal part production.
Molten metal solidifies in a matter of seconds, or even milliseconds, for faster production.	The process is mainly suitable for high-fluidity metal parts.
Perfect casting method for producing intricate machine parts.	A large capital investment is required for the setup.
Pressure die casting is suitable for large scale production of parts. This is because the pressure increases the rate of flow of molten metal.	Less suited to limited production runs or individual casting, which become proportionately more expensive the fewer of them there are.
It may not be suitable for short-run production. This is due to the high setup costs of the system.	Relatively inflexible when compared to gravity die casting.
Pressure casting is relatively economical compared to other casting techniques. This is for large-scale part production.	It is not suitable for all materials because the limitations of the alloys used must have a low melting point.

7.5.1. Low pressure die casting

Low pressure die casting is a method of production that uses pressure, rather than gravity, to fill molds with molten metal such as aluminum and magnesium. Molten metal is poured into a die casting mold using low pressure. In this process, the holding furnace is located below the cast and the liquid metal is forced upwards through a riser tube and into the cavity. The pressure is applied constantly, sometimes in increasing increments, to fill the mold and hold the metal in place within the die until it solidifies. Due to the continual filling of the die cavity during the shrinking process, it is extremely precise (solidification). In other words, it makes up for the volume drop. Reduced oxide formation, increased porosity, and greater uniformity of the molten metal from top to bottom are other characteristics. Once the cast has solidified, the pressure is released and any residual liquid in the tube or cavity flows back into the holding furnace for “recycling.” When cooled, the cast is simply removed.

The reduction of the feeders from the process assures high casting outcomes. Around 0.7 bar to 1 bar is the normal low pressure die casting pressure range. Low pressure die casting provides excellent internal mechanical properties because the filling is very controlled.

This process was created for the production of axially symmetrical parts such as car wheels. However, by employing sand cores within the die, it is also well suited to producing parts with hollow sections and complex geometries. Today, low pressure die casting is mainly used in the production of aluminum castings and magnesium castings, such as automotive wheel hubs, cylinder blocks, cylinder heads, pistons, missile shells, impellers, wind wheels and other complex shaped castings. Besides, low pressure casting can also be applied to produce small copper alloy castings, such as pipe fittings, bathroom cock faucets, etc. Equipment costs are somewhat high, but labor costs are generally low because the process is now semi or fully automated.

Low pressure die casting materials.

- Dies are usually grey cast iron, although for long production runs, alloy cast iron or tool steel are used.
- Process uses a wide range of aluminum alloys, nearly all of which contain silicon to improve fluidity. Relatively high concentrations of impurities can be tolerated and are even desirable since they help to minimize «sticking» and improve the hot strength of castings.

- Due to non-equilibrium cooling, alloys containing copper “age” after casting, cause a change in dimensions, so if dimensional stability is important a “stabilizing” heat treatment is required, which also relieves stresses.

The process.

In the low pressure die casting process, the mold is generally mounted above the sealed crucible containing molten metal. The melting furnace, which melts the metal alloys and raises them to the casting temperature, is where the process starts. Aluminum, for instance, has a casting temperature range of 710–7200C. The molten metal will then be transferred to a holding furnace beneath the mold, serving as a vessel and keeping the liquid at the casting temperature.

The riser tube is connected to the mold above and extends into the crucible of molten metal below. Compressed dry air exerts a pressure (0.015–0.1MPa) on the liquid surface of molten metal in the crucible, and forces the metal liquid into the cavity from the bottom up through the riser tube. The pressure is relieved after casting has solidified in the die, then the molten metal in the riser tube will recede back into the crucible.

The mold for low pressure casting can be die or sand mold. The filling process is different with gravity die casting such as gravity die casting and sand casting, or high pressure die casting.

In the low pressure die casting process, the molten metal in the bottom of the crucible is forced into the cavity through the riser tube, which thoroughly avoids the slag floating on the surface getting into the cavity. So castings made by this process are of higher purity than by other casting processes.

Molds for low pressure casting have no risers normally, and molten metal in the riser tube will return in the crucible after pressure relief, so the recovery rate of molten metal can be as high as 90%.

The filling process of molten metal is very smooth, and there are no flips, impacts and splashes, which reduces the formation of oxided slag during filling.

The solidification and crystallization of metal are under pressure, which enables this process with good feeding ability and castings with a more compact microstructure.

The mold filling properties of low pressure die casting makes it very suitable for castings with large surfaces and thin wall thickness.

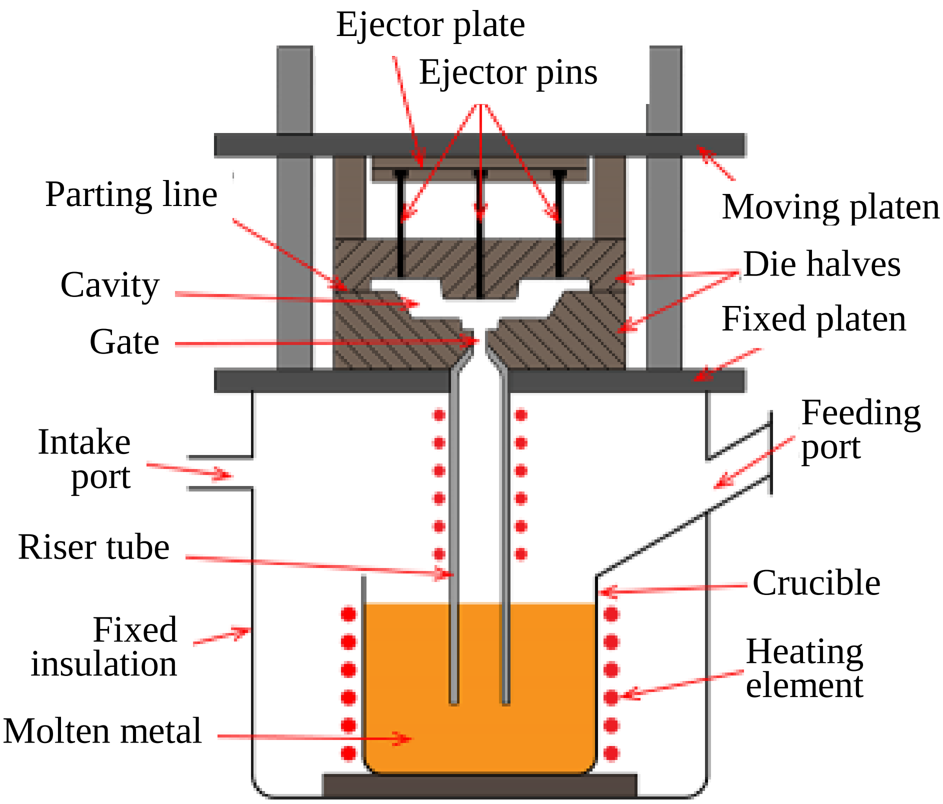


Figure 104 – Low pressure die casting

Preparation before pouring.

- Mold manufacturing and metal smelting. Like other permanent mold casting processes, the mold is made of heat-resistant steel. And the metal smelting process is alike as well.
- Preparation for pouring. Preparation work includes crucible seal examination, riser tube cleaning up, liquid level measurement, airtightness test, etc.
- Making sand cores (if has). Like sand casting but unlike high pressure die casting, low pressure die casting allows inserting sand cores in the die to form the inside structure of a casting. A sand core is fabricated by utilizing manual labor or machine to fill the resin sand into the sand core box. After the sand core is solidified, open the core box and get the sand core.

Steps of a typical low pressure die casting process:

1. Feeding. The molten metal is fed into the crucible through the feeding port. The crucible is equipped with a heating element which can keep the molten metal in a proper casting temperature.

2. Filling. The crucible is sealed again after feeding, then the pressuring gas is filled in and the molten metal is forced in to mold cavity via a riser tube. The pressure of the gas ranges from 15 to 100Kpa.

3. Solidification. Keep the pressure for a certain time until the part left in the mold gets solidified. Then the pressure is relieved, and the molten metal goes back into the crucible from the riser tube.

4. Ejection. At this point, the mold is opened up and the casting is ejected out by ejector pins. The mold is sprayed with lubricant, closed again, and gets ready for the next cycle.

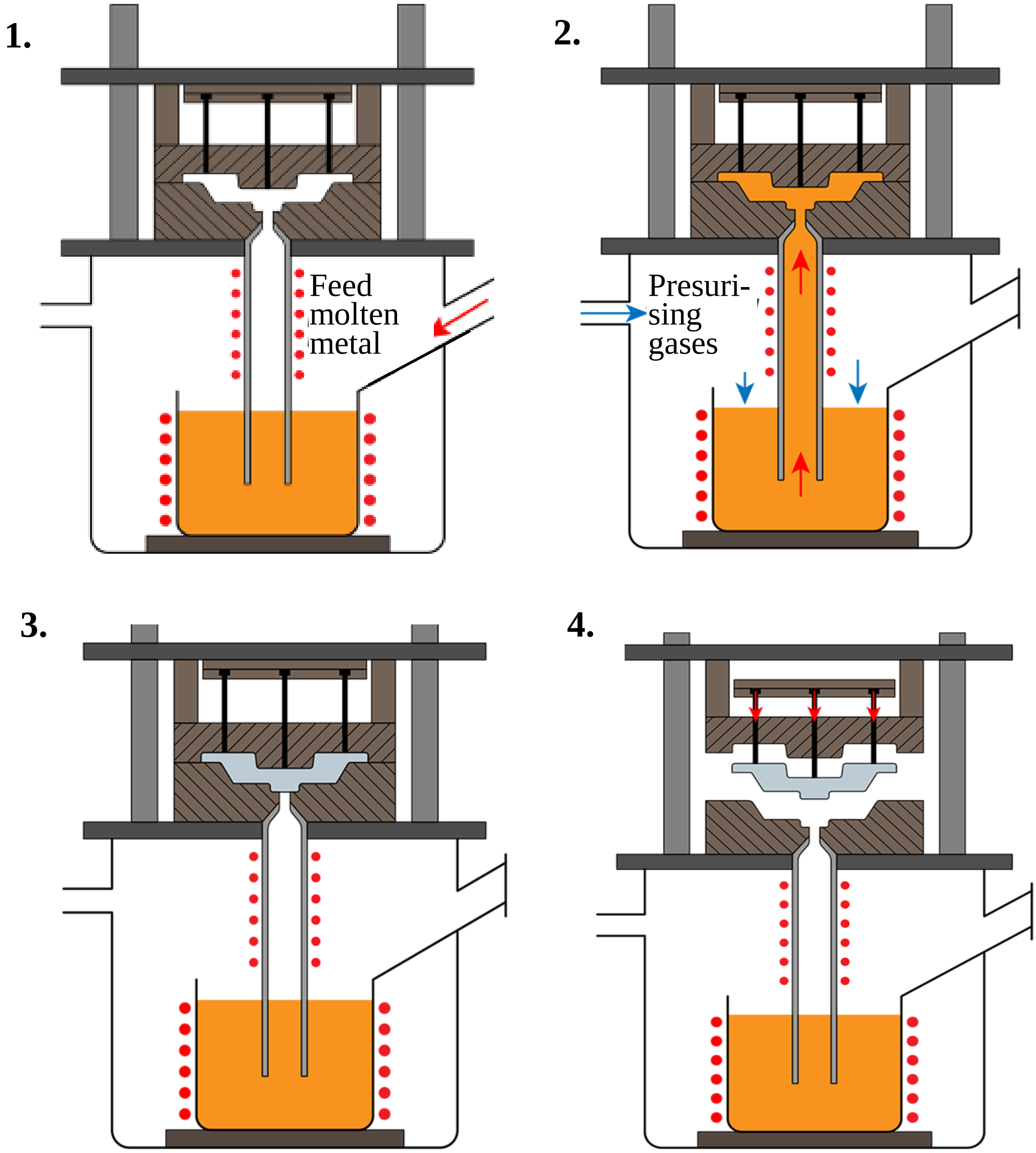


Figure 105 – Steps of the low pressure die casting process

Properties and considerations of manufacturing by low pressure die casting:

- Metal is displaced from the furnace and forced up the riser tube using air at 20–100 kN m-2, or by evacuation of the mold. “Counter-pressure die casting” is a variation in which the mold is filled by having a slight pressure differential produced by controlled leakage from the mold. This slow, smooth and progressive filling of the die cavity reduces metal turbulence and gives temperature gradients that are favourable to feeding, thus producing sound, high-quality castings.
- Riser tubes are usually cast iron and require regular cleaning and renewal of the mold coating to prevent “sticking” and freezing of the molten metal. Refractory riser tubes can be used and, although their initial cost is high, they can last up to a year and only need cleaning once every 2 weeks. This cleaning can be carried out hot, thus reducing the loss in production time.
- Dies are usually cooled between castings, using air or water sprays, and have die-coatings similar to those used for gravity die casting.
- Sand or shell cores can be used in the dies to produce internal cavities, but usually require a refractory coating to prevent metal penetration under pressure.
- Castings have no runners or feeders in the true sense, and hence high yields (80–90%) and low remelt ratios are obtained which, coupled with reduced fettling, gives a high energy saving.
- Casting machines are expensive, come in a wide variety of designs, and take up more floor space than gravity die casting machines.
- Automatic cycling and casting removal are possible, enabling an unskilled operator to cope with more than one machine, thus giving a 10–20% increase in production rate.
- Production rates depend largely on the size and complexity of castings but are similar to gravity die casting and less than high pressure die casting.
- Least expensive casting process for relatively high production runs, although using aluminum alloy dies production runs of 100 castings can be economical with alloys of zinc and aluminum.
- Typical products include aluminum alloy wheels, cylinder blocks, guttering and beer barrels.
- Internal cavities are produced using sand or shell cores and undercuts; holes and recesses are produced using retractable metal cores, although this increases tool and maintenance costs and reduces accuracy.

- Die design is extremely important, and bad die design is the cause of most of the problems in low pressure die casting.
- The high die temperatures necessary to prevent premature chilling result in less massive dies than for high pressure casting. Die walls are often kept at a constant thickness with the outside matching the contours of the inside, and as most dies are cast, this presents little problem. Where higher temperatures are required, to control solidification, the die thickness is increased. Dies should have a slight taper to assist in the removal of castings.
- Venting of the die cavity is extremely important and is achieved by allowing flash to form at the parting lines or including vents in the die itself. If venting occurs at the parting line, care must be taken to prevent die coatings from sealing the gap.
- Overflows and risers are often included to remove inclusions and, in some cases, to hold the casting in the top half of the die, enabling the use of a "catcher arm" for automatic removal of the casting.
- Due to the positive pressure surface finish, surface detail and accuracy are better than gravity die casting, although not as good as high pressure die casting.
- Design capabilities are very similar to gravity die casting, and fins and walls down to approximately 1 mm thick can be produced.

Low pressure die casting has many advantages making it an applicable die casting method in several industries (Table 22). Some of them require an extended explanation. Parts made using the process are highly pure due to the little to no slag responsible for the impurity. The low level of slag is due to the setup of the casting machine. Generally, slags are on the surface of molten metals. However, since the riser tubes go down the holding furnace, the liquid metal forced into the cavity does not contain slags. Hence the highly pure casting. Also, since this is a low pressure process, the chance of slag entering the mold is low.

Moreover, the process does not lead to oxidation of the molten metal due to the stable filling process. Stability reduces or eliminates tumbling, impacting, and splashing of the molten metal during the process. Hence, there is no formation of oxidation slags that can affect the purity of the castings. The low-pressure filling leads to good formability because of the improvement in the fluidity of liquid metal. Therefore, castings made using the process have a clear outline and smooth surface. Generally, the process is ideal for making cast parts with complex geometries because of its high formability.

Table 22 – Advantages and disadvantages of low pressure die casting

Advantages	Disadvantages
The rising speed of metal liquid and crystallization pressure can be adjusted during pouring.	The life of the lift tube is short, and the metal fluid is easy to oxidize and produces slag in the process of heat preservation.
It’s possible to obtain parts with thin walls.	Not proper for every material as of limitation of die materials and alloys used must have a low melting point.
Strength values are good.	
The casting can be heat treated.	The casting size is short.
Obtained good surface finish and casting directly anodized, no other processes are required.	Mainly used for casting some high-quality requirements of aluminum alloy and magnesium alloy castings.
In the low pressure casting process casting with fine walls so lighter in weight.	Feeding thin sections through thick sections is not optional casting weight range of 5–25 kg.
An improved linear tolerance than gravity die casting.	High porosity is regular and heat treatment is not easy.
Low pressure die casting has a fairly high metal part production rate.	The size of castings is limited by machine size.
Improved surface finish thus, reduced finishing operation. The surfaces produced through high pressure die casting are better.	The tooling costs are slightly higher than other casting technologies such as gravity die casting.
The low pressure die casting is the best method for getting precise results, it has drawbacks as well.	It requires complex machinery that may be very expensive.
The production costs are slightly lower than the high pressure die casting.	Casting cycles are slow.
Low pressure die casting is suitable for small production quantities.	Operating and investment cost are high.
Low labor intensity, good labor conditions, simple equipment, easy to realize mechanization and automation.	In low pressure die casting the dies are complicated and costly.

7.5.2. High pressure die casting

The high pressure die casting is one of the most competitive metal processing technologies used in the manufacturing industries today. At times, it may be referred to as pressure die casting. This process primarily entails injecting molten metal, mainly steel, zinc, copper, aluminum, lead, magnesium, etc. into a specially shaped three-dimensional mold. The base metal is heated at extreme temperatures until its state changes from a solid to molten. This molten liquid is then forced into a mold’s cavity and takes its shape once it has cooled down to a certain temperature. Normally, the process takes place under high speed and pressure. In most cases, the die casting temperature is always around 700°C during the casting process.

Due to the superior quality of products obtained through high pressure die casting, the process has found various critical applications in a diverse set of industries. This technology has been adopted by a number of manufacturing companies. This is due to the superior and thin-walled die cast parts.

High pressure die casting can produce various aluminum and magnesium automotive structural components. It makes parts such as engine blocks, gearbox casings, oil sumps, engine mounts and structural parts like cross-car beams.

It is also a popular technique in producing lightweight surgical tools in the medical industry. Moreover, medical devices and high production imaging equipment, infusion pumps, etc., are also manufactured using the high pressure die casting process.

Due to the ability to manufacture complex and intricate designs and automation, this process is highly popular in the aerospace industry. Alloys of aluminum, zinc, and magnesium are used to manufacture engine parts for aerospace applications.

Components of the high pressure die casting process.

The high pressure die casting process uses two different systems: cold and hot chambers. Both systems use nearly the same components with similar functions. Below are a few components of an high pressure die casting machine and their functions.

1. Die cast mold. This is the most important part of the machine made majorly from steel using a process such as CNC machining due to the high precision, accuracy, and tolerance. It has a design that represents the intended product. Die cast molds have two halves

(movable and fixed) attached to the machine. Both halves clamp under force when the operator injects molten metal.

2. Ejector pins. These components function in the ejection of the die-cast after solidification. They are mostly on the movable die half.

3. Piston. The piston produces the pressure that injects molten metal from the blow chamber into the mold. Depending on the type of machine, it can be automated.

4. Heating components. The heating components are the heating element, thermocouple, and blow chamber (location of the molten metal). They function in heating metal while storing and maintaining the temperature of the molten metal. Heating components are absent in the cold chamber system.

5. Riser tube. It acts as a passageway for the molten metal into the die-cast mold.

High pressure die casting materials.

- High pressure die casting is restricted to the lower melting point alloys.
- The bulk of die casting is carried out in zinc-, magnesium- and aluminum-based alloys.
- The most popular zinc-based alloys (known as Mazak) contain 3.8–4.3% aluminum and 0.10–1.25 wt% copper, with tensile strengths of 293–355 MPa, and elongations of 3–4%. Zinc alloys have a higher impact strength than die cast aluminum alloys.
- There are six main aluminium die casting alloys used in the UK. All contain 4–13 wt% silicon, which is used to promote good castability. The most common alloy is LM6-M (BS 1490), which contains 10–13% silicon and has a tensile strength of 280 MPa and an elongation of 2–5%.
- Strict melting practice is required with magnesium-based alloys, which are mainly used on hot-chamber machines. The most popular alloy contains 9–10% aluminum and 1% zinc and achieves a tensile strength of 215 MPa and an elongation of 2%. The degree of retained porosity in the die casting affects the properties of the product.

The process.

High pressure die casting is a process whereby molten metal is fed into a die and solidified to obtain the desired component. The molten metal is forced, under high pressure (generally hydraulic pressure), within the die cavity and a powerful press secures it inside. Once solidification completes, removal of casting takes place by opening the die. Upon ejection of the final product, the die is locked again for the next production cycle. High pressure die casting tooling comprises two steel blocks that form the two ends of a die cavity that forms the desired object.

High pressure dies casting typically works on the 4 processes of mold preparation, injection, ejection/part removal, and post-casting treatment. There may be variations in the method to cater to different product requirements. These enhancements include vacuum die casting, slow-fill die casting, and semisolid metal processing, etc. However, the general procedural steps are as follows:

1. Preparing the mold. The initial step of the process is to prepare the mold. At the start of the production cycle, it is important to clean the die cast mold to remove impurities. During this step, an industrial company applies then a specific lubricant to the inner walls of the mold to control and regulate its temperature while simultaneously forming a film between the molten metal and the mold. This aids in the ease of removal of the casting once it has cooled.

2. Injection. When the mold has been thoroughly prepared, it is time for it to be injected with molten metal. During this step, the entire mold bust is shut tight and sealed. This is very important as the mold will otherwise reject the high pressurized molten metal if not closed properly. However, the method of injection depends on the machine's injection system. There are two systems: a hot chamber and a cold chamber. Below is an explanation of both methods.

The hot chamber injection system is suitable for working with low melting point metals such as zinc, magnesium, and lead. In this method, immerse the injection system into the melting furnace. The molten metal makes its way through the shot plunger into the nozzle and, thereafter, the die. Cold chamber injection involves pouring the molten metal into the blow chamber before injecting it into the mold. In this method, pour the molten metal by hand or through an automated mechanism, into a cold chamber sleeve.

Then, force a hydraulic plunger through the sleeve. This plunger seals the port and forces the metal into the die. Once the completion of the solidification, remove the plunger and then open the die to eject the cavity. This method is suitable for solids with high melting points like aluminum, brass and magnesium. The cold chamber process, furthermore, uses either horizontal injection or vertical injection.

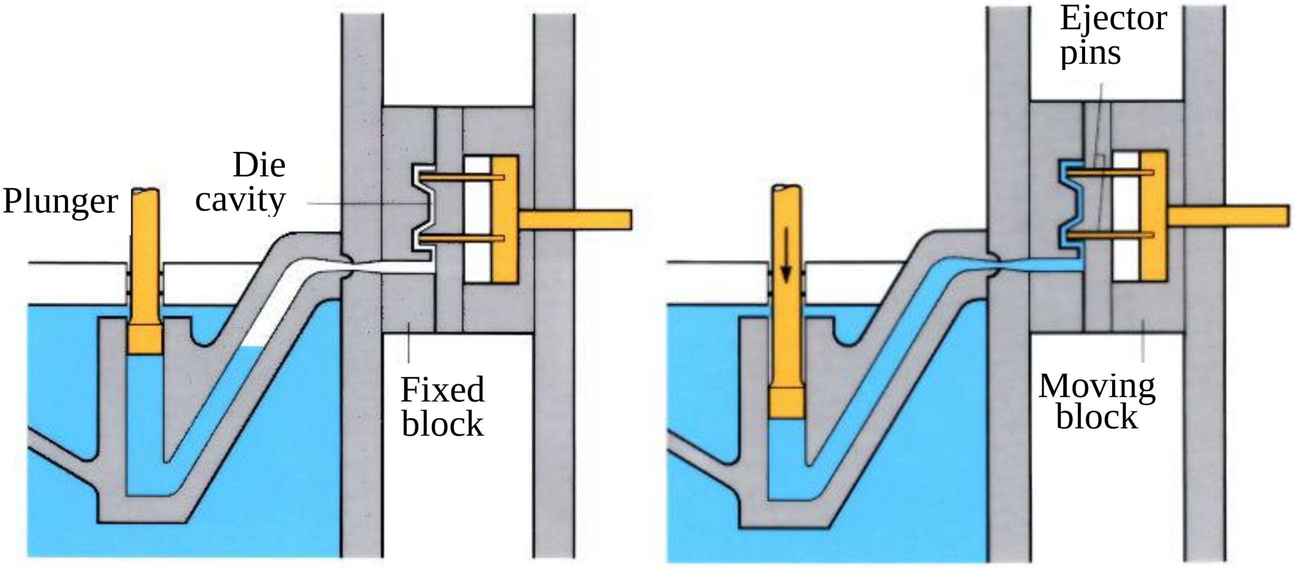


Figure 106 – Hot chamber high pressure die casting

Cold chamber injection involves pouring the molten metal into the blow chamber before injecting it into the mold. In this method, pour the molten metal by hand or through an automated mechanism, into a cold chamber sleeve. Then, force a hydraulic plunger through the sleeve. This plunger seals the port and forces the metal into the die. Once the completion of the solidification, remove the plunger and then open the die to eject the cavity. This method is suitable for solids with high melting points like aluminum, brass and magnesium. The cold chamber process, furthermore, uses either horizontal injection or vertical injection.

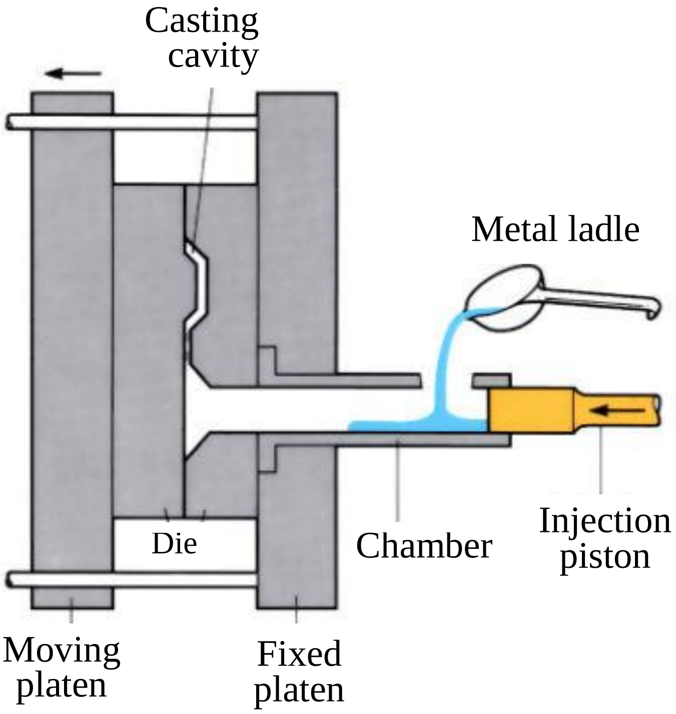


Figure 107 – Cold chamber high pressure die casting

Magnesium can work with both the cold chamber and hot chamber injection processes. Typically, small and intricate parts are produced through hot chamber machines because these machines have size restrictions. Moreover, high pressure zinc die casting parts are typically stronger than aluminum pressure die casting parts. Due to the material's high melting point, it is necessary to melt them outside the system.

Below are a few keynote takeaways about the two systems:

- The hot chamber injection system is quicker due to the cold chamber system's extra step of heating the metal.
- The hot chamber uses less pressure (1,000–5,000 psi), unlike the cold chamber's 1500 to 25000 psi.
- The cold chamber system can use horizontal or vertical injection, while the hot chamber system uses only horizontal injection.
- The hot chamber injection system is suitable for making small, intricate parts due to the machine's size restrictions.

3. Part removal. Upon ensuring that all the molten metal has solidified, the cavity removes from the mold. Ejector pins can release the cavity. The ejector pins are typically featured on the movable end of the mold and push out the solidified casting part from the cavity.

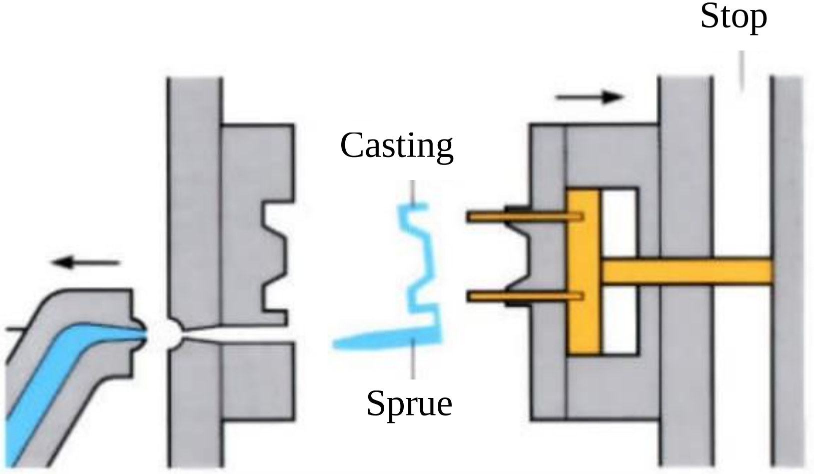


Figure 108 – Part removal

Most molds come with ejector pins as a standard feature to automatically release the cavity. The ejection is only possible if the formed cavity is in a solid state. If the molten metal hasn't solidified, more time needs to elapse until it completely cools down so that the ejector pins can perform their function and aid in the easy ejection of the cavity.

4. Trimming. The final step of high pressure die casting involves the removal of extra material from the product and the mold. A trim die, saw, etc., can help conduct the trimming process. Moreover, metal scraps can be reusable and recyclable in subsequent production cycles.

Sometimes the last step of the high pressure die-casting process is called the ‘shakeout’. The industrial company separates any scrap or waste metal that forms during the process from the freshly manufactured cavity. High pressure die-casting is sometimes known to produce excessive amounts of scrap metal and removing the excess amounts is a common occurrence. No liquified metal is used to create the casting. Typically, some of the molten metal gets stuck inside the mold and in order for it to be reusable, the excess scrap metal must be removed.

Properties and considerations of manufacturing by high pressure die casting:

- High pressure die casting can be divided into “cold-chamber” and “hot-chamber” processes.
- In the cold-chamber process, molten metal is metered into a cold chamber for each machine cycle (or shot).
- The molten metal is then forced by a single plunger through a narrow feeder channel (or gate), into the die cavity itself, by the application of pressures from 7 to 207 MPa.
- The metal solidifies rapidly because the die is water-cooled within a fraction of a second.
- Upon solidification, the dies are opened and the casting is removed using ejector pins.
- Most of the castings will have flashes where the two die halves come together. This is usually removed in a trimming die.
- Hot-chamber die casting is limited to the low melting point of magnesium and zinc alloys, where contamination by iron will be less extensive. A gooseneck shot sleeve is submerged in a heated pot of molten melt. A plunger descends and forces the molten metal into the die. As the piston retracts, the cylinder is filled with metal.
- High pressure die castings can provide thinner cross-sections than any other casting process. Wall thicknesses as thin as 0.38 mm can be achieved in small aluminum components. For large components, wall thicknesses range from 2.7 to 4.5 mm.
- Die size is only limited by the capacity of the machine. Most die castings are limited to about 34 kg (zinc), 30 kg (aluminum) and 20 kg (magnesium).
- Close tolerances are possible. The surface finish depends on the quality of finish on the dies. Parts made from new or repolished dies may have surface finishes of 0.6 μm. This high-quality finish enables other coatings, such as chrome plating and painting, to be applied directly.

Vertical high pressure die casting.

As opposed to low pressure die casting, high pressure die casting has a shorter casting cycle and utilizes the horizontal casting process instead of vertical. The main benefits of high vertical pressure casting are higher parts quality, quicker mold changes, less tonnage required and reduced cycle time.

Vertical high pressure die casting materials.

- Similar to the range of materials that are die cast on conventional high pressure die casting machines.
- Range of materials includes aluminum alloys (castable) zinc alloys magnesium alloys.
- The quality of casting is improved compared with the conventional technique. Vertical casting through large in-gates reduces porosity problems due to air entrapment and prevents spray injection into the die cavity.

The process.

Molten metal is poured slowly into a shot chamber situated at the top of a drive cylinder that's slightly tilted off vertically. The drive cylinder is moved back to vertical and raised to a position at the base of the die. Pressure is applied to the shot piston so that the molten metal is forced vertically into the die cavity, and left to solidify, producing a high-density casting.

Vertical high pressure die casting process step-by-step explained with the following operation (Fig. 109):

1. Drive cylinder mechanism is tilted to a slight angle from the vertical. Molten metal is automatically ladled into the shot chamber.
2. Drive cylinder is adjusted back to the vertical position.
3. Shot chamber is raised to the lower die position.
4. Pressure is applied to inject the molten metal into the die cavity.

Properties and considerations of manufacturing by vertical high pressure die casting:

- Vertical high pressure die casting is an alternative to high pressure die casting in a horizontal mode.
- Molten metal is automatically ladled into the shot chamber, which is attached to a drive cylinder in the vertical plane.
- The drive cylinder is adjusted back to the vertical position and the shot chamber is raised to the lower die position.

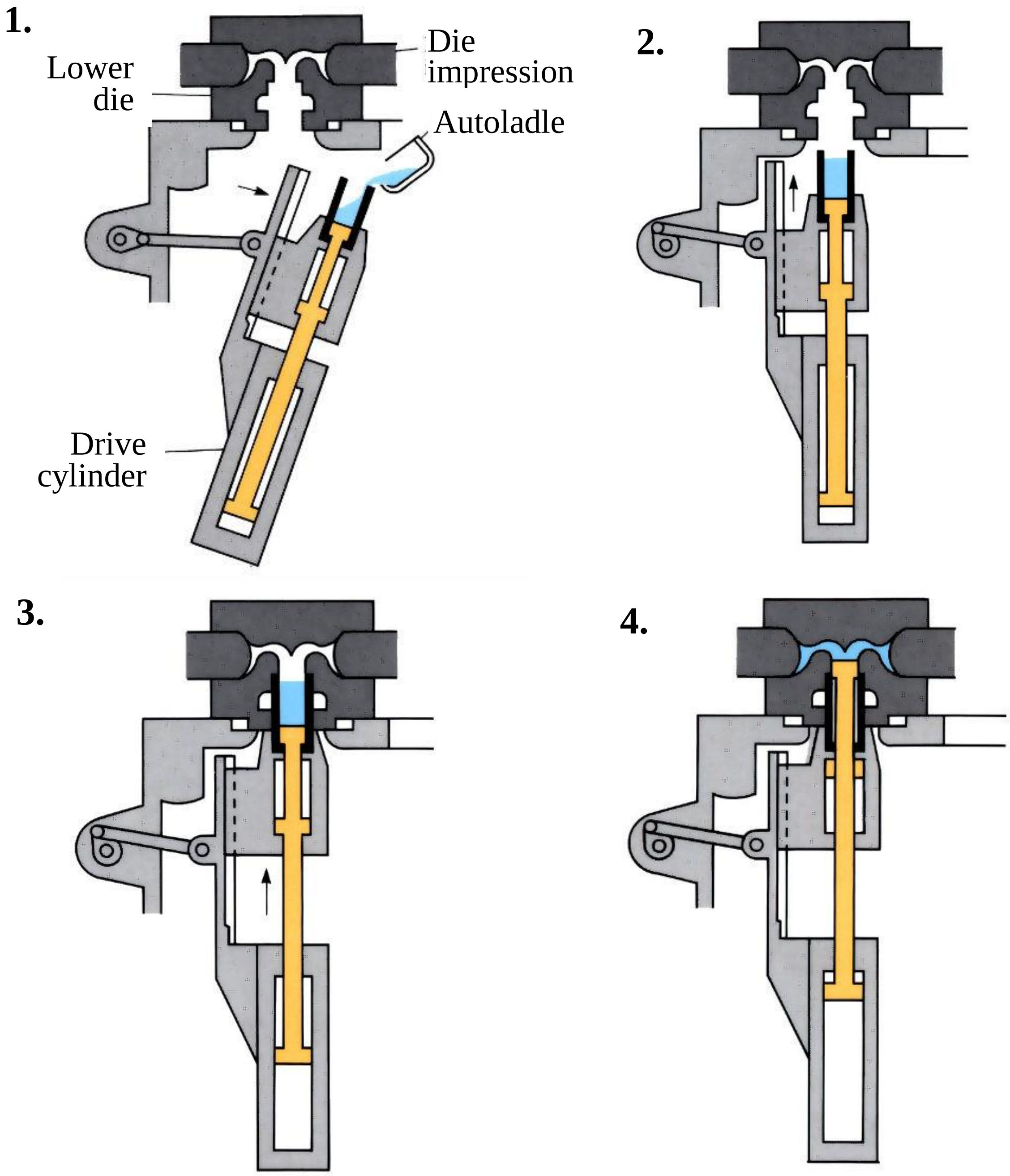


Figure 109 – Steps of vertical high pressure die casting process

- Pressure is increased to force the molten metal into the die cavity in a vertical manner.
- Dies are designed with large in-gates compared with conventional die casting, which has narrow in-gates.
- Used for similar applications to those used for conventional high pressure die casting.
- The major application is for automobile wheel rims in aluminum alloys.

Table 24 summarizes some of the characteristics of high and low pressure die casting, comparing and analyzing the two processes.

Table 23 – Advantages and disadvantages of high pressure die casting

Advantages	Disadvantages
High pressure die casting is suitable for high-volume production of parts.	Limited to high-fluidity metals and alloys.
This process is suitable to achieve parts with very tight tolerances.	Low strength values than other casting methods.
High pressure die casting is the grate for accommodating strict quality requirements for appearance and dimensional accuracy.	The high pressure die casting process may be prone to porosity problems.
The die cast parts have superior finish i.e. they have a smooth surface with fine grain finish.	Only for die-cast parts without under-cuts, as sand cores cannot be used.
High pressure die casting guarantee high metal part production rate.	Components produced by high pressure die casting typically cannot be thoroughly heat treated because of the existence of these pores (carrying trapped gases).
The process is also suitable for parts with very small thickness i.e. about 1 to 2.5 mm.	
This is a precise manufacturing process, thus, little or no additional machining may be required.	Complicated and expensive dies are used in high pressure die casting.
Very light parts may be manufactured through this process.	Limits on how thick the components can be.
It can be used to manufacture complex parts.	This process requires complex machinery.
It guarantees flexible and rapid delivery.	The size of castings is limited by the machine size.
Create sturdy, lightweight components that require less machining than those that are produced.	High pressure die cast weight limited by the locking force of the machine.
By forming delicate and complex shapes all at once, assembly and welding are not necessary.	The tooling costs are higher than the gravity die casting processes.
High pressure die casting provides a wider variety of shapes than other methods for making metal.	It may not be economical for small scale part production process.

Table 24 – Comparison of high and low pressure die casting processes

Low pressure die casting	High pressure die casting
The pressure is low, generally less than 0.08 MPa, and can reach 0.15 MPa in exceptional cases.	The pressure is higher and can reach hundreds of MPa.
The flow speed of the metal liquid is slow, generally 150mm/s in the casting state. And the scouring of the cavity by the metal liquid is small.	The flow speed of the metal liquid is fast, which can reach 60m/s and up to about 120m/s. The scouring of the cavity by the metal liquid is large.
The flow of the metal fluid is smooth.	The flow of the metal fluid is relatively unstable.
The material required for the mold cavity is relatively low. It can be metal, sand, or other materials.	The material required for the mold cavity is high, and it can only use metal dies.
It is possible to produce castings with more complex cavities.	Currently, die casting can only produce castings with relatively simple cavities.
It can produce small and medium-sized castings as well as larger ones.	It is usually only suitable for the production of small and medium-sized castings.
No porosity inside the casting.	There may be porosity inside the casting, and a particular process is required for castings with airtightness requirements.
The castings can be heat treated.	It cannot be fully heat treated and strengthened.
The surface smoothness of the casting is relatively average.	The surface of the casting is relatively smooth.
The casting cycle is relatively long, and the production speed is average.	The casting cycle is relatively short, and the production speed is relatively fast.
The finished product rate is relatively high, about 80–95%.	The finished product rate is relatively low, about 60–90%.
The operating cost is low. And the low pressure casting can be applied to situations where the quantity is not very large.	The equipment running cost is higher. And the high pressure casting (die casting) is more suitable for high-volume order production.

7.5.3. Gravity die casting

Gravity die casting is the oldest, simplest and most traditional form of permanent mold casting. It is a permanent mold casting in which the molten metal flows by the force of gravity without the use of external pressure; tilt pouring is a modified form of gravity die casting features a mechanized system tilts the mold and directs the modern metal into the casting mold. Liquid or molten non-ferrous metal is poured into a permanent mold or steel die. What makes this process unique is that gravity, rather than high pressure, enables the metal to fill the mold.

The metal is transferred manually or automatically into the mold, the casting is allowed to cool and solidified casting will be ejected out of the mold. During the gravity die casting, the rate of the flow of material into the die cavity and the rate of heat transfer during solidification should be controlled.

Gravity die casting refers to the process in which molten metal is injected into the mold under the action of the earth's gravity. It is also called casting. Gravity die casting in a broad sense includes sand casting, metal casting, investment casting, and mud casting. Narrow gravity die casting specifically refers to metal casting.

Gravity die casting can produce complex parts, sometimes with cavity or pin holes thanks to sand cores or metal pins. Also, it is suitable for small to medium size castings having fairly uniform wall thickness, with no or few undercuts. The metal mold enables better dimensional stability and surface finish compared to sand casting. Gravity die casting can cast thinner walls than sand casting, and complex designs can be produced easily. It is typically used to produce larger, thicker or heavier components, including escalator treads, wheels, automobiles struts, internal combustion engines, cylinder blocks, cylinder heads, oil pump housings and copper alloy shaft tiles, bushings, aircraft, automobile, motorcycles, etc.

Gravity die casting materials.

- Mainly aluminum alloys, but also alloys of copper, magnesium and zinc, steels and cast irons. Suitable only for fluid alloys due to the high freezing rates in the die.
- Physical and mechanical properties are better than those of comparable sand castings, and defects associated with sand castings are eliminated.

- Metal enters the die more slowly than pressure die casting, hence there is less turbulence, resulting in sounder, denser castings.
- Grey or ductile cast iron is the most common die material, although dies are also made from low carbon and alloy steels, graphite and copper-2% beryllium.
- Die coatings and chills are used to control the solidification and amount of shrinkage porosity. Die coatings, which are applied by spraying or dipping, should prevent metal from sticking to the die, insulate, lubricate, allow adequate ventilation and be durable.
- With clean, modified and grain-refined aluminum alloys the cast, quench and ageing process (CQA) has been shown to give improvements in both strength and ductility over as-cast or heat treated castings. CQA consists of quenching the component directly from the die, followed by ageing.

The process.

There are seven main stages of gravity die casting:

1. Before the gravity die casting process can begin, the first step is to prepare the die itself. The mold is cleaned using a wire brush or compressed air to remove dust and other particles from it.

2. The die is preheated to a temperature of 200–280 ℃ by gas or oil flame and then sprayed with a refractory coating or lubricant**,** and closed. The coating helps control the temperature of the die during manufacture and it also assists in the removal of the casting.

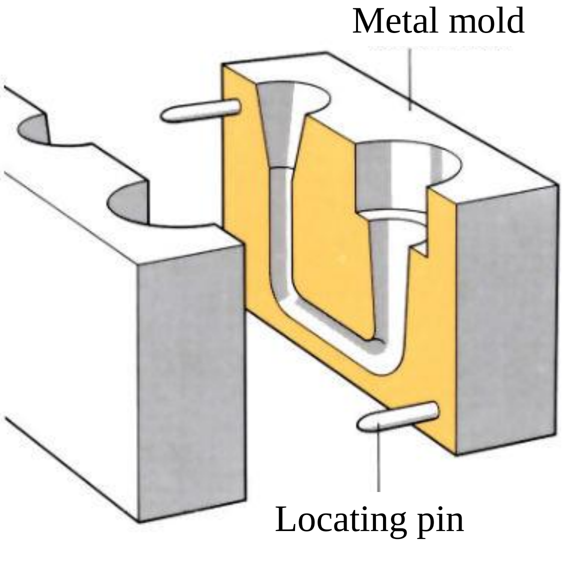


Figure 110 – Die and cores sprayed with mold coat

3. When the mold is closed tightly, the liquid metal of the desired composition is poured into the mold under gravity. Molten metal is poured into the tool by hand using a steel ladle or by machine and allowed to solidify.

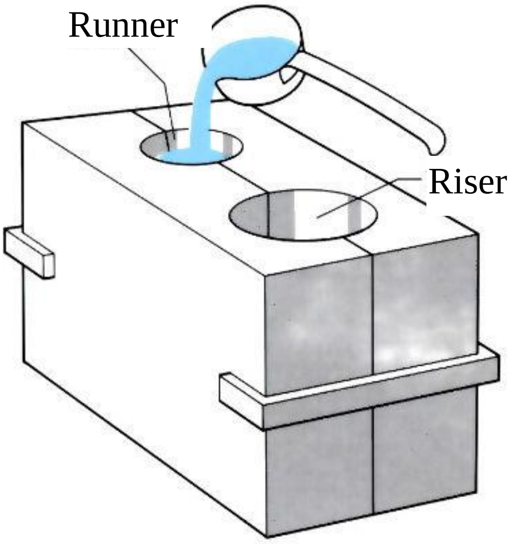


Figure 111 – Die parts assembled, clamped and metal poured into runner

4. The casting part has been held and cooled down.

5. After the part has cooled, the mold is then opened and the cast parts are ,either removed by hand or in some cases ejector pins are used on the mechanized machines.

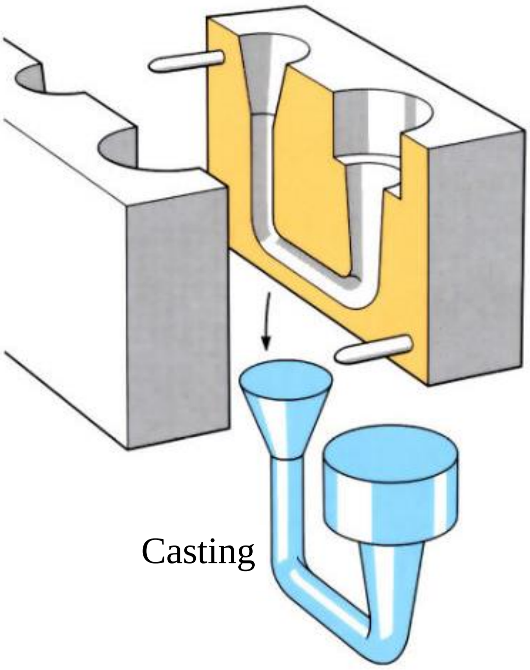


Figure 112 – Die set opened and casting ejected, fettled and heat treated

6. Gating and risering systems, which include the gate, runners, sprues and flash, are separated from the casting.

7. The casting is then processed to remove sharp edges and excess material, then The mold is sprayed with lubricant and cleaned for the next casting process. The mold does not need to be preheated again.

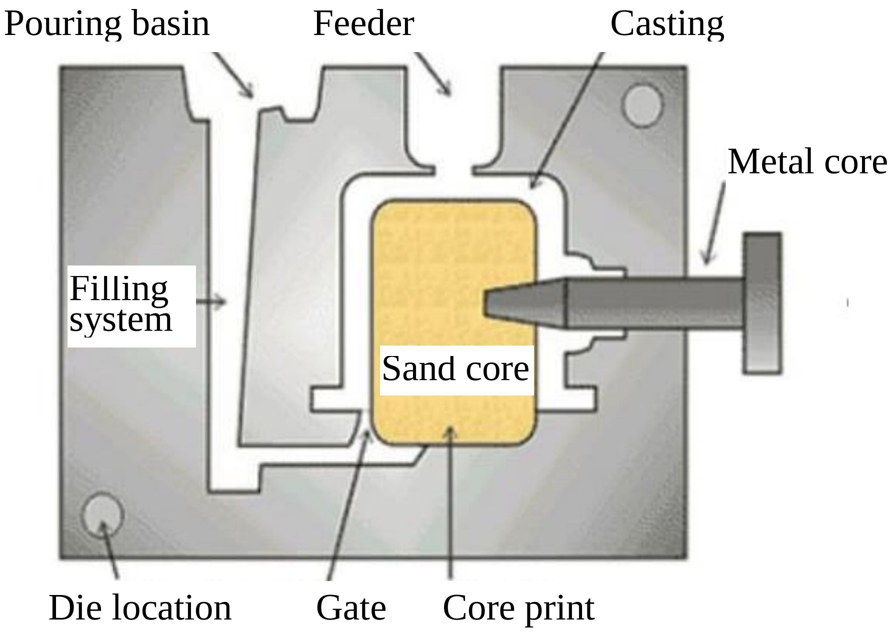


Figure 113 – Gravity die casting

The first step is heating the mold and coating it with a die-release agent. The release agent spray also serves as a cooling agent after the part has been removed from the die. In the second step, the molten metal is poured into channels in the tool to allow the material to fill the entire mold cavity.

The metal is either dosed or hand poured by using ladles. Usually, there is a mold “down sprue” that allows the alloy to enter the mold cavity from the lower part of the die. This reduces the formation of turbulence and subsequent porosity and inclusions in the finished part. After the part has cooled, the die is opened by either using a mechanical tool or manually.

Additionally, this process has a higher casting rate than aluminum sand casting, however, the metal molds are a higher cost than sand. The gravity die casting process includes the possibility of low gas porosity, and fine grain sizes can be achieved. Design of the gating system (which can be bottom, side or top) is important since it affects metal turbulence and yield.

Compared to sand casting, this process requires less finishing and fettling and gravity die casting tends to produce higher quality products with higher physical and mechanical properties.

Properties and considerations of manufacturing by gravity die casting:

- Gravity die casting is a type of permanent mold casting, therefore many of the basic principles of a permanent mold process will apply.
- In this process the molten metal flows by the force of gravity without the use of external pressure.
- Two metal mold halves are joined together to form the mold cavity.
- Molten metal is poured down into the pouring basin (using gravity) and travels through the gating system into the mold cavity where it solidifies into the cast component.
- Large molds, used mainly for aluminum and magnesium alloys, are usually assembled and stripped by hand. Small molds, particularly for ferrous castings, are automatically stripped. Mold design and clamping pressure are such that there is little or no thermal distortion.
- Large castings are often hand-poured, but there is a tendency with smaller ferrous castings to use fully automated pouring, where both ladle and molds are tilted and controlled throughout pouring, to minimize turbulence.
- Gravity die casting has a mold that can be used many times and repeatedly.
- Each casting of liquid metal gives a casting that has a long life and high production efficiency.
- Metal-type castings not only have good dimensional accuracy and smooth surface but also have the same casting strength as sand molds and are less likely to be damaged.
- For medium or small volume production, gravity die casting is cheaper than other methods. Suitable for a minimum of 500 castings, although large complex castings may be viable for much smaller numbers. However, for large volume production of intricate parts, aluminum die casting is a good alternative to gravity die casting. Another good alternative is sand casting. But sand casting parts require more post-production machining, and so it is costlier in some cases.
- Yield depends on design of the gating system, but is usually 40–60%.
- Energy requirement is about half that of conventional sand casting. Steel castings are 15–20% cheaper than comparable sand castings.
- The process can be automated and also can produce semi-gravity die-castings employing sand or plaster of Paris cores for the production of interior details.

Table 25 – Advantages and disadvantages of gravity die casting

Advantages	Disadvantages
Good reusability, “one die, use many castings”, saving molding materials and modeling hours.	It is complicated to manufacture complex parts using this method.
The cooling ability of the metal type to the casting is strong, which makes the casting dense and has high mechanical properties.	Because the heat-resistant alloy and its hollow cavity are more expensive to process, the molds are expensive to manufacture**.**
It offers good dimensional accuracy and a smoother cast surface finish than sand casting.	Ferrous alloy castings, it is also limited to medium and small castings with simple shapes.
It improved mechanical properties compared to sand casting.	Not suitable for casting made of metals with a high melting point.
Provides better surface quality of products due to rapid solidification.	For low-volume production, the cost to be allocated to each product is obvious.
Lower tooling costs than other processes.	The cycle time is long, and the process requirements are strict, so it is not suitable for the production of single-piece small-batch castings.
Thinner walls can be cast compared to sand casting.	
Large range of alloy choices.	
Highly repeatable process.	Mainly applicable to the mass production of non-ferrous alloy castings.
Steel pins and inserts can be cast into the part.	
Faster production times compared to other processes.	The manufacturing cost of metal types are high.
Reverse draft internal pockets and forms can be cast in using preformed sand core inserts.	At times, the ejection mechanism to remove the casting from the mold forms a dent in the product.
Metal-type casting without sand or with less sand improves labor conditions.	Manual gravity die casting takes more time than other casting processes.
Gravity die casting provides faster production times compared to the other processes.	Automatic gravity die casting parts are less precise than manual gravity die casting parts.

7.6. Centrifugal casting

Centrifugal casting refers to several casting techniques that use rotation's centrifugal forces to distribute the molten metal to the outer regions of a circular mold cavity, where it solidifies to create a part.

This technology emerged in the early 1800s and can be a cost-effective method of creating complicated near-net shape parts compared to other manufacturing processes like forgings and fabrications.

Centrifugal casting, sometimes called rotocasting, is a metal casting process that uses centrifugal force to form cylindrical parts. This differs from most metal casting processes, which use gravity or pressure to fill the mold. In centrifugal casting, a permanent mold made from steel, cast iron, or graphite is typically used. However, the use of expendable sand molds is also possible.

Centrifugal casting is the most economical method of producing a superior-quality tubular or cylindrical castings concerning the casting yield, cleaning cost, and mold cost.

There are three types of this process: true centrifugal casting, semi-centrifugal casting and centrifuge casting. The principle is the same for all three types: the mold is rotated around an axis and molten metal is poured into the pouring cup, from where it is forced into the mold by centrifugal force.

The essential feature of centrifugal casting is the introduction of molten metal into a pre-heated mold which is kept rotating even during the solidification of the casting. The centrifugal force produced by rotation is large when compared with the normal hydrostatic forces, and is utilized in two ways:

- uniform distribution of the molten metal over the inner surfaces of a mold, forcing them to deposit on the mold walls;
- development of high pressure in the casting during freezing – this assists the metal feeding and accelerates the separation of non-metallic inclusions and precipitated gases. These have a density lower than the cast metal and are therefore extruded from it onto the inner surface of the casting.

The mold material is determined partly by the shape and partly by the number of castings required. For simple shapes, metal molds are usually preferred on economic grounds, as well as for their effect in inducing directional freezing. For more complex shapes or the parts required in small quantities, refractory molds are normally used. These may be based on the high-strength conventional molding mixtures or the investment molds. A steel mold case with inner refractory linings of different thicknesses is usual. Graphite molds are also used. Graphite has excellent thermal conductivity and resistance to thermal shock, and it is easily machined. Besides, graphite does not react with most of the molten metals.

Molds are usually cooled by a water spray. The machine must be equipped to pour the molten metal into the rotating mold. Special tools, either mechanical, hydraulic or pneumatic, are used to remove the casting from the mold after solidification.

Vacuum centrifugal casting is used when part detail and control of exposure to the atmosphere is critical since some alloys, including nickel-cobalt super alloys, are reactive to oxygen. In addition to the advantages of casting in a vacuum, the inherent high metal integrity delivered by centrifugal casting is realized, including directional solidification, absence of porosity, and net-shaping. Vacuum centrifugal casting provides products with very high reliability, often used in aerospace and military applications.

Centrifugal casting has a wide range of applications in the industry and is used to make parts such as bushings, engine cylinder liners, rings, brake drums, water supply lines, sewage pipes, street lamp posts and gas pipes. They are used in high-reliability applications such as jet engine compressor cases, hydro wear rings, and numerous military items because they produce components with excellent material soundness due to very high centrifugal forces.

The process is also further divided into principles: vertical and horizontal, depending on their construction.

Vertical centrifugal casting.

Some manufacturers produce centrifugal components, including some with OD (outside diameter) shaping, in dies rotating about the vertical axis. These vertical castings may achieve that OD shaping by inserting graphite, sand, or ceramic molds into the die – resulting in significantly reduced post-processing, like machining or fabrication.

Details on the outside surface of the casting may be modified from the true circular shape by the introduction of flanges or bosses to the inner diameter of the mold. The finished part need not be symmetrical but, in some cases, the casting mold does to maintain balance while spinning.

The inside diameter and therefore the wall thickness of the casting are functions of the amount of metal poured into the rotating mold and the quantity machined away. When casting vertically, the height of the casting will typically be less than twice the width.

Horizontal centrifugal casting.

Some centrifugal casters produce only horizontal castings where the die rotates about the horizontal axis. This is a cost-effective method for producing high-quality tubular components.

This process is especially suited for long cylindrical parts where the casting length is significantly longer than its outside diameter. This includes straight tube sections, long cylinders with end flanges, or short parts such as rings or flanges where multiple parts can be machined effectively from a straight cylinder.

A long steel casting mold is spun at high speed while positioned horizontally. The rotational speed of the mold is high, to offset gravitational forces. Covers are fixed at each end of the mold to contain the molten metal and a pour funnel is used to deliver a specified weight of metal inside the mold. Just as in vertical casting, the interior dimension of the mold determines the OD size of the part, while the amount of metal poured into the mold determines the ID (inside diameter) size.

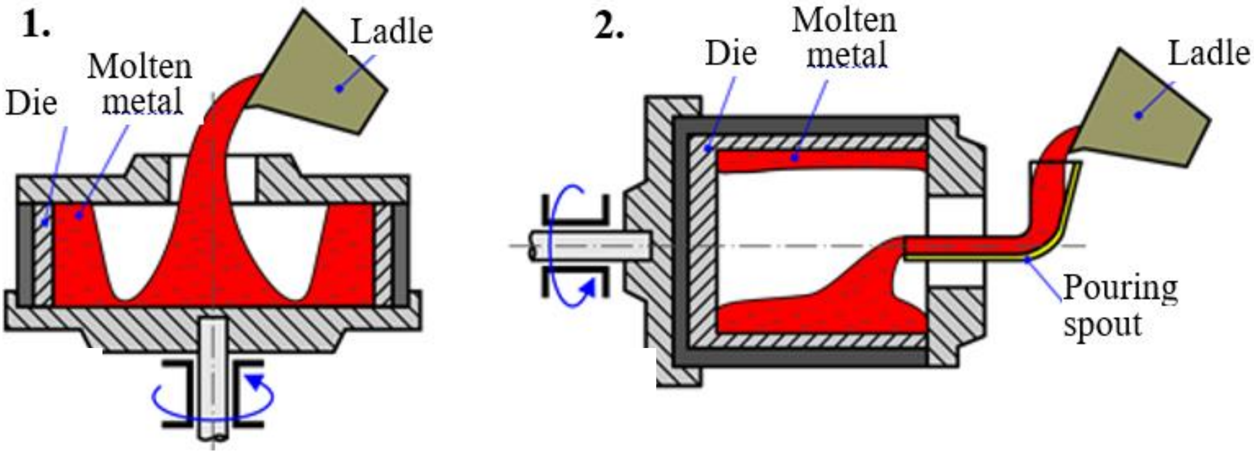


Figure 114 – Principles of centrifugal casting:
vertical (1) and horizontal (2)

Centrifugal casting components.

The following parts of the centrifugal casting process are:

1. Ladle. The ladle is a component that is used to put the molten metal into the pouring basin. It is made up of steel, or stainless steel.

2. Pouring basin. The pouring basins are used to pour the molten metal into the mold. The molten metals are poured into the basin using a ladle.

3. Core. A core is a preformed, bonded, sand insert placed into the metal mold to shape the interior of a casting. The cores are used to create hollow sections or cavities in a casting.

4. Rollers. The machine has four rollers and all of them are being used. Two rollers are at the bottom and two are at the top of the system. Two rollers that are in the bottom are connected to the motor and rotate with it. And the other two rollers which are in the top, provide support to the metal mold while rotating.

5. Motor. The motor is used to provide rotary motion to the rollers, which in turn rotates the mold.

6. Metal mold. The molten material is placed with the help of a poring basin. With the help of a motor and roller, it is being rotated and it rotates continuously at high speed about its axis when an operation is to perform. The molten metals are poured into the mold using an inset basin.

The process.

Like any other metal casting process, all three of the centrifugal casting processes follow the main casting steps of pattern-making, mold-making, melting, molten metal pouring and post-processing. The casting process is usually performed on a horizontal centrifugal casting machine (vertical machines are also available) and includes the following steps:

- Mold preparation. The walls of a cylindrical mold are first coated with a refractory ceramic coating, which involves a few steps (application, rotation, drying, and baking). Once prepared and secured, the mold is rotated about its axis at high speeds (300–3000 RPM), typically around 1000 RPM.
- Pouring. Molten metal is poured directly into the rotating mold, without the use of runners or a gating system. The centrifugal force drives the material toward the mold walls as the mold fills.
- Cooling. With all of the molten metal in the mold, the mold remains spinning as the metal cools. Cooling begins quickly at the mold walls and proceeds inwards.
- Casting removal. After the casting has cooled and solidified, the rotation is stopped and the casting can be removed.
- Finishing. While the centrifugal force drives the dense metal to the mold walls, any less dense impurities or bubbles flow to the inner surface of the casting.

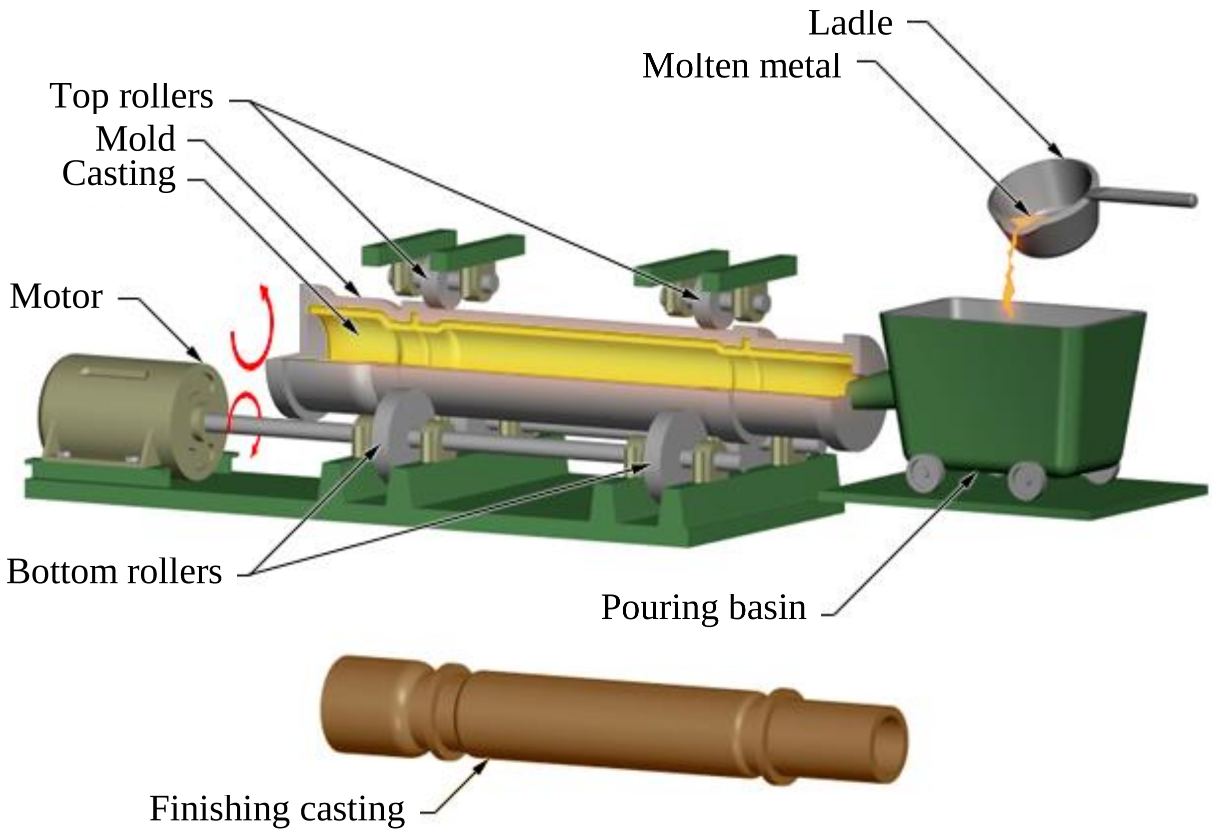


Figure 115 – Centrifugal casting

As a result, secondary processes such as machining, grinding, or sandblasting, are required to clean and smooth the inner diameter of the part.

Centrifugal casting is used to produce axisymmetric parts, such as cylinders or disks, which are typically hollow. Due to the high centrifugal forces, these parts have a very fine grain on the outer surface and possess mechanical properties approximately 30% greater than parts formed with static casting methods. These parts may be cast from ferrous metals such as low alloy steel, stainless steel, and iron, or non-ferrous alloys such as aluminum, bronze, copper, magnesium, and nickel. Centrifugal casting is performed in a wide variety of industries, including aerospace, industrial, marine, and power transmission. Typical parts include bearings, bushings, coils, cylinder liners, nozzles, pipes/tubes, pressure vessels, pulleys, rings, and wheels.

Centrifugal casting is a process that delivers components of high material soundness. It is the technology of choice for applications like jet engine compressor cases, hydro wear rings, many military products, and other high-reliability applications. It has also proven to be a cost-effective means of providing complex shapes with reduced machining requirements and lower manufacturing costs as compared to forgings and fabrications.

Properties and considerations of manufacturing by centrifugal casting:

- Centrifugal casting is both gravity- and pressure-independent since it creates its force feed using a temporary sand mold held in a spinning chamber at up to 900 N. Lead time, varies with the application.
- Centrifugal force tends the poured metal and the freezing metal to fly outward, away from the axis of rotation, and this tendency creates high pressure on the metal or casting while the lighter slag, oxides, and other inclusions being lighter, get pushed towards the center.
- Casting cools and solidifies from outside towards the axis of rotation, so it results in good directional solidification.
- Properties and quality of the finished part depend upon the distance of the mold from the rotational axis.
- Causes unidirectional cooling of the molten material, so defects like shrinkage do not exist in a finished part.
- Fine grain structure and control over the mechanical properties make this process suitable for high-quality production.
- Centrifugal force is utilized to distribute liquid metal over the outer surface of the mold.
- Castings can be made in almost any length, thickness and diameter.
- Different wall thicknesses can be produced from the same size mold.
- Eliminates the need for cores.
- Draft angle of approximately 1° is required.
- Resistant to atmospheric corrosion, a typical situation with pipes.
- Mechanical properties of centrifugal castings are excellent.
- Only cylindrical shapes can be produced with this process.
- Size limits are up to 3 m (10 feet) in diameter and 15 m (50 feet) in length.
- Wall thickness range from 2.5 mm to 125 mm (0.1–5.0 in).
- Tolerance limit: the OD can be 2.5 mm (0.1 in), the ID can be 3.8 mm (0.15 in).
- Surface finish ranges from 2.5 mm to 12.5 mm (0.1–0.5 in) rms.
- Machining allowances of up to 6mm should be added mostly for the inner surface in true centrifugal casting.
- Moderate production rate, which depends upon the size of the product. Moderate labor, equipment and tooling costs.
- Finishing of the product is normally required (machining to net shape, deburring, etc).

Table 26 – Advantages and disadvantages of centrifugal casting

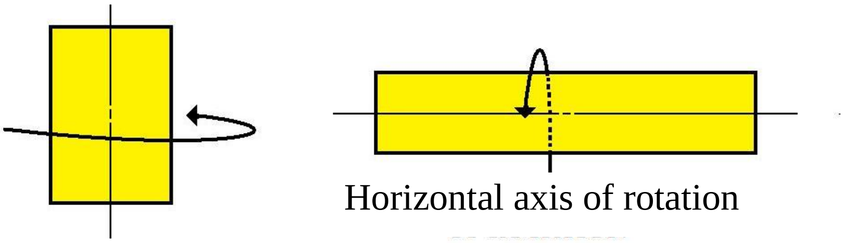
Advantages	Disadvantages
This process can produce complex geometrical components at a low cost.	It is good for manufacturing only cylindrical structures. When casting other than cylindrical structures there is a loss in structural and purity benefits.
Products can be designed to have a variety of features by altering the inner and outer layers.	
Parts produced using centrifugal casting have a fine-grained microstructure that can easily resist atmospheric corrosion.	The centrifugal casting cast only symmetrical shapes. Limited design can be cast from this process.
Suitable for a wide range of materials.	Limits on product geometry.
	The size of components is limited.
Residual stress after casting is minimized because there is nothing to disturb solidification shrinkage.	Post processing and finishing are required.
Directional solidification, starting from the outer face in contact with the metal mold, realizes a sound-cast metal quality, free of cavities and inclusions.	More machining is required when casting components other than cylindrical and there is more chance of making the process more costly.
The centrifugal force produces a hollow cylindrical product with no wall thickness variations.	In centrifugal casting, the temperature distribution and solidification time is difficult to determine.
Suitable for both low-volume and high-volume production.	
The outer and inner layers are metallurgically bonded into a completely integrated structure.	More maintenance and skilled operator is required.
A wide choice of outer and inner layer combinations is available through perfectly controlling the molten metal temperature and optimally configuring casting conditions.	When casting the small diameter pipe and if some impurities come in the internal diameter from this process it is very hard to remove which is a major disadvantage of centrifugal casting.
Inclusions and impurities of the casting process are lighter.	Ineffective for shapes that don’t have a circular profile.

7.6.1. True centrifugal casting

The manufacturing process of centrifugal casting is a metal casting technique, that uses the forces generated by centripetal acceleration to distribute the molten material in the mold. Centrifugal casting has many applications in the manufacturing industry today. The process has several very specific advantages. Cast parts manufactured in theindustry include various pipes and tubes, such as sewage pipes, gas pipes, and water supply lines, also bushings, rings, the liner for engine cylinders, brake drums, and street lamp posts. The molds used in true centrifugal casting manufacture are round and are typically made of iron, steel, or graphite. Some sort of refractory lining or sand may be used for the inner surface of the mold.

The process.

It is necessary when manufacturing a cast part by the true centrifugal metal casting process, using some mechanical means, to rotate the mold. When this process is used for industrial manufacture, this is accomplished by the use of rollers. The mold is rotated about its axis at a predetermined speed. Molds for smaller parts may be rotated about a vertical axis. However, most times in true centrifugal casting manufacture the mold will be rotated about a horizontal axis. The effects of gravity on the material during the metal casting process make it particularly necessary to cast longer parts with forces generated from horizontal rather than vertical rotation.



Horizontal axis of rotation

Vertical axis of rotation

Figure 116 – Vertical vs horizontal rotation

The true centrifugal casting process consists of the following steps:

- Molten metal is poured straight into the mold without any gating mechanism.
- Once within the hollow, the centrifugal forces of the spinning mold propel the molten material to the cavity’s exterior wall.
- After the necessary amount of molten metal has been poured, the mold is rotated until the part is hardened.

- After the casting has been set, the mold is removed, opened, and the part removed for post-processing.

The molten material for the cast part is introduced to the mold from an external source, usually using some spout. The liquid metal flows down into the mold. Once inside the cavity, the centripetal forces from the spinning mold force the molten material to the outer wall. Molten material for the casting may be poured into a spinning mold or the rotation of the mold may begin after pouring has occurred.

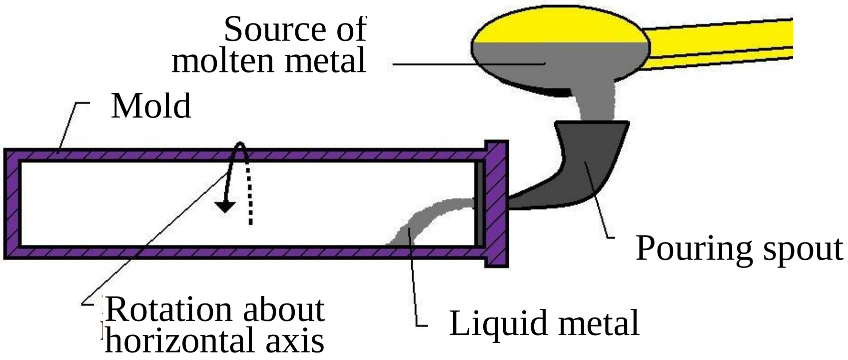


Figure 117 – Pouring in true centrifugal casting

The metal casting will harden as the mold continues to rotate.

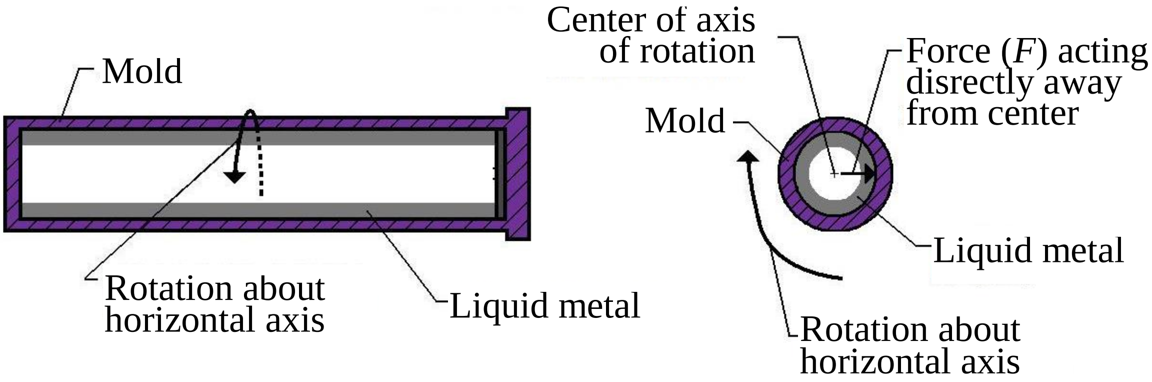


Figure 118 – Solidification in true centrifugal casting

It can be seen that this casting process is very well suited for the manufacture of hollow cylindrical tubes. The forces used in this technique guarantee good adhesion of the casting material to the surface of the mold. The thickness of the cast part can be determined by the amount of material poured. The outer surface does not need to be round. Polygonal geometries such as squares and other shapes can be cast.

However, due to the nature of the process, the inner surface of a part manufactured by true centrifugal casting must always be round.

During the pouring and solidification phase of true centrifugal casting, the forces at work play a large role in the properties of castings manufactured by this process. It can be seen that forces will be greater in the regions further away from the center of the axis of rotation. The greater forces towards the rim will cause the regions of the metal casting nearer the outer surface to have a higher density than the sections located nearer the inner surface.

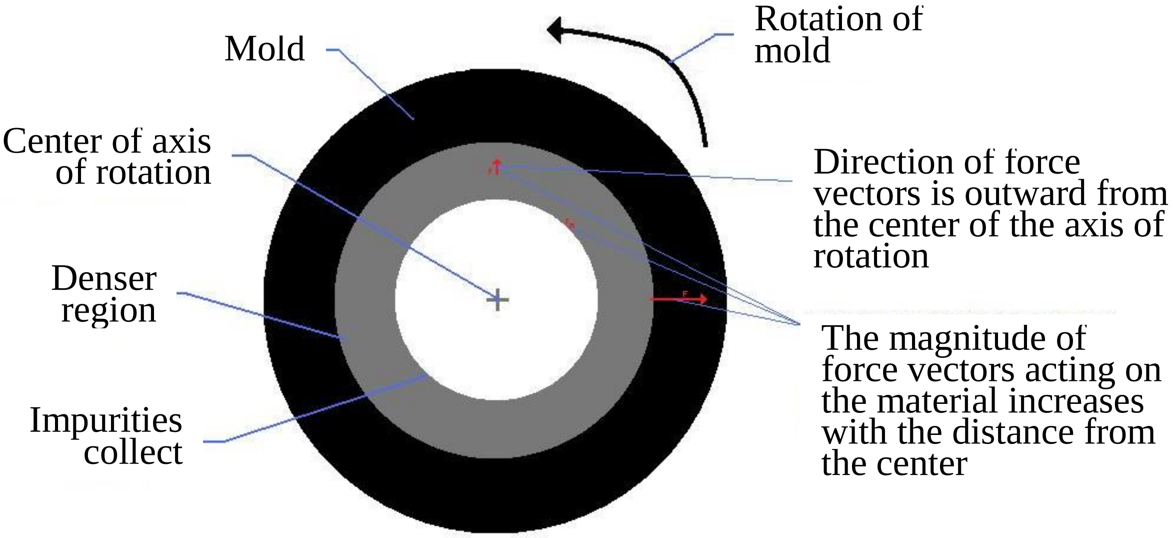


Figure 119 – Force vector diagram for true centrifugal casting (cross-section)

Most impurities within the material have a lower density than the metal itself, this causes them to collect in the inner regions of the metal casting, closer to the center of the axis of rotation. These impurities can be removed during the casting operation or they can be machined off later.

Properties and considerations of manufacturing by true centrifugal casting:

- True centrifugal casting is a great manufacturing process for producing hollow cylindrical parts.
- Since large forces press the molten material for the cast part against the mold wall during the manufacturing operation, good surface finish and detail are characteristic of true centrifugal casting.
- Rotational rate of the mold during the manufacture of the casting must be calculated carefully based on the mold dimensions and the metal being cast.

- If the rotational rate of the mold is too slow, the molten material for the casting will not stay adhered to the surface of the cavity. From the top half of the rotation, it will rain metal within the casting cavity as the mold spins.
- The metal casting's wall thickness is controlled by the amount of material added during the pouring phase.
- This manufacturing operation produces metal cast parts without the need for sprues, risers, or other gating system elements, making this a very efficient industrial metal casting process, in terms of material usage.
- Quality castings with good dimensional accuracy can be produced with this process.
- Material of high density and with few impurities is produced in the outer regions of cylindrical parts manufactured by true centrifugal casting.
- Impurities, such as metal inclusions and trapped air, collect in the lower-density inner regions of cylindrical parts cast by this process.
- These inner regions can be machined out of the cast part leaving only the dense, more pure material.
- Shrinkage is not a problem when manufacturing by true centrifugal casting, since material from the inner sections will constantly be forced to instantly fill any vacancies that may occur in outer sections during solidification.
- This method can produce very large metal castings. Cylindrical pipes 10 feet in diameter and 50 feet long have been manufactured using this technique.
- True centrifugal castings may be produced in metal or sand-lined molds. It largely depends on the quantity to be produced.
- A water jacket is provided around the mold for cooling it.
- With the employment of a sand lining in the mold, it is possible to manufacture castings from high melting point materials such as iron and steel.
- This is a large batch production operation.
- True centrifugal casting is a manufacturing process that is capable of very high rates of productivity.
- The casting machine is mounted on wheels with the pouring ladle which has a long spout extending till the other end of the pipe to be made.

True centrifugal casting has a wide range of applications in the industry and is used to make parts such as bearings for electric motors and industrial machinery; cast iron pipes, alloy steel pipes and tubings; rings, short or long pots and other annular components.

Table 27 – Advantages and disadvantages of true centrifugal casting

Advantages	Disadvantages
Dense and fine-grained metal castings are produced by this technique.	These are limited up to/for certain shapes (axisymmetric).
No gating system is required.	This method is not suitable for all alloys.
No risers are used in the true centrifugal casting process.	In some operations, mold rotation commences after pouring rather than before.
This process does not require any core.	The casting inner surface diameter will not be accurate.
Castings have a high density, high mechanical strength, an excellent outer surface finish.	The true centrifugal casting process is limited to cylindrical parts.
Impurities and inclusions can be easily removed.	Secondary machining is often required for inner diameter.
Proper directional solidification is obtained except for castings with greater wall thickness.	The quality of the true centrifugal castings and cost savings in post-processing including machining must be balanced with the tooling cost.
Casting cools and solidifies from the outside therefore it results in good directional solidification.	
Formation of hollow interiors without cores.	True centrifugal castings require very high investments.
Can form very large parts with high accuracy.	Only for large-scale production is profitable.
Relatively higher impurities within the liquid such as sand, slag, oxides and gas float more quickly toward the center of rotation.	True centrifugal casting needs to use a complex centrifugal casting machine, generally its price is very expensive.
Low equipment and labor costs.	Long lead time possible.
Generates minimum scrap.	Many other casting processes are better than this process because it is a traditional technique.
This process can be used for mass production.	
This process can be easily machined to produce a clean metal casting.	Skilled workers are required for operation and maintenance.

7.6.2. Semi-centrifugal casting

Semi-centrifugal casting manufacture is a variation of true centrifugal casting. The main difference is that in semi-centrifugal casting the mold is filled completely with molten metal, which is supplied to the casting through a central sprue.

Castings manufactured by this process will possess rotational symmetry. Much of the details of the manufacturing process of semi-centrifugal casting are the same as those of true centrifugal casting. For a better understanding of this process and centrifugal casting manufacture in general see true centrifugal casting. Parts manufactured in industry using this metal casting process include such things as pulleys, and wheels for tracked vehicles. This process is used for making railroad car wheels, nozzles and similar parts.

The process.

In semi-centrifugal casting manufacture a permanent mold may be employed. However, often industrial manufacturing processes will utilize an expendable sand mold. This enables the casting of parts from high-temperature materials.

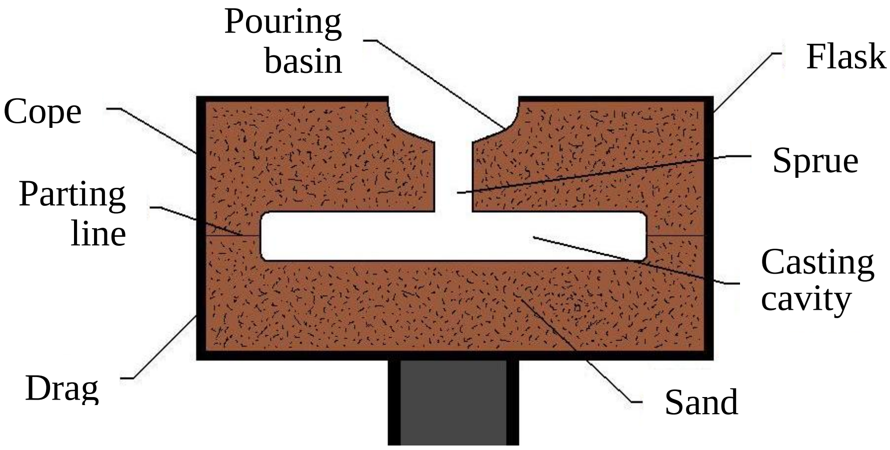


Figure 120 – Semi-centrifugal casting expendable sand mold used to manufacture a wheel

The molten material for the metal casting is poured into a pouring basin and is distributed through a central sprue to the areas of the mold. The forces generated by the rotation of the mold ensure the distribution of molten material to all regions of the casting.

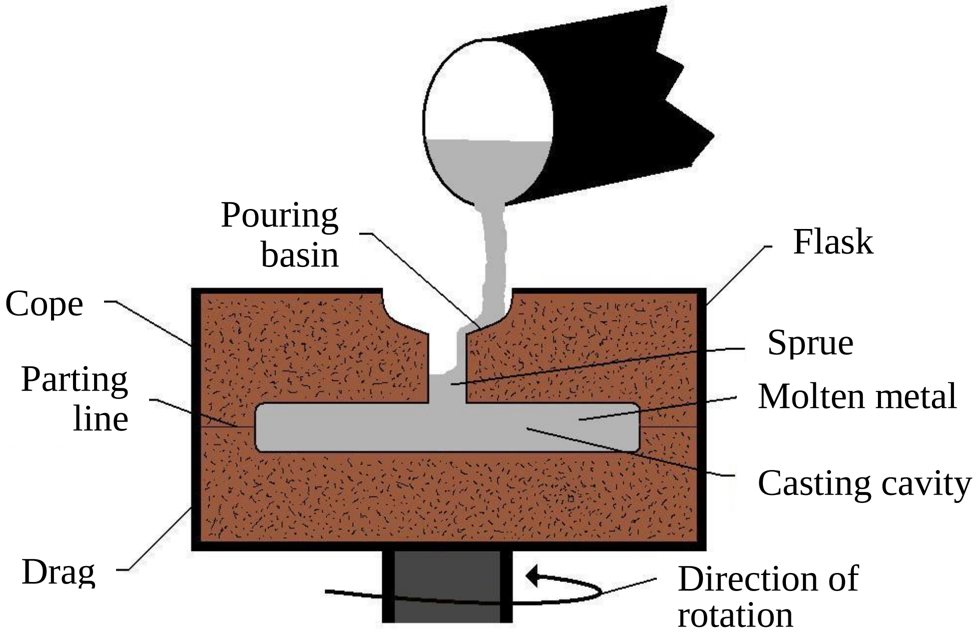


Figure 121 – Semi-centrifugal casting pouring a wheel

As the metal casting solidifies in a rotating mold, the centripetal forces constantly push material out from the central sprue/riser. This material acts to fill vacancies as they form, thus avoiding shrinkage areas.

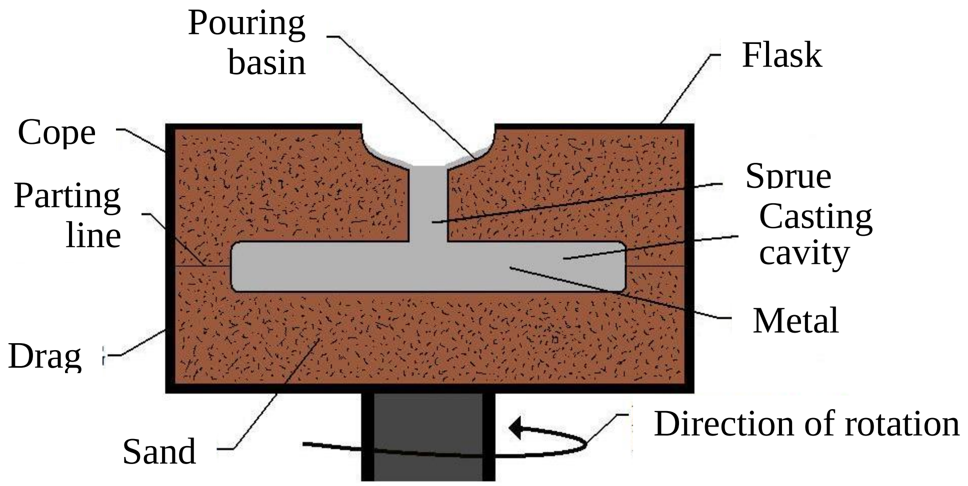


Figure 122 – Semi-centrifugal casting solidification a wheel

The centripetal forces acting on the casting's material during the manufacturing process of semi centrifugal casting, play a large part in determining the properties of the final cast part. This is also very much the case with cast parts manufactured using the true centrifugal casting process. Forces acting in the true centrifugal process are similar to those that influence the material of a metal casting being manufactured by semi-centrifugal casting.

When manufacturing by semi-centrifugal casting, the centripetal acceleration generated on the mass of molten metal by a rotating mold is the force that acts to fill the casting with this molten metal. This is also the force that continues to act on the material as the casting solidifies. The main thing to remember about centripetal forces is that the force will push in a direction that is directed away from the center of the axis of rotation.

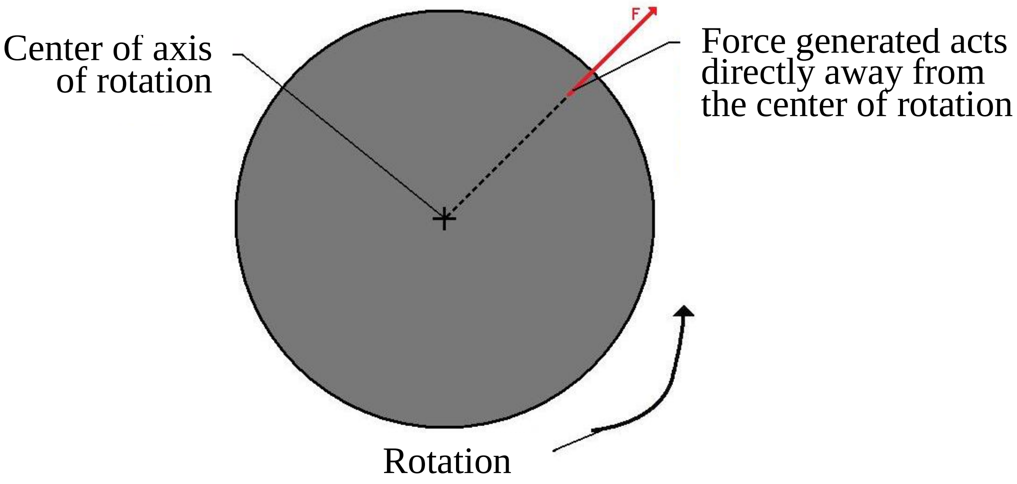


Figure 123 – Spinning wheel

Also, the farther away from the center of the axis of rotation, the greater the force.

It can be seen that during the semi-centrifugal manufacturing process, the material in the outer regions of the casting, (further from the center of the axis of rotation), is subject to greater forces than the material in the inner regions.

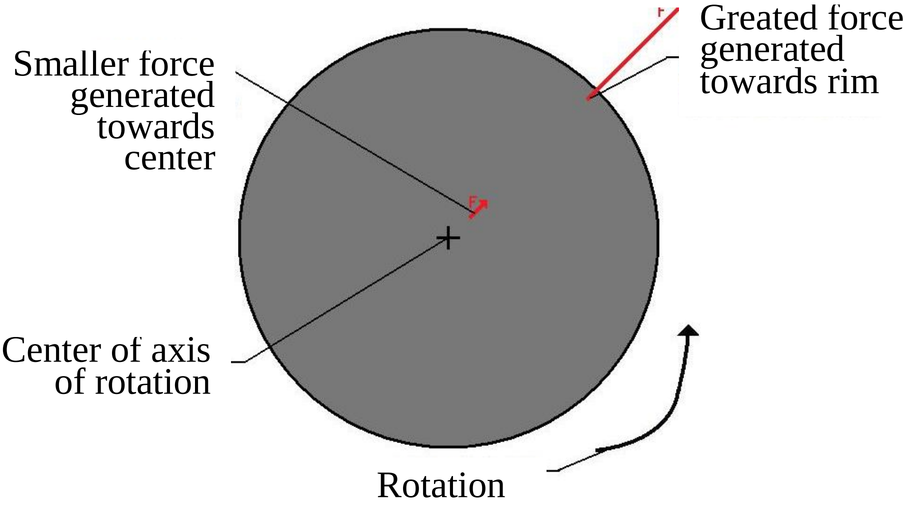


Figure 124 – Spinning wheel

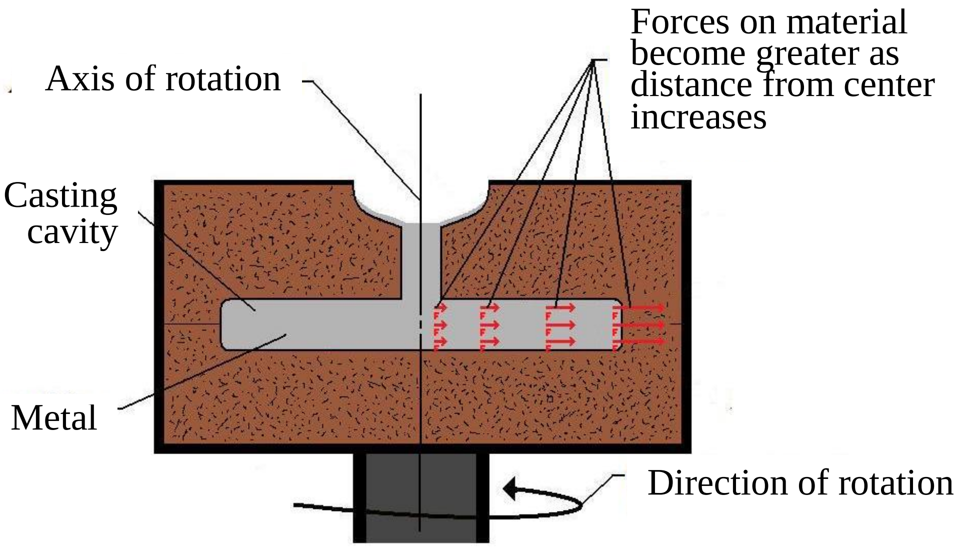


Figure 125 – Semi-centrifugal casting

When the metal casting solidifies, the outer region of the cast part forms of dense material. The greater the forces under which the molten metal solidified, the denser the material in that region. So the density of a cast part manufactured by semi-centrifugal casting will increase as travels radially outward from the center.

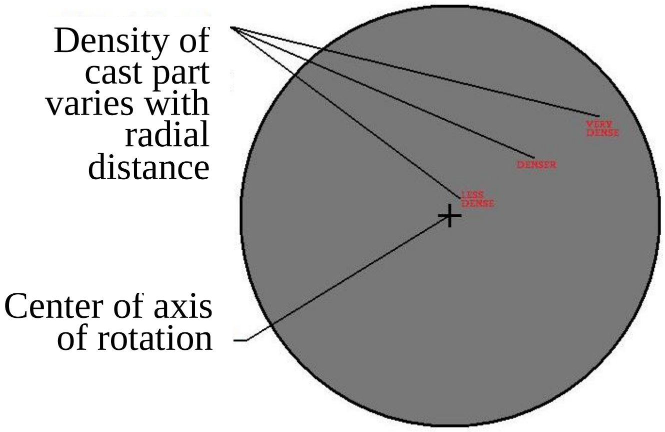


Figure 126 – Cast wheel

The high forces in the outer section that push the molten material against the mold wall also ensure a great surface finish of cast parts manufactured by semi-centrifugal casting.

Another feature of this process, attributed to the usage of centripetal forces, is that impurities within the metal, (such as solid inclusions and trapped air), will form towards the inner regions of the casting.

This occurs because the metal itself is denser than the impurities, denser material subject to centripetal forces will tend to move towards the rim, forcing less dense material to the inner regions.

This particular detail is also a feature in other types of centrifugal casting manufacture.

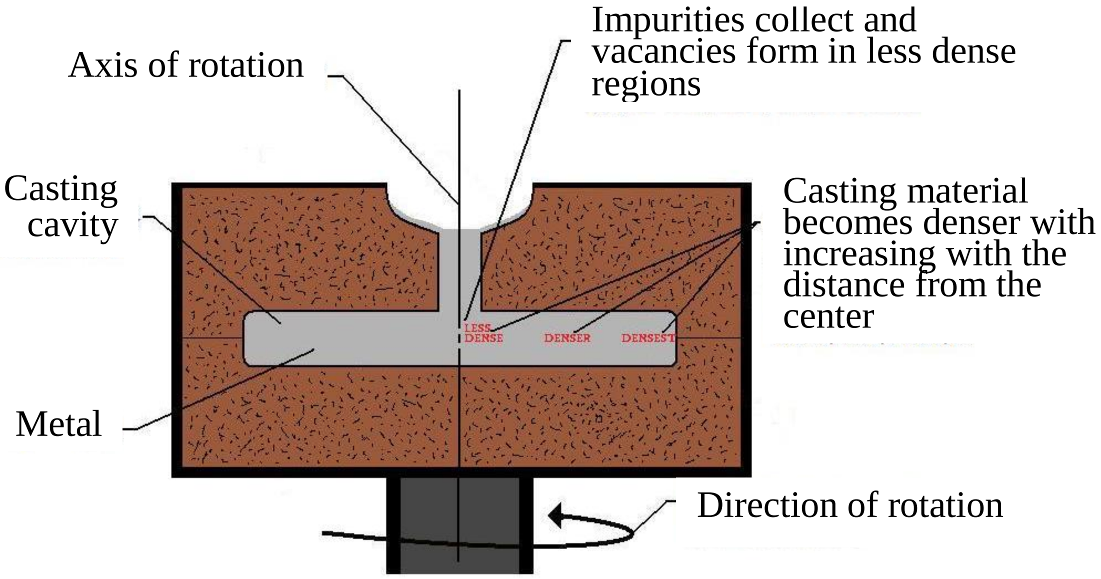


Figure 127 – Semi-centrifugal casting

In the industrial manufacture of parts by semi-centrifugal casting, it is common to machine out the impurity-filled center section, leaving only the purer, denser outer region as the final cast part.

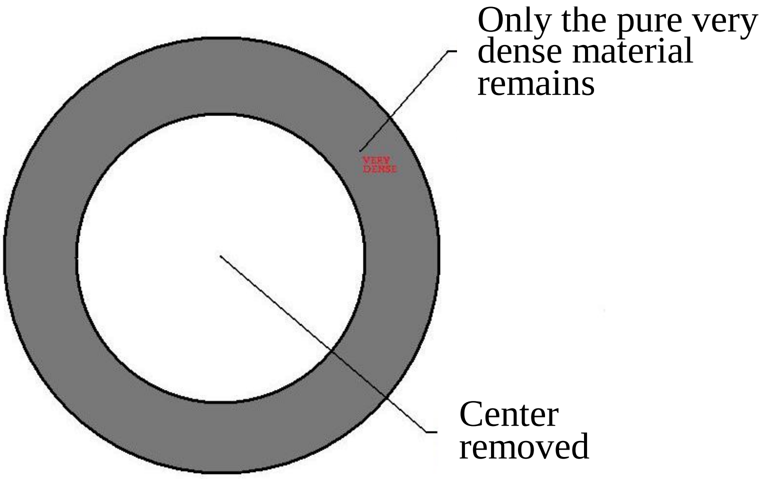


Figure 128 – Cast wheel

The quality of the final casting is affected by factors such as rotating speed, component diameter, pouring temperature, pouring speed, mold temperature, and cooling rate.

Semi-centrifugal casting is a variant of centrifugal casting. The main difference is that the mold is completely filled during the process through the use of a central sprue. If a central bore is required in the casting, a dry sand core is best suited.

Table 28 – Advantages and disadvantages of semi-centrifugal casting

Advantages	Disadvantages
This process ensures purity and density at the extreme point of casting as cast wheel or pulley.	The semi-centrifugal casting process is limited to cylindrical and circular objects.
The semi-centrifugal casting process is cost-effective.	The mold is rotated around its symmetry axis.
Both ferrous and non-ferrous metals can be used.	Cannot produce complex geometric shapes.
The equipment can be used for multiple types of metals without sacrificing quality.	This process can suffer from inclusion defects as well as porosity.
Castings with good dimensional accuracy and quality are produced.	Vibration defects due to improper mounting and faulty equipment.
The process is miles apart when it comes to mechanical strength and delivers the best-performing products.	The molds are either permanent or expandable. It may have cores also.
In this number of molds can be stacked together, one over the other can be fed by a common central sprue to produce more than one casting at a time.	Raining: the mold rotating too slowly or the pouring rate too fast can result in the metal falling down from the top of the rotation on to the bottom.
This process allows modifications of the shape of the hollowed interior of a cast ring or cylinder.	Vibration defects due to improper mounting and faulty equipment/
Can produce castings with up to 10 feet in diameter and 50 feet in length.	The diameter of the inner surface is incorrect in this casting.
Poor structure forms at the center of the casting, it can be readily machined.	Not all metals and alloys are compatible with this process.
The semi-centrifugal casting process is very economical and generates minimum scrap while allowing to create of large parts with high accuracy and relative ease.	High initial investment is required in machinery and tool.
The high rate of productivity.	More skilled laborers are required for the implementation of the process.

7.6.3. Centrifuge casting

Centrifuge casting is the third main branch of centrifugal casting processes used for the industrial manufacture of cast parts. For more detailed information on the other two manufacturing processes that fit into the category of centrifugal casting see, true centrifugal casting and semi-centrifugal casting. Developing an understanding of these techniques will greatly assist in learning about centrifuge casting since the main principles that govern centrifuge casting are the same for all centrifugal casting processes. Centrifuge casting is different in that castings manufactured by the centrifuge casting process need not have rotational symmetry. With centrifuge casting, metal castings of desired shapes can be manufactured with all the distinct benefits of castings produced by a centrifugal casting process.

The Process.

In centrifuge casting manufacture, molds employed to produce the desired castings are arranged around a central sprue. These molds contain all the necessary geometry for the cast part, as well as the gating system. Runners travel from the central sprue to the mold entrances.

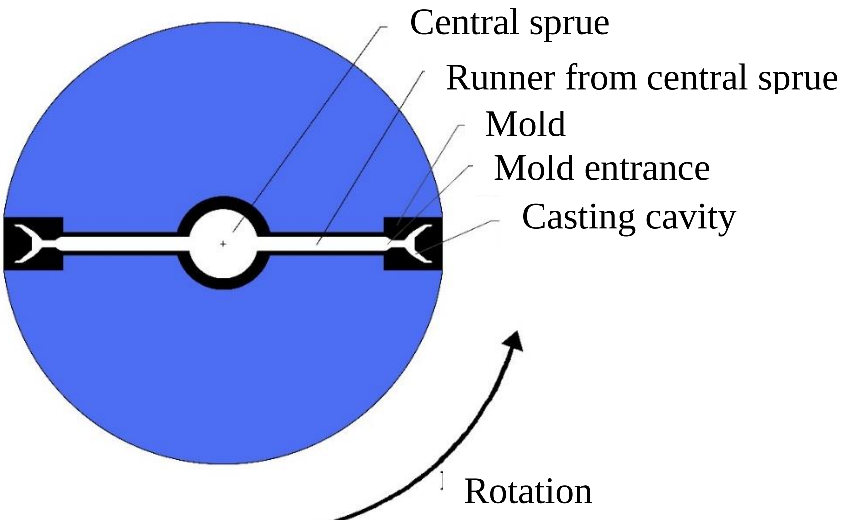


Figure 129 – Centrifuge casting (set up)

During the pouring phase of centrifuge casting manufacture, molten material is introduced into the central sprue. The entire system is rotated about an axis with the central sprue at the center of rotation. When an object is rotated, forces are produced that act directly away from the center of the axis of rotation. It would be known from the previous discussions concerning the other two branches of centrifugal casting, that the utilization of the forces of centripetal acceleration which act to push material away from the center of rotation is the trademark characteristic of all the manufacturing processes of centrifugal casting. Centripetal force is not only utilized to distribute molten material through a mold but to help control the material properties of a cast part. In centrifuge casting manufacture, the molten material to produce the casting is poured into the central sprue. Centripetal forces from the rotating apparatus push this material outward from the center, through the runners and into the molds.

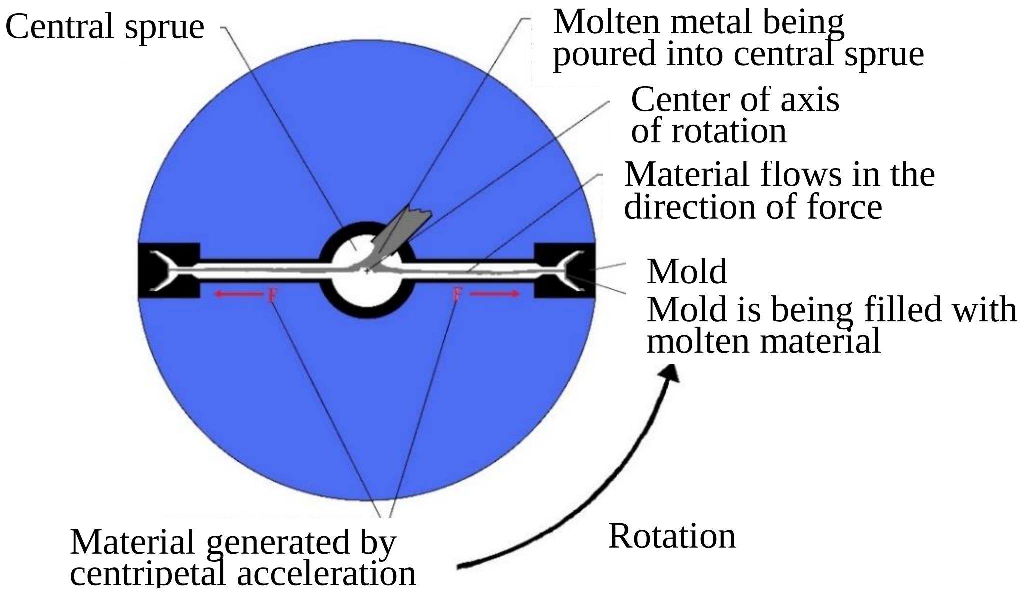


Figure 130 – Centrifuge casting (pouring)

When the correct amount of molten metal to manufacture the casting is poured and distributed completely into the molds, the apparatus will continue to rotate as solidification is occurring. After the castings have completely solidified, the apparatus will stop rotating and the parts can be removed.

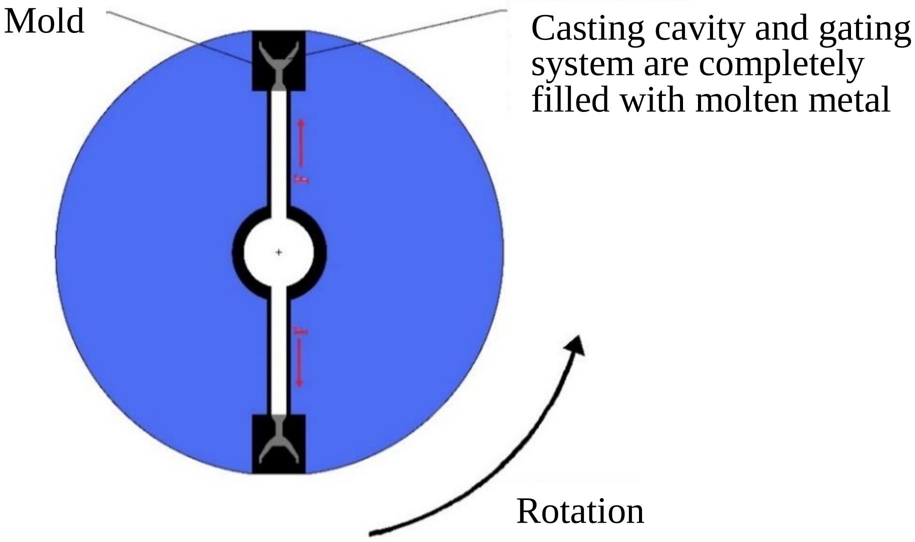


Figure 131 – Centrifuge casting (solidification)

Centrifuge casting manufacture.

There are many specific advantages in the quality of parts manufactured by centrifuge casting. Since the metal is forced into the mold, the mold cavity usually fills completely and cast parts with thin-walled sections are possible. Also, great surfaces can be produced by centrifugal casting, which is another characteristic of castings manufactured by a process that uses large amounts of force to fill a mold.

One of the most notable features, specific to the centrifugal casting processes and discussed in the preceding sections, is the effect of centripetal forces acting continuously on the material as the casting solidifies. Molten material that solidified under greater force will be denser than the same material that solidified under less force. This can be observed in a round cylinder manufactured using the true centrifugal casting process.

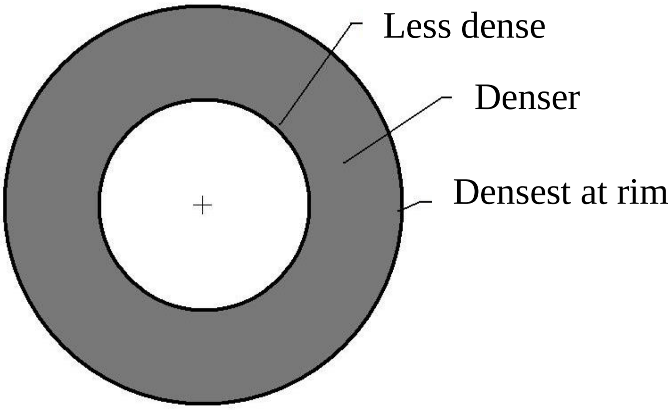


Figure 132 – Cast part produced by true centrifugal casting (i)

During the solidification of this part, the mold was rotating. The forces acting on the material farther from the center were greater than the forces that were acting on the material closer to the center.

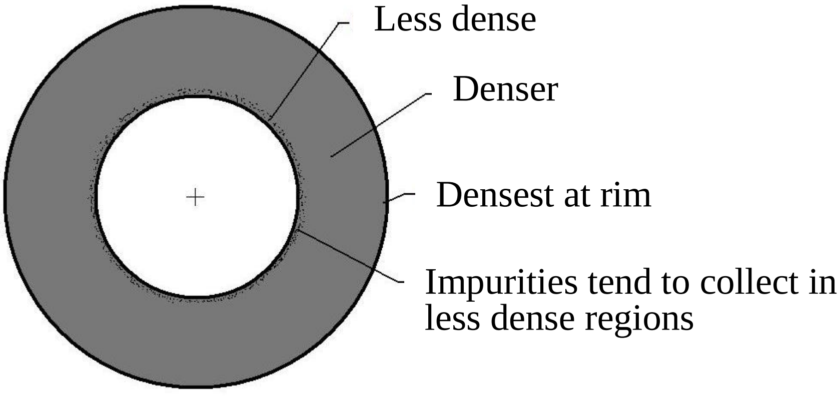


Figure 133 – Cast part produced by true centrifugal casting (ii)

Consequently, it can be seen in the manufactured part that the density is greatest in the outer regions and decreases towards the center.

Another specific effect that the centripetal forces used in centrifugal casting methods have on the material of a cast part is that impurities, such as inclusions and trapped air, tend to collect and solidify in the less dense material closer to the center of the axis of rotation.

This happens because the material itself is denser than these impurities, when subject to centripetal forces the denser metal pushes to the outer regions, forcing the lighter impurities to the less dense inner regions. These effects of centripetal forces on casting can be observed not only in cast cylindrical tubes but also in the wide variety of parts that can be manufactured using the centrifuge casting process as well.

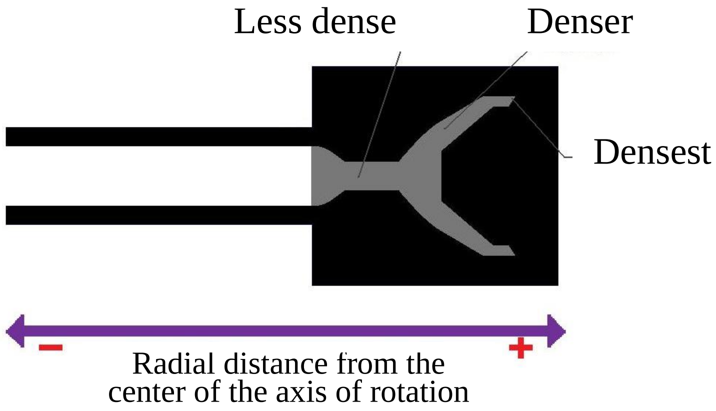


Figure 134 – Effects of centripetal forces

It can be seen that the density of the material varies throughout the cast part. The least dense section of the part will be the section that was closest to the center of rotation. The density of the material of the casting will increase with increasing radial distance from the center. Also, impurities that were present in the metal will have collected in the areas of the casting closest to the center of rotation.

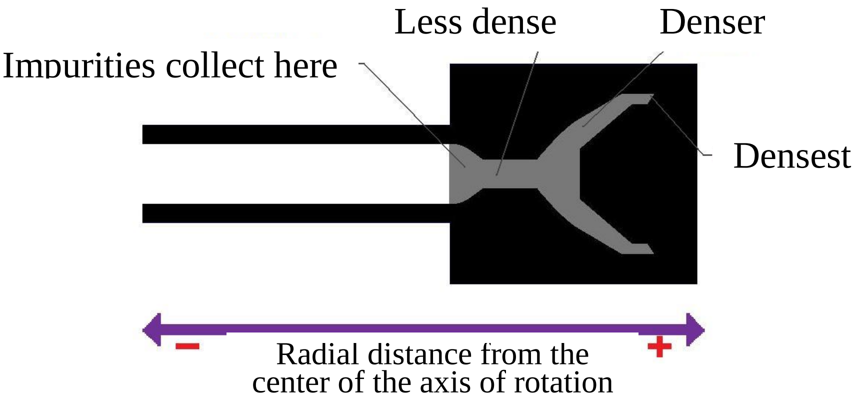


Figure 135 – Effects of centripetal forces

In a carefully planned centrifuge casting operation, the cast part can be designed to be manufactured in such a way that the less dense region containing the inclusions is removed after the production of the casting. This will create a finished part of pure, dense material.

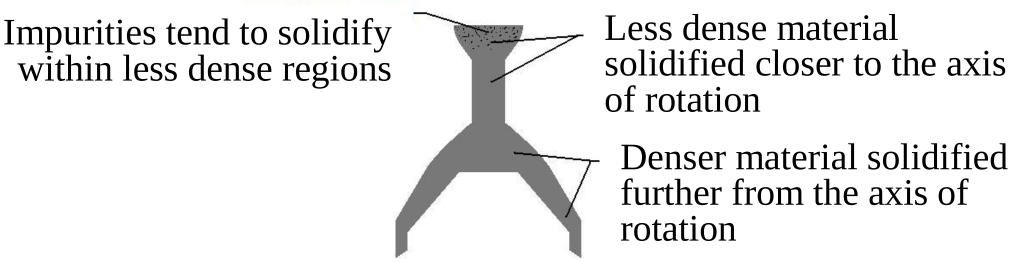


Figure 136 – Casting removed from mold

Figure 137 – Final manufactured cast part of only pure dense material

Table 29 – Advantages and disadvantages of centrifuge casting

Advantages	Disadvantages
Thin-walled and small parts are possible due to the centrifugal forces filling the cavity.	Used only for smaller parts.
	Not suitable for all alloys.
Good surface finish due to the amount of force imparted on the molten metal.	Radial symmetry of the part is not required as in other centrifugal casting methods.
The same die can be used even for parts with different wall thickness values.	Sprue and runner will have to be machined.
Due to low density, impurities such as trapped gases and inclusions will be near the axis, away from the desired part.	The biggest downside of centrifuge casting is that it is limited only to rotationally symmetrical parts.
Since the cast parts are further away from the rotational axis, the part is denser.	As with many traditional manufacturing methods, much of the cost associated with centrifuge casting comes from creating the die or mold.
The process of material deposition via centrifugal forces promotes density layering and good grain distribution.	

7.7. Squeeze casting

Squeeze casting as liquid-metal forging, is a process by which molten metal solidifies under pressure within closed dies positioned between the plates of a hydraulic press. The applied pressure and instant contact of the molten metal with the die surface produce a rapid heat transfer condition that yields a pore-free fine-grain casting with mechanical properties approaching those of a wrought product. Squeeze casting is easily automated to produce near-net-to-net shape high-quality components.

The process was introduced in the United States in 1960 and has since gained widespread acceptance within the nonferrous casting industry. Aluminum, magnesium, and copper alloy components are readily manufactured using this process. Several ferrous components with relatively simple geometry, for example, nickel hard-crusher wheel inserts-have has also been manufactured by the squeeze casting process.

Squeeze casting is a manufacturing process, which combines both die casting and metal forging. It can potentially provide a casted component with the highest attainable mechanical properties on the final part. Squeeze casting is acquired by original equipment manufacturers to make aluminum alloy parts, which are yet to be commercialized properly.

Squeeze cast parts have better strength, better density, less weight, and more precise parts than normal casting parts. That is why manufacturers of defense, construction, automotive, and heavy machinery industries use squeeze die cast parts. Some examples are as follows: pistons, engine blocks, brass pipes, chassis frames, nodes, steering knuckles, aluminum dome roofs, bevel gears, etc.

Squeeze casting materials.

1. To date only aluminum casting and forging alloys are used commercially, but there is no reason why the process cannot be used with most metals and alloys.

2. Secondary quality aluminum casting alloys can be used without coarse iron aluminide needles impairing mechanical properties.

3. Process produces a fine grain structure (typically 120 μm) with small dendrite cells (typical arm spacing 20 μm).

4. Tensile properties of casting alloys are better in all respects than conventionally cast material.

5. Tensile properties of squeeze-formed components compare favorably with those of conventionally forged components.

6. Unlike forging, squeeze forming produces isotropic properties with ductilities between that longitudinal and transverse forgings.

7. Fatigue properties of squeeze-formed components compare favorably with forged components but are superior to chill cast.

The process.

The squeeze casting technique results in higher tensile and mechanical properties of alloys such as zinc and aluminum and some ferrous alloys. The process begins when molten metal is poured at the lower half of the preheated and lubricated die cavity, and pressure is applied before and after solidification. The pressure applied in the squeeze casting is lesser than the pressure applied in metal forging. The preheated die is set on a hydraulic press along with a coating of an ejecting agent such as graphite. It helps with the ejection of the final product when it is entirely in hard form.

As the metal starts to lose its liquid molten state, the upper half of the die is pressed into the bottom half until the casting fully solidifies. The pressurization aids in ensuring that the metal moves equally among the solidifying casting, which reduces the risks of the metal component falling apart. Once the alloy is in a firm, solid form, the press ram withdraws, and the casting alloy is extracted from the plates of the hydraulic press. Three factors result in improved non-uniformed meta structures and mechanical properties: macro segregation found in the squeeze castings, close contact with the alloy in the die cavity and high pressure applied in the process.

The pressure and the molten alloy’s contact with the surface of the die in squeeze casting. It will ensure the end product has mechanical properties that are improvised alongside less porosity. Foundries use coring alongside squeeze casting for forming recesses and holes in the component.

Squeeze casting process step-by-step explained with the following operations:

1. Melting the metal.
2. Pouring it into the lower half part of the cavity.
3. When the liquid metal starts to solidify, pressing the top half die (punch) on the metal.
4. Holding the die (punch) until the metal solidifies completely.
5. Finally, ejecting the part using the ejector.

Also, there are three main stages of squeeze casting:

1. Die set positioned on a hydraulic press, preheated to 200–250°C and coated with a releasing agent such as graphite. Accurate metering of liquid metal into die cavity via a «launder».

2. Press actuated to bring two parts of the die set together. Metal is displaced to fill the die cavity and pressure is held until solidification is complete.

3. Press ram is withdrawn. Die set separated. Component ejected. Components are heat-treated and machined when necessary.

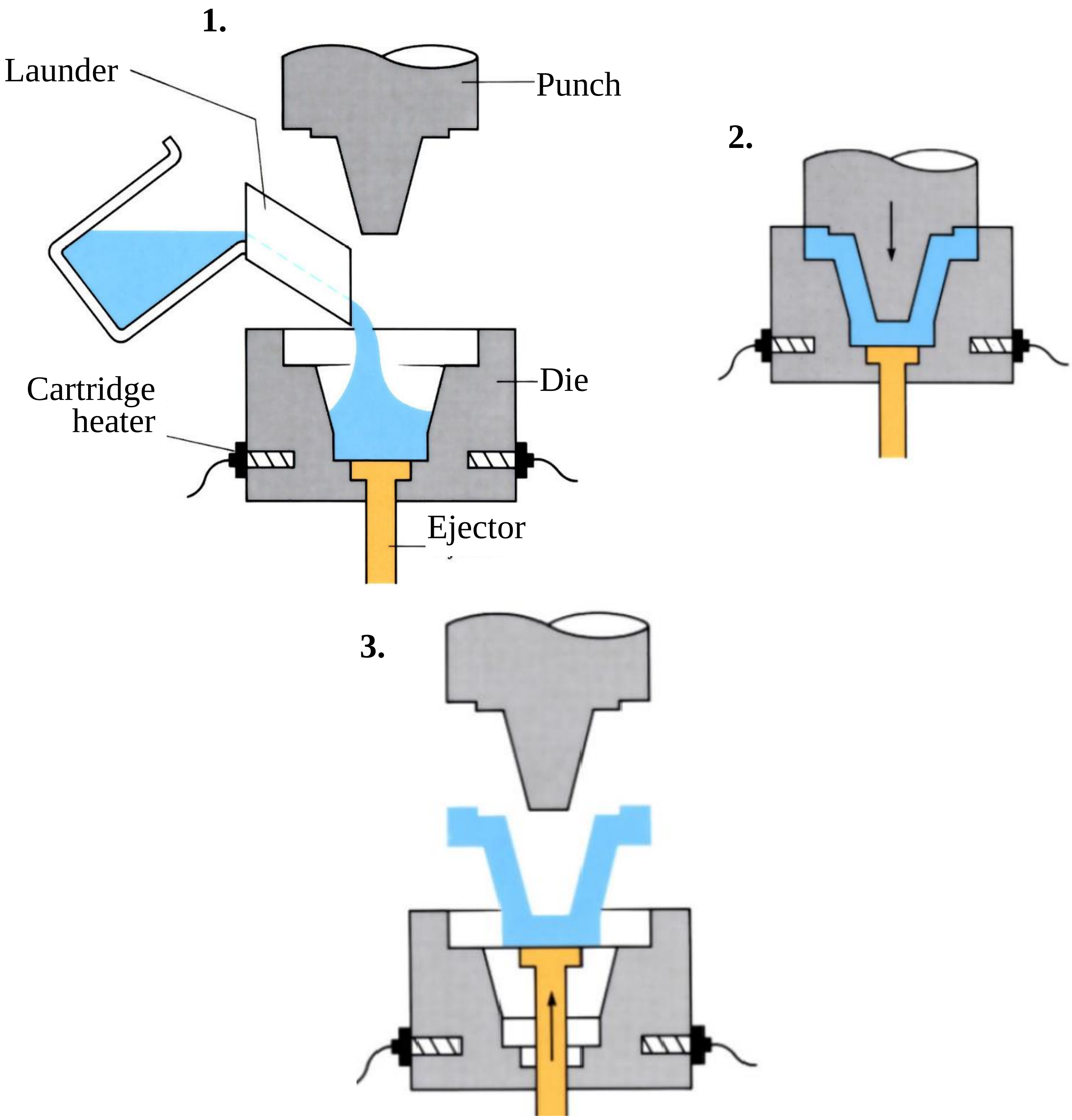


Figure 138 – Stages of squeeze casting

Squeeze casting parameters.

The essential processing parameters that need to be monitored to produce a successful squeeze-casting component are listed below:

1. Casting temperature: the initial point is typically between 6–55 degrees C above the liquid's temperature. But the temperature can vary depending on the alloy and the geometry.

2. Squeeze pressure: The pressure level should be between 50 to 140 MPa in general. Applying pressure for 30 to 120 seconds can achieve satisfactory results for castings weighing about 9 kg.

3. Tooling temperature: the range usually varies between 190 to 315 degrees C.

4. Lubrication: for common casting metals such as aluminum, copper, and magnesium, any good grade of colloidal graphite is used as a spray lubricant. When applied to the warm dies before the casting process, the lubricant gives satisfactory results.

5. Time delay: it is the measure of the actual time between the metal's pouring and the moment the press ram starts the pressurization on the metal in the die cavity.

6. Squeeze pressure holding time: for casting that weighs around 9 kg, the range between 30 to 120s is considered suitable.

Squeeze casting types.

Since its development, there have been many modifications in the procedure and the techniques of squeeze casting. The traditional squeeze casting process is divided into two types, namely:

- direct squeeze casting;
- indirect squeeze casting.

The direct method closely resembles the liquid forging procedure. In the direct method, the molten metal is poured directly into the bottom half of the die, and the upper half is closed, causing the molten metal to fill the entire cavity. After that, a pressure of around 70–140 MPa or more is applied using a hydraulic press over the whole cavity during the solidification process. The direct method of squeeze casting gives better heat transfer, which produces adequate structures.

Indirect squeeze casting is more like high pressure die casting, as the chamber used is similar. In this process, the grain-free liquid metal is injected into an indirect squeeze casting machine through a shot sleeve, which can be vertical or horizontal. The melt is injected into the die chamber through a much thicker gate and lower velocity than that of high pressure die casting.

The casting process is accomplished when the liquid metal solidifies. The speed and the pressure with which the melt is injected can be controlled. A computer-controlled system can help in indirect squeeze cast manufacturing by offering greater speed and control of the production.

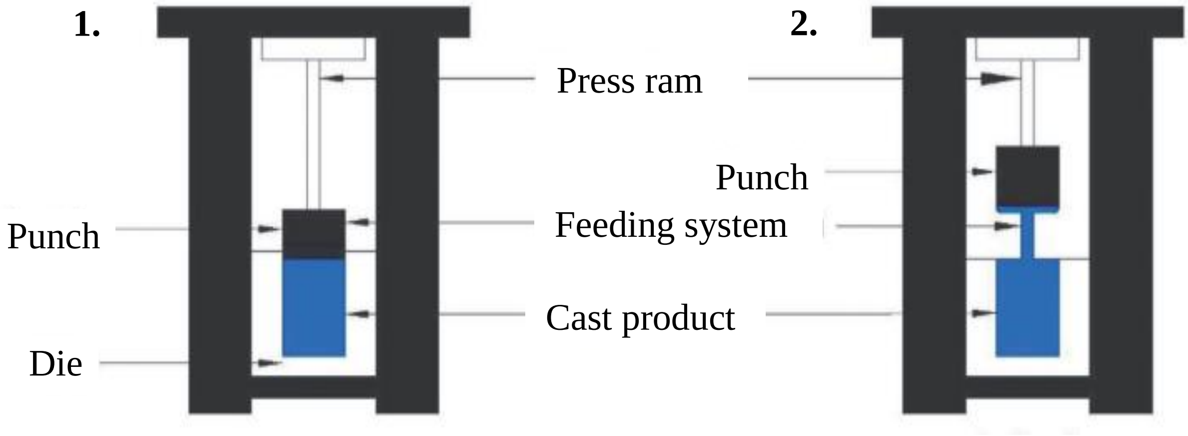


Figure 139 – Direct (1) and indirect (2) squeeze casting

The indirect method has more commercial applications as it does not require highly specific metering systems.

In both of these types, the manufacturers may accomplish the casting operations in vacuum-controlled conditions. Although both of these types have gained popularity in recent years due to lesser porosity, the method and the raw material are mainly picked based on manufacturing technologies.

Table 30 – Differences between direct squeeze casting method and indirect squeeze casting method

Direct squeeze casting	Indirect squeeze casting
The pressure for preform penetration is provided directly to the melt in the direct squeeze casting method.	The melt is forced into the preform by a gate system in indirect squeeze casting.
There is no gate mechanism, direct squeeze casting tooling is relatively easy.	The tooling is more complicated, and a gating mechanism is present.
The existence of oxide residue in the composite is another difference.	The oxide residue in the composite is stopped by the gating system.
In most cases, this is done on a vertical machine (similar to a forging press).	Indirect squeeze casting, which uses both vertical and horizontal machines, is more analogous to traditional high pressure die casting.

Properties and considerations of manufacturing by squeeze casting:

- An alternative to gravity and high pressure die casting and forging for low-cost, high-strength aluminum alloy components.
- Only requires one die set and operates at lower pressures than forging, in the range of 30–110 MPa depending on component geometry and material.
- Runner and feeder systems are not usually required, giving high metal yields and weight tolerances of ±2%.
- Accurate control of all process variables makes the process difficult to operate under production conditions and often leads to slow cycle times. Typical production rates are 5–30 shots h-1.
- Final machining is kept to a minimum.
- Typical products include wheels, hubs, pistons, etc. for the automotive and aerospace industries.
- Weight range 2–50 kg, depending on press capacity.
- Thickness range 3–50 mm.
- Uniform thickness is preferred to give uniform solidification and minimize residual stresses and porosity.
- Careful design enables porosity to be «manipulated» to the least critical regions.
- External undercuts are possible.
- Complex internal shapes possible using disposable cores.
- Blind and through holes easy to incorporate; lateral holes using retractable cores.
- Tolerances of 0.2 mm 100 mm-1 possible before heat treatment. Wider tolerances are advisable to allow for distortion during subsequent heat treatment and to minimize costs.
- Tolerances across part lines are at least 0.25mm 100 mm-1.
- Surface finish depends on material and die condition, but is usually in the range Ra= 0.4–3.2.
- Inserts can be incorporated into components to improve properties in critical areas, e.g. fiber reinforced Al_2O_3 pads in piston heads.

Differences between die casting and squeeze casting.

The castings of squeeze casting and die casting are extremely similar, especially after the machining process. How to distinguish casting workpieces of the two casting processes? Table 31 shows the comparison of squeeze casting vs die casting processes.

Table 31 – Comparison of squeeze casting vs die casting processes

Squeeze casting	Die casting
Suitable for most metal alloys.	Use only casting alloys.
It combines the benefit of forging and casting.	It does not offer the benefits of forging.
The velocity of pouring molten metal is slower than regular die casting.	Melted metal is poured faster than squeeze casting.
It takes longer than usual die casting to eject the final part.	The final part can be ejected faster than squeeze casting.
Squeeze-cast parts have less porosity than normal die-cast parts.	Normal die-cast parts have more porosity than squeeze-cast parts.
Both high and low pressure can be applied simultaneously for squeeze casting.	Either high or low pressure can be applied for regular die casting.
Squeeze cast parts have a typical crushing-grain texture as forging conditions.	Die casting parts have typical dendrite-shape texture as cast condition.
Squeeze castings have lower shrinkage than regular die-casting parts.	Die castings have higher shrinkage than squeeze-cast parts.
Much wider surface finish applications like anodizing and heat treatment methods like solid-melt strengthening.	Limited surface finish like powder coating. Not able to apply anodizing.

Squeeze casting is simple and economical, efficient in its use of raw material, and has excellent potential for automated operation at high rates of production. The process generates the highest mechanical properties attainable in a cast product. The microstructural refinement and integrity of squeeze cast products are desirable for many critical applications.

The squeeze casting process, combining the advantages of the casting and forging processes, has been widely used to produce quality castings. Because of the high pressure applied during solidification porosities caused by both gas and shrinkage can be prevented or eliminated. The cooling rate of the casting can be increased by applying high pressure during solidification since the contact between the casting and the die is improved by pressurization, which results in the foundation of fine-grained structures.

Table 32 – Advantages and disadvantages of squeeze casting

Advantages	Disadvantages
When casting and forging combine, it results in better mechanical properties for the components made by squeeze casting than normal casting parts.	Costs are extremely expensive due to complex intricate tooling.
	Dimension and weight of products are limited.
Squeeze casting is done with tightly sealed dies and high pressure, so the parts have low shrinkage.	No flexibility as tooling is dedicated to specific components.
It is great for mass production because the process saves energy by operating through software programming.	The process needs to be accurately controlled which shows the cycle time down and increases process costs.
It is suitable for both non-ferrous metal (such as non-ferrous aluminum alloy) and ferrous metal, unlike most other die casting processes.	High costs mean high production volumes are necessary to justify equipment investment.
The squeeze casting metal components have lower porosity than parts made by other casting processes.	Only liquid metal can be used in this application. While materials such as plastic can melt at high temperatures, this technique will not be suitable to cast plastic.
Squeeze casting parts have good surface texture.	
Squeeze casting parts have fine micro-structures with higher strength components.	High precision control is required.
Squeeze casting does not emit gas, and the cooling rate allows more control over the final structure.	The metallic mold’s life expectancy is reduced.
Cost savings in terms of fewer rejected products and lower waste byproducts.	The squeeze casting process is limited to high-fluidity metals and alloys.
Manufacturers can use automatic machines for this process and thus reduce the cost of production.	Squeeze casting tooling has no versatility.

7.8. Continuous casting

Continuous casting, also referred to as strand casting, is a process used in the manufacturing industry to cast a continuous length of metal. Molten metal is cast through a mold, the casting takes the two-dimensional profile of the mold but its length is indeterminate. The casting will keep traveling downward, its length increasing with time. New molten metal is constantly supplied to the mold, at exactly the correct rate, to keep up with the solidifying casting. The industrial manufacture of continuous castings is a very precisely calculated operation. Continuous casting can produce long strands from aluminum and copper, also the process has been developed for the production of steel.

Continuous casting typically utilizes molten steel. However, copper, aluminum, and even some types of cast irons can also serve as raw materials. This casting process requires an investment in high-volume production facilities: a blast furnace, automated metal ladles, a tundish, water sprays, and graphite molds. Manufacturers must supply mold lubricating and cooling capabilities.

The continuous casting process is a very effective method to manufacture semi-finished products such as bars, profiles, slabs, strips and tubes made from steel and non-ferrous metals such as copper, aluminum and their alloys. Nowadays, more than 90% of the liquid steel produced worldwide is processed by continuous casting, for example.

The process.

The process of continuous casting developed during the 1950s. This sophisticated casting system has increased efficiency at many steel mills by eliminating several steps involved in the casting of steel ingots using discrete stationary molds.

Continuous casting relies on four important steps:

1. Preparations. It is important to choose mold materials with excellent thermal conductivity and oxidation resistance. Therefore, water-cooled crystallization molds, such as high-quality graphite, are used in continuous casting production. The graphite mold is then machined into the required size and shape.

2. Melting process. The metal is liquefied in a furnace. The temperatures vary depending on the metal, from around 700° C for aluminum to over 1600° C for steel. The melting point for copper lies in between at around 1100° C.

3. Forming process. The molten metal is then poured out of the ladle into an intermediate container, from which it flows through a water-cooled mold and solidifies there in the peripheral zone. The resulting strand, which is still liquid on the inside, is continuously drawn downwards out of the mold. In an arch-shaped cooling chamber, the strand is deflected and sprayed with water before it is finally straightened and cut to length.

4. Finally, the metals emerge from the process as solid strands of brass, copper, steel, Versa-bar cast iron, or aluminum are cut into manageable strands for further manipulation, storage, or shipment.

The basic operation of the continuous casting process is to convert liquid steel of a given composition into a strand of desired shape and size through a group of operations like mold operation, spray cooling zone, straightener operation, etc. For successful continuous casting, it is necessary to understand the process behavior under different conditions for these operations. The process of continuous casting basically comprised of the following sections:

1. Tundish, located above the mold, to receive the liquid steel from the steel-teeming ladle and feed it to the mold at a regulated rate.

2. Primary cooling zone consists of a water-cooled copper mold through which the liquid steel is fed from the tundish for generating a solidified outer steel shell sufficiently strong enough to maintain the strand shape as it passes into the secondary cooling zone.

3. Secondary cooling zone in association with a containment section positioned below the mold, through which the steel strand (still mostly liquid) passes and is sprayed with water or a mix of water and air (air mist) for further solidifying of the steel strand.

4. Section for the unbending and straightening of steel strand. This section is not there in the straight vertical casting machines.

5. Cutting section consisting of cutting torches or mechanical shears for the cutting of the solidified steel strands into desired lengths for removal.

6. Run out the table to cooling beds or directly to a product transfer area.

Molten metal, from some nearby source, is poured into a tundish. A tundish is a container that is located above the mold, it holds the liquid metal for the casting. This particular casting operation uses the force of gravity to fill the mold and to help move along the continuous metal casting. The tundish is where the operation begins and is thus located high above ground level, as much as eighty or ninety feet. As can be seen, the continuous casting operation may require a lot of space.

It is the job of the tundish to keep the mold filled to the right level throughout the manufacturing operation. Since the metal casting is constantly moving through the mold, the tundish must always be supplying the mold with more molten metal to compensate.

The supply of metal to the mold is not only going on throughout the entire manufacturing operation, it must be carried out with accuracy. A control system is employed to assist with this task. Basically, the system can sense what the level of molten metal is, knows what the level should be, and can control the pouring of the metal from the tundish to ensure the smooth flow of the casting process. Although the tundish can typically hold several thousand pounds of metal, it too must be constantly supplied from the source of molten material.

The tundish also serves as the place where slag and impurities are removed from the melt. The high melting point and reactive nature, at high temperatures, have always made steel a difficult material to cast. When a manufacturing operation is continuously casting steel, the reactivity of the molten steel to the environment needs to be controlled.

For this purpose, the mold entrance may be filled with an inert gas such as argon. The inert gas will push away any other gases, such as oxygen, that may react with the metal. There is no need to worry about the inert gas reacting with a molten metal melt since inert gases do not react with anything at all.

The metal casting moves quickly through the mold, in the continuous manufacture of the metal part. The casting does not have time to solidify completely in the mold. As can be remembered from our discussion on solidification, a metal casting will first solidify from the mold wall, or outside of the casting, then solidification will progress inward. The mold in the continuous casting process is water-cooled, this helps speed up the solidification of the metal casting. As stated earlier, the continuous casting does not completely harden in the mold. It does, however, spend enough time in the water-cooled mold to develop a protective solidified skin of adequate thickness on the outside.

The long metal strand is moved along at a constant rate, by way of rollers. The rollers help guide the strand and assist in the smooth flow of the metal casting out of the mold and along its given path. A group of special rollers may be used to bend the strand to a 90-degree angle. Then another set will be used to straighten it, once it is at that angle. Commonly used in the manufacturing industry, this process will change the direction of flow of the metal strand from vertical to horizontal.

The continuous casting can now travel horizontally as far as necessary. The cutting device, in the manufacturing industry, is typically a torch or a saw.

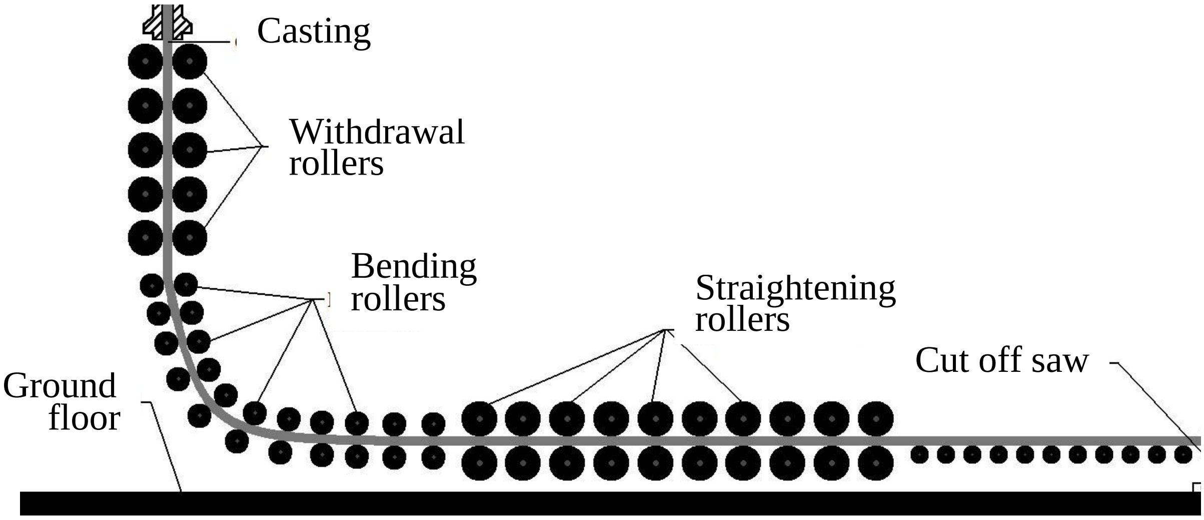


Figure 140 – Vertical to horizontal direction change for continuous casting manufacture

Since the metal casting does not stop moving, the cutting device must move with the metal casting, at the same speed, as it does its cutting. There is another commonly used setup for cutting lengths of metal casting strands from a continuous casting operation.

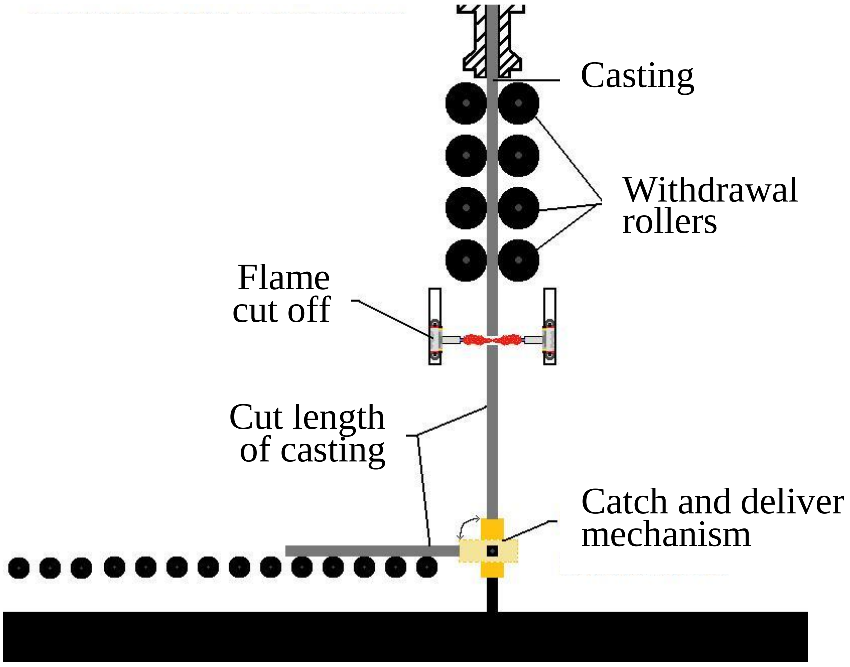


Figure 141 – Alternate method of cutting slabs for continuous casting manufacture

This particular manufacturing setup eliminates the need for bending and straightening rollers. It does, however, limit the length of the metal casting strand that may be produced, based in large part on the height of the casting floor where the mold is located.

There needs to be an initial setup for a continuous casting operation since it is impossible to simply pour molten metal through an empty system to start the process. To begin continuous casting manufacture, a starter bar is placed at the bottom of the mold. Molten material for the metal casting is poured into the mold and solidified to the bar. The bar gives the rollers something to grab onto initially. The rollers pull the bar, which pulls along the continuous casting.

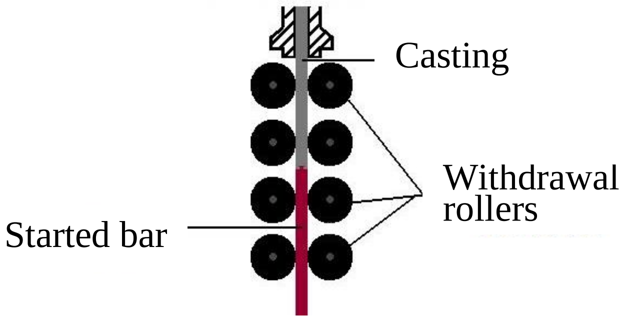


Figure 142 – Starting a continuous casting manufacturing process

In the manufacture of a product, often two or more different kinds of operations may need to be performed. Such as a metal casting operation followed by a metal forming operation. In the modern commercial industry, the continuous casting process can be integrated with metal rolling. Do not confuse the rolling operation with the rolls used to guide the casting. The rolling operation is a forming process and it will change the metal it processes.

Rolling of the metal strand is the second manufacturing process and it must be performed after the casting operation. Continuous casting is very convenient in that the rolling mill can be fed directly from the continuously cast metal casting strand. The metal strand can be rolled directly into a given cross-sectional shape such as an I beam. The rate of the rolling operation is synchronized with the speed that the continuous metal casting is produced and thus the two operations are combined as one.

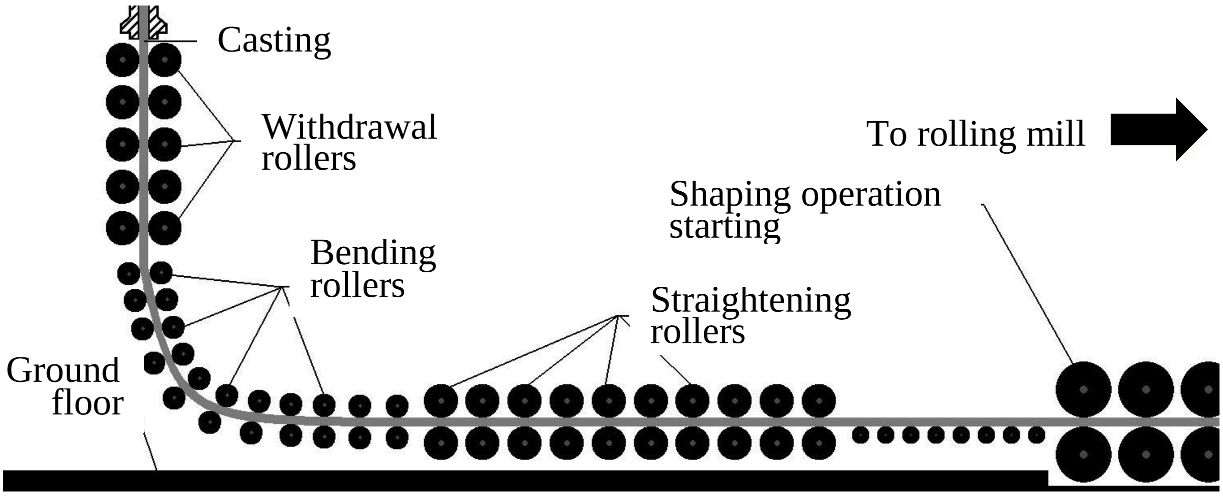


Figure 143 – Continuous casting combined with a rolling operation

Properties and considerations of manufacturing by continuous casting:

- Continuous casting manufacture is different from other metal casting processes, particularly in the timing of the process. In other casting operations, the different steps to the process such as the ladling of metal, pouring, solidification, and casting removal all take place one at a time in a sequential order. In continuous casting manufacture, these steps are all occurring constantly and at the same time.
- This process is used in commercial manufacture as a replacement for the traditional process of casting ingots.
- Piping, a common problem in ingot manufacture, is eliminated with the continuous casting process.
- Structural and chemical variations in the metal of the casting, often present in ingots, have been eliminated. When manufacturing with the continuous metal casting process, the casting's material will possess uniform properties.
- When employing continuous metal casting manufacture, the castings will solidify at 10 times the rate that a casting solidifies during ingot production.
- With less loss of material, cost reduction, higher productivity rate, and superior quality of castings, continuous casting manufacture is often the choice over ingot production.
- A continuous casting manufacturing process will take considerable resources and planning to initiate, it will be employed in only very serious industrial operations.

Table 33 – Advantages and disadvantages of continuous casting

Advantages	Disadvantages
Ability to cast regular shapes and certain irregular configurations in long tubular form, which is difficult for other casting methods.	Continuous casting allows manufacturing metal slabs or bars in large amounts to be shot time.
Continuous cast bars require appreciably less machining stock.	Continuous casting requires a high initial investment.
Straight, true, and concentric products for high-speed bar machines.	Due to the considerable mold cost and casting machine set-up, it is uneconomical to consider the continuous cast method for special shapes or special alloys in small quantities.
The continuous cast material is consistently dense and homogeneous in structure and therefore well-suited for pressure applications.	
Many suppliers maintain stock sizes for ready availability to distributors and others requiring full lengths.	Only simple shapes can be cast, which must have a constant cross-section.
If the shape is optimized, the clean-up stock required on continuous cast material is often less than that needed for parts produced with other casting processes.	Due to both the high cost of creating a mold and the time spent setting up the machine for each project, it is not practical to use this method for small quantities or special shapes of a product.
Continuous castings perform well under pressure.	
Suppliers often maintain stock of standard products, available to distributors on demand.	A large capital investment is required to set up the process.
Less material is wasted than in some other casting methods.	Continuous casting requires large ground space.
These castings are straight and concentric, meaning there is no deviation.	Sprue, runner and riser are do not use thus, there are no wastes of metal in this case.
Continuous castings have an inherent advantage in mechanical properties over other methods because of the chilling and the excellent feeding of molten metal during solidification.	Continuous and capable cooling of molds is required: else, center-line shrinkage develops.
Cost advantages can be offered for standard shapes and sizes.	Not proper for small amount production.

7.9. Evaporative pattern casting

Evaporative casting, consumable or eva-foam casting is a sand casting process where the foam pattern evaporates into the sand mold. A process is similar to investment casting, this expendable casting process is predicted to be used for 29% of aluminum and 14% of ferrous casting in 2010. There are two main evaporative casting processes: lost foam casting and full mold casting which are widely used because intricate designs can be cast with relative ease and with reasonable expense. The main difference between the two is that in the lost foam casting, unbonded sand is used and in the full mold casting green sand or bonded sand is used.

Evaporative pattern casting is widely used for aluminum casting. Iron founding also makes use of the process for the production of various products like a water pipe and pump parts. Magnesium and its alloys are now being cast using the method. The first public recognition of the application of the process was in 1980 when General Motors produced some automobile components with it. Aluminum railway valve bodies, aluminum cylinder heads, pipe fittings and shaft hubs are now being produced by foundries all over the world.

The process.

The evaporative pattern casting process steps are diagrammatically illustrated in Fig. 144. It is of interest to see the steps simply outlined but every step needs to be carefully monitored and controlled because of the physicochemical interactions in the steps coupled with the process parameters that are involved for the purpose of producing consistent and high-quality castings.

In the first step of evaporative casting, a foam pattern is shaped using a material like polystyrene. The pattern is attached with sprues, and gates using adhesives and brushed with refractory substances so that the molds are strong and resistant to high temperatures. Refractory-covered pattern assembly is then surrounded by a sand mixture to form a mold. In some instances, the pattern assembly is mixed in the ceramic slurry which forms a shell around the pattern when it dries.

In both cases, the mold is kept at a specific temperature to allow the metal to flow smoothly and enter into every design and cut made by the pattern. Molten metal is poured into the mold and the pattern-forming material disappears into the mold.

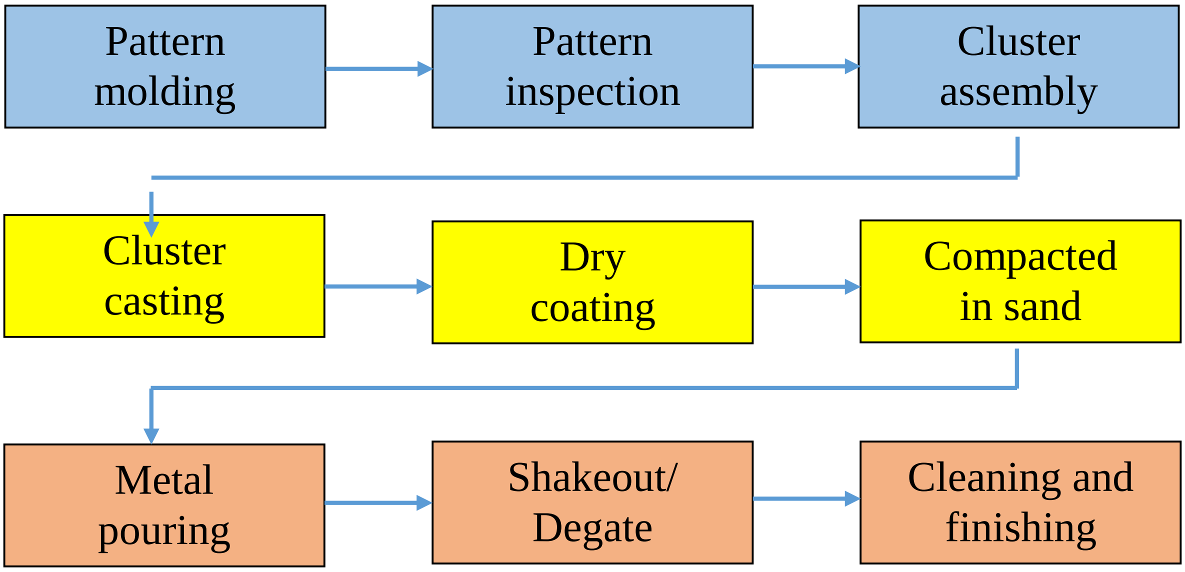


Figure 144 – Steps ofevaporative pattern casting process

The molten metal takes the shape of the mold and solidifies. When the metal solidifies it is removed from the mold to form the casting.

Unlike in the traditional sand casting method, in evaporative sand casting, the pattern does not have to be removed from the mold which reduces the need for draft provisions. Some of the parameters that are used to determine the quality of a eva-foam casting are grain fineness number, time of vibration, degree of vacuum and pouring temperature on surface roughness, etc.

The very many variables of the evaporative pattern casting process grouped into six categories have made the process react to changes that occur in the system. The combined and individual effects of these variables sometimes produce significant effects on the process and its products. The chain of systems observed to make castings by the evaporative pattern casting process is divided into two main classes:

1. Evaporative pattern production, assembly and inspection.
2. Casting production and inspection.

The first division is a six-step operation. Step 1 is the pattern molding. This is done industrially by the injection process. Beads of polystyrene foam are injected into the molding machine under pressure. The foam material together with the amount of applied pressure for compaction determines the density of the polystyrene pattern that would be employed for casting. This is an industrial option. On the other hand, patterns are machined from a block of polystyrene foam with a device called heated wire.

Step 2 is the inspection of the patterns produced industrially or manually. Dimensional accuracy and correctness of the shape are inspected at this level. Distortion of the patterns is avoided. This is paramount to the evaporative pattern casting process. Many a time, the evaporative pattern casting process involves the casting of intricate shapes such that a shape will be broken into segments, and patterns will be produced for these segments. The patterns of the segments are joined together with glue.

The joining process is referred to as cluster assembly which is step 3. To provide the ability to withstand thermal energy from advancing liquid metal and prevent sand penetration in evaporative pattern castings, refractory coating which is made from highly refractory materials is sprayed on the patterns.

Step 4 takes care of this. The patterns are left to dry. The drying period is within a matter of seconds; maximum of 15 s. This is possible because of the reducer/carrier which is usually methyl alcohol at 99% concentration that is employed in the transfer of the coating to spraying the pattern.

The drying process is done in step 5. Step 6 deals with the compaction of the coated patterns in the sand mold. The sand mold is prepared with molding sand usually river sand whose grain fineness number has been determined and some other properties which molding materials should have like green strength, refractoriness, hot strength, and so on. Immediately the bed is laid, the pattern is put inside the molding flask then it is filled with molding and backing sand. The pattern is not removed from the mold.

The second division deals with casting production and inspection. Three steps are involved. Step 1 deals with metal pouring. Casting materials are charged into the furnace and allowed to melt. Each metal has its melting temperature. The foundry man takes the melt from the furnace with pouring equipment and pours it into the prepared mold. Solidification of the casting takes place inside the mold.

Step 2 takes care of the shakeout and de-gating of the casting. The process of removing the casting from the mold is the shakeout while the removal of the sprue, runner bar, and ingates from the casting is the de-gating.

Step 3 which is the last of all sees to the cleaning and finishing of the casting. Here brushes are employed to clean by removing sand attached to the casting. Unnecessary projections are also cut off.

Evaporative pattern casting process parameters.

The evaporative pattern casting process is relatively new and from the works of researchers, many process parameters have been known to affect/influence the process. It is also believed to be very sensitive as these variables affect the soundness of the castings produced by it. In both local and industrial applications of the process, difficulties have been encountered.

The difficulties have led to casting defects. Some of the process parameters are the patterns, pattern coating, pouring temperature, vibration, gating ratios and geometry of components.

Patterns in evaporative pattern casting process.

Patterns are made of expanded polystyrene foam; polymethyl methacrylate and polyalkylene carbonate. The materials are light in weight. They must be carefully handled after production to avoid distortion. The expanded polystyrene is used for aluminum and its alloys; it is not used in iron founding because of the defects that it causes for the casting.

It is known that the materials have different density values and this has effects on the quality of castings produced. It is then required that there must be consistency in the material used as a pattern for consistent quality in terms of the mechanical properties and the microstructures of the castings.

It is observed that the pattern used in evaporative pattern casting is in sharp contrast to the ones employed in the traditional sand casting methods where wooden, metallic and plastic materials are used to create cavities in the molds and then removed before pouring casting material into the molds.

Pattern properties.

The properties of the pattern significantly affect the casting quality. also showed that to a very large extent, defects caused in castings are attributed to the non-uniformity in pattern density. Consistency should be observed in the properties of the pattern, especially, the density which is a result of the bead compaction.

The density affects the flow of molten metal expected to displace the pattern material buried in the sand mold when the compaction of the beads on one side is different from the other side. Instead of having the uniform flow of molten metal, the metal tends to flow to low-density areas, thus causing folds and foam inclusion in the casting because metal flows faster in the area of low density showing low bead compaction. The decomposition of the patterns may be by scission or unzipping; a number of reactions are involved in this before completion and patterns rejected usually become environmental problems.

Pattern coating.

Pattern coating which is a mixture of refractory material and binder or many times only the refractory material, when applied on patterns, forms a solid layer on the pattern when it is dry. The coating must be permeable to allow gas to escape into the surrounding; otherwise, the gas would be trapped, causing defects in the castings. The escape of the gas from the mold is subject to the coating applied on the foam. Mold filling times decreased with the permeability of the coatings.

Depending on the type of coating, the time to fill the mold with the liquid metal is affected. The gas generated must escape continuously from the mold to avoid defects. The pyrolysis products are the main causes of defects in the evaporative pattern casting process. The release of the gas products should be on time; if they are too fast, it leads to mold collapse because of pressure drops such that the coating layer is no longer supported and could not, therefore, bear the weight of the sand.

An ideal pattern coating must allow gaseous and liquid foam degradation products to be transported out of the casting in a timely and balanced manner. Variables such as coating material, percent solid, viscosity, liquid absorption capability, coating thickness and gas permeability affect the quality of casting.

The application of the pattern coating must be carefully done on the pattern to ensure that it is consistent. If the coating is applied wet, the wettability must be consistent. If it is applied dry, the thickness must be consistent. This will allow for controlled liquid absorption and gas permeability. The coating layer provides clean and smooth surfaces on the castings because it is easily removed.

In reality, the particle size can be reduced to 65 μm. This gives a good surface finish to the castings produced with it. The surface roughness obtained in the castings when the coatings are used is subject to the type of casting method employed.

Usually one of the three methods; spraying, dipping and swabbing, is used to apply the refractory coating to the surface of patterns. Spraying has proved to be the most effective in that a uniform spread of the coating is obtained leading to the almost uniform thickness. In reality, constant thickness cannot be obtained for all patterns. The dipping process will not give a uniform spread of the coating. There is great variation in the thickness that would be obtained. In the swabbing, the brush used in the painting makes marks on the pattern thereby reproducing the marks on the castings produced with it.

Molding practices in evaporative pattern casting process.

After the patterns have been produced by injection molding as applied to the industrial method or machined out from a block of polystyrene, they are assembled with the gating systems design for the patterns and coated with refractory material. Time is given to allow the refractory material to dry. The patterns with the gating systems are then taken and positioned in the molds and supported with green molding sand and rammed carefully. The ramming is necessary to provide rigidity for the molds so that they would not collapse when molten metal is poured.

The patterns with the gating systems buried in the molds are not removed like those in traditional sand casting methods. When the liquid metal is poured, the patterns and gating system evaporates leaving only the castings at solidification. The schematic of the pattern-gating system assembly positioned in the mold is shown in Fig. 145. The thermal energy helps foam patterns to decompose and leave desired dimensional casting products. As the metal replaces the foam pattern, the process involves a series of complex foam reactions: collapse, liquefaction, vaporization, and depolymerization. The degradation products are vented through the coating layer into the surrounding sand.

The quality of castings in the evaporative pattern casting process is strongly affected by the elimination of liquid and gaseous products produced by the foam pattern. If the foam pattern pyrolysis products cannot be effectively eliminated from the casting, they can cause various defects. After the castings cool down, they are shaken out, de-gated, cleaned, and inspected for quality. These final procedures are similar to those used in the conventional casting process.

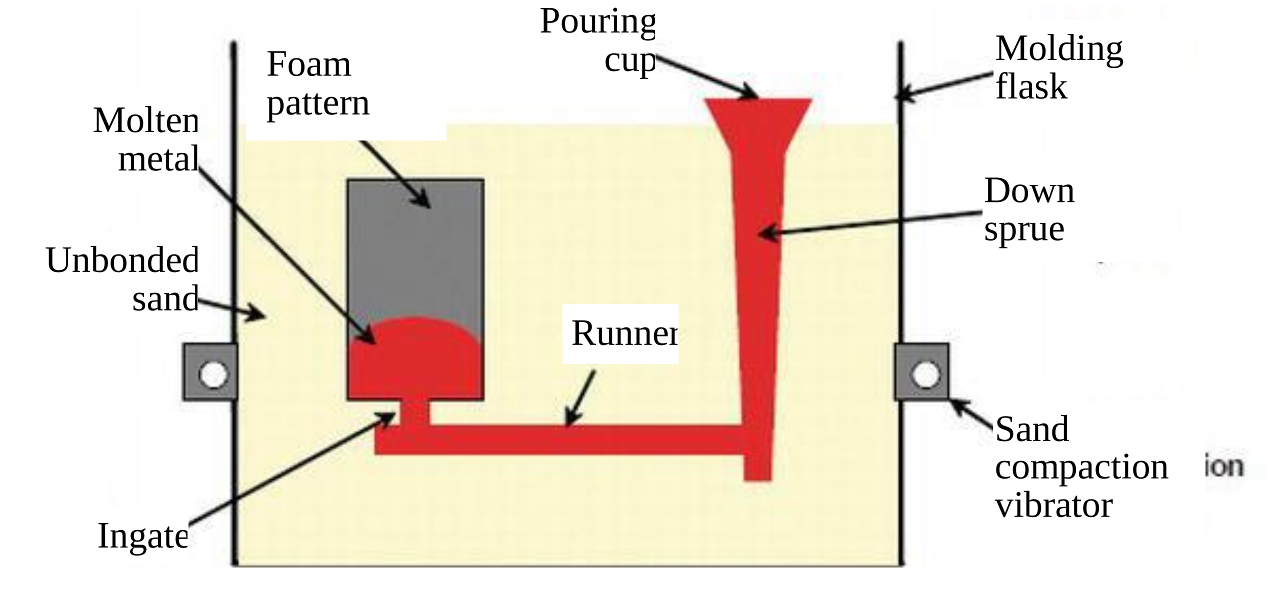


Figure 145 – Schematic of molten metal pouring in evaporative pattern casting process

Vibration.

The vibration of the sand around the pattern to obtain the optimum density and compaction of the mold is a critical feature in the successful production of castings by evaporative pattern casting. The vibration characteristics are critical since the sand must be caused to flow into internal cavities and undercuts for good compaction.

The frequency, amplitude, and intensity of vibration, the direction of movement impacts, the shape of the container, and the point at which the vibration is applied all influence the quality of the castings. Vibration can modify the solidified microstructure by promoting nucleation and thus reducing the grain size and leading to a homogenous microstructure. The frequency can be of range 10 to 60 Hz, the amplitude ranges from 0.11 to 0.45 while the intensity which is quantified as force ranges from 80 to 12,000 N.

Characteristic behavior of molten metal in prepared molds.

To eliminate mold erosion in sand molding processes, it is important that the gating and feeding system must be designed and constructed for the particular casting that would be produced. It is the gating system that will eliminate turbulence that may occur as a result of the pouring of the liquid metal into the prepared mold. It enters the mold by gravity.

In evaporative pattern casting, immediately the liquid metal contacts the buried polystyrene foam, it begins to decompose and violent gas escapes from the mold through vents that have been provided. Physical and chemical reactions begin to take place inside the mold. The gas evolving develops a back pressure to resist the advancing liquid metal; by this, a kinetic zone is established. The molten metal displaces the foam because of its high temperature; resulting in pyrolysis products like monomers and emissions toxic to humans.

All the products formed in the mold have been established as potential causes of defects in castings obtained by the evaporative pattern casting process. Attempts have been made to study comprehensively the behavior of the liquid metal poured into evaporative pattern casting molds. Some researchers have employed X-rays to study the physico-chemical reactions taking place at the sites. Attempts have been made to model and simulate the interactions that have been known to occur for possible predictions. However, the difficulty still exists to quantitatively/qualitatively represent that the behavior of the fluid in the mold.

Pouring temperature.

This refers to the temperature at which the liquid metal is poured into the mold. It is one of the pouring material variables. By experimental determination, it has been established that pouring temperature has significant effects on the mechanical properties of the castings obtained by sand molding processes, evaporative pattern casting inclusively. Usually, it is at high temperatures that the casting material is melted in the furnace. Once the casting material melts, the prepared mold is poured. By experiment, it is determined that some aluminum alloys when poured into an evaporative pattern casting mold at 650°C, quality casting obtained.

Effects of pouring temperature on the mechanical properties and microstructures of casting can be studied by observing a range of values and levels taken within the range when the casting material is poured at the levels, opportunity is provided to compare results in terms of visual and mechanical examination of the casting obtained. The visual examination reveals some defects on the surface of the casting if they are existing. Surface roughness can as well be measured. The mechanical examination reveals the mechanical properties in terms of impact, tensile, creep, % elongation, hardness and elasticity. These provide an evaluation of the casting to know if it is of good quality. Sometimes the effect of the pouring temperature is examined on the grain refinement.

Each casting material has a temperature range at which it must be poured. Therefore the temperature is measured to determine the pouring range. Usually, a k-type chromium-nickel thermocouple is employed to take the measurement. It has a grinded junction. Other forms of thermocouplies can be used. The pouring temperature because of the high thermal energy that it has is responsible for the dissociation of H_2O in the molding sand, thereby producing H_2 which escapes from the mold and the decomposition of the evaporative patterns used in the evaporative pattern casting process.

The gating system.

Molten metal is poured into an already prepared mold through a gating system. The gating system designed for casting is informed by the weight of the casting. There are many parts that make up the gating system. A pouring basin is a reservoir at the top of the gating system that receives the stream of molten metal poured from the ladle. Next to the pouring basin is the sprue which usually tapers down to the sprue base well. The sprue usually in the form of a cone has an exit diameter determined by employing the formula for the area of a cone.

The sprue base well is usually taken to be five the size of the cross-sectional area of the sprue exit. The choke informs what the cross-sectional areas of the runner bar and ingates will be by employing the gating ratios. Pressurized and non-pressurized gating ratios are used; pressurized for the ferrous castings and non-pressurized for the light alloys such as Al-alloys. The runners and ingates convey the molten metal to the cavity of the mold or the polystyrene pattern buried in the mold in the case of the evaporative pattern casting process. The riser's function is to feed the casting during solidification so that no shrinkage cavities are formed.

There are many types of gating system designs; top, bottom, side and step. The gating system enjoys the advantages of both the top and bottom gating designs. However, a gating system should be used based on the shape of the component to be produced. For example, the bottom design is best for the cylinder. Figures 146–148 show the top, bottom, and side or parting line gating designs. These gating systems must be designed, constructed, and assembled with the patterns and positioned in the mold ready for the pouring of the liquid metal.

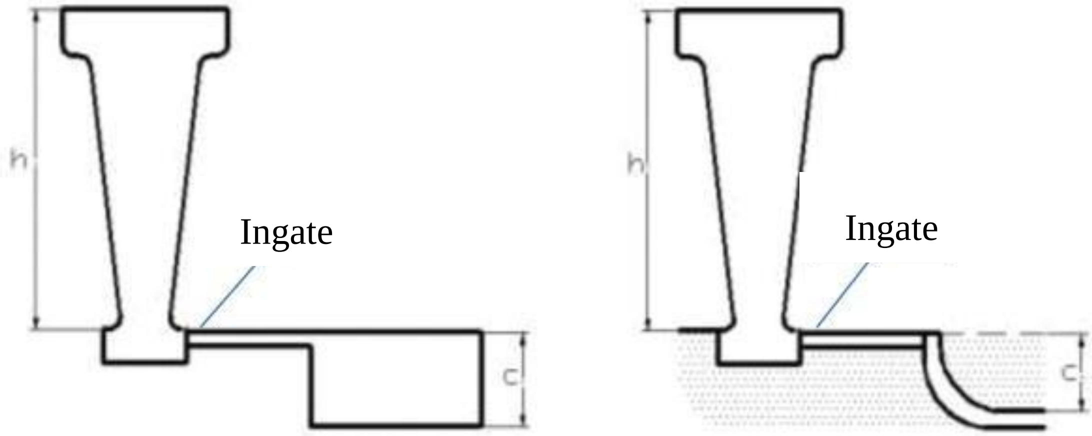


Figure 146 – Top gating system

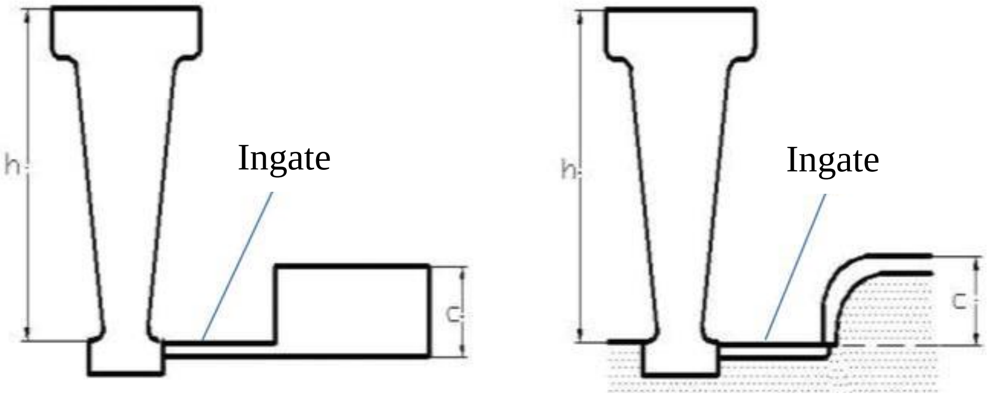


Figure 147 – Bottom gating system

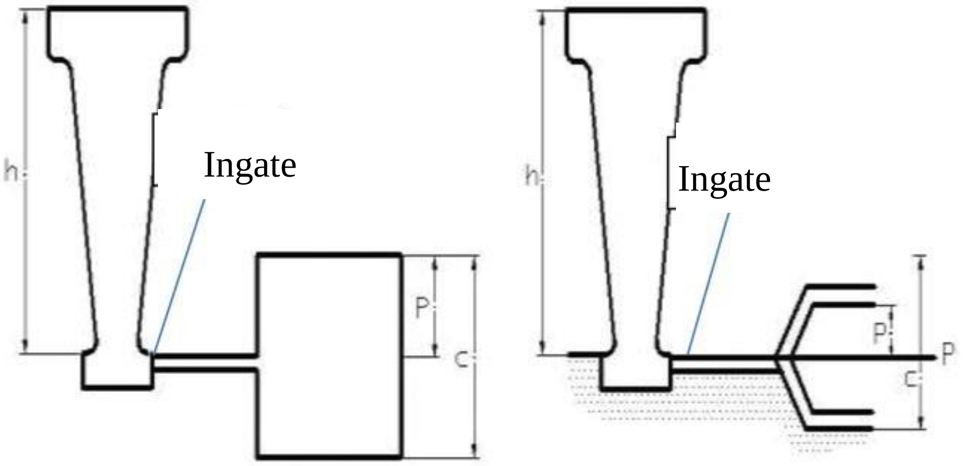


Figure 148 – Parting line gating system

Specific work on evaporative pattern casting process.

The influence of refractory material porosity on mold filling in the evaporative pattern casting process by changing coating thickness shows that mold filling times decreased with the permeability of the coating. From a practical perspective, the gas permeability of the refractory coating has been a critical factor in the evaporative pattern casting process for casting soundness control.

The fundamental knowledge may lead to a more environmentally responsible process by reducing the airborne emissions from evaporative pattern casting process. A limitation known with evaporative pattern casting which has not been eliminated by experiments is blow hole formation. This provides a platform to make some analysis on the variables that may have weighty results on the soundness that would be produced using the evaporative pattern casting process.

Pouring and pouring equipment.

To achieve soundness in metal casting, more importantly in EPC Process that is susceptible to many variables, pouring the liquid metal into the sand mold is carefully done. In pouring, the liquid metal must be clean and free from slag. The pouring is done such that air aspiration and turbulence are excluded. By this, mold erosion is avoided and defect like metal penetration does not occur. Sound castings are then obtained.

The pouring equipment which is the ladle should not be too heavy for the foundry man to carry, otherwise, a mechanical system should be used to carry out the pouring to prevent accidents that may occur as a result of the inability of the foundryman to carry the equipment.

Table 34 – Advantages and disadvantages of evaporative pattern casting

Advantages	Disadvantages
Easier to perform than other types of casting processes.	The process offers a good surface finish but it is subject to the surface of the pattern.
Supports a wide range of shapes and sizes.	
Increases thermal and abrasion resistance.	The pattern density has a significant effect on the quality of casting produced with it.
Low material and operational costs.	
Complicated shapes can be cast without using cores or drafts.	The density values of the patterns vary due to the level of compaction of the beads by steam molding.
Supports ferrous and non-ferrous metals.	
It offers high dimensional accuracy and superior casting surface smoothness.	The foams, if not carefully handled may be distorted or permanently damaged.
It offers a high surface finish (smoothness) to the casting.	The evaporative pattern casting foam pattern undergoes a series of complex reactions: collapse, liquefaction, vaporization and depolymerization.
Castings have improved heat resistance and also abrasion resistance and other cast steel properties.	
Reduced work process, unlike other casting methods.	Porosity defects are created when a fast-moving metal front engulfs portions of the foam pattern which form voids in the solidified castings.
Ability to cast lightweight parts.	
It is easy to perform when compared with other casting processes.	
The process is widely documented, with guides revealing the step-by-step process.	Surface defects are present at the surface of the casting, and are a result of foam pyrolysis products trapped at the metal-coating interface.
The process offers the manufacture of complex shapes without the need for cores which must be provided for in the production of holes and passages when the green sand mold method is used.	Variables like refractory coating, pattern density uniformity, and pouring temperature are critical factors affecting the formation of defects in the castings.

7.9.1. Lost foam casting

Lost foam casting is a type of evaporative pattern casting. This method is quite similar to investment casting which uses wax instead of foam in the pattern-making process.

The foam pattern was first used in metalworking in 1958. Although this mold casting technique is not as popular as other methods such as sand mold casting or permanent casting, it maintains outstanding advantages, especially in casting complicated and precise molds.

Unlike traditional methods, which include the pattern withdrawn process before casting and require skillfulness in the pattern removal step, concerning to the lost foam method, the pattern is evaporated when the molten metal is poured into helping to reduce these considerations.

Lost foam casting is best suited for intricate designs found in automotive, marine, agricultural, military, and heavy truck applications. It is also a perfect solution for mass-produced pieces that all need to be uniform in dimension and shape.

The process.

Lost foam casting is a process used to make complex and intricate metal parts. This method can create full, net-shape patterns with unparalleled dimensional accuracy and precision. It also cuts several steps out of the manufacturing and assembly processes that ultimately lead to saving time and extra labor costs.

The lost foam casting technology included the following steps: designing the pattern; applying insulation painting; placing the pattern into the sand flask; pouring the molten metal, and collecting the castings.

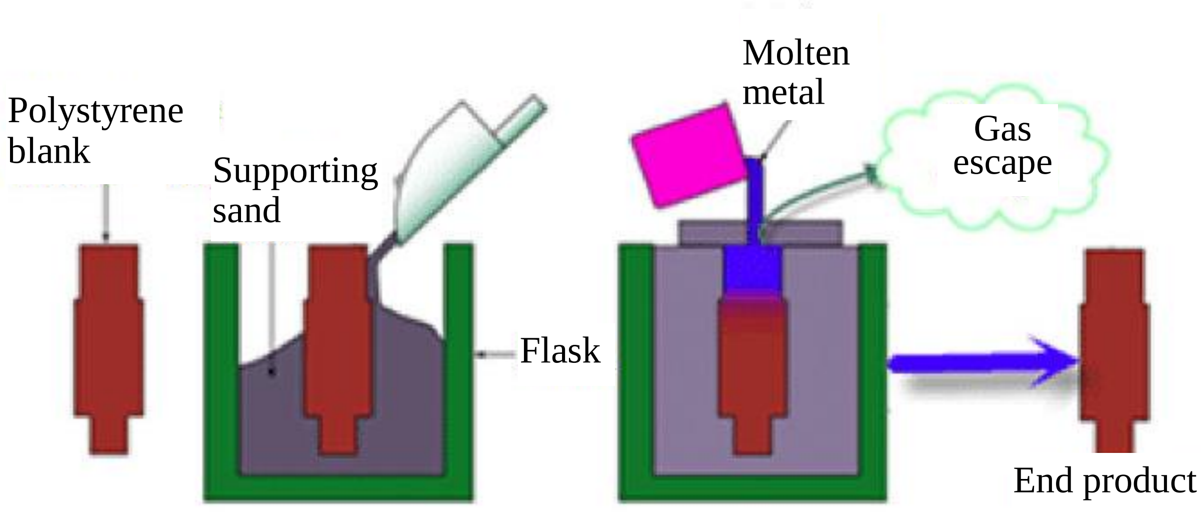


Figure 149 – Lost foam casting process illustration

1. A foam pattern is made using expanded polystyrene. This can be formed by closed-die molding, machining, or assembly from multiple parts. Risers and gates are included at this stage.

2. Multiple finished patterns are glued together to form a cluster.

3. The cluster is coated with permeable refractory slurry, usually by dipping. When dry, the refractory coating forms a hard shell around the foam pattern. Various refractory coatings can be used depending on the surface finish required.

4. The lost foam mold is placed in a foundry flask or box and surrounded by loose, un-bonded sand which is then vibrated to compact.

5. Molten metal is poured into the mold. The foam pattern instantly vaporizes, and metal fills the void left within the refractory shell.

6. Once cooling and solidification have taken place, the sand and shell are broken away, risers and gates are removed, and the finished foam cast piece remains.

7. The cast product or component can then be finished, treated, or machined as with any other casting.

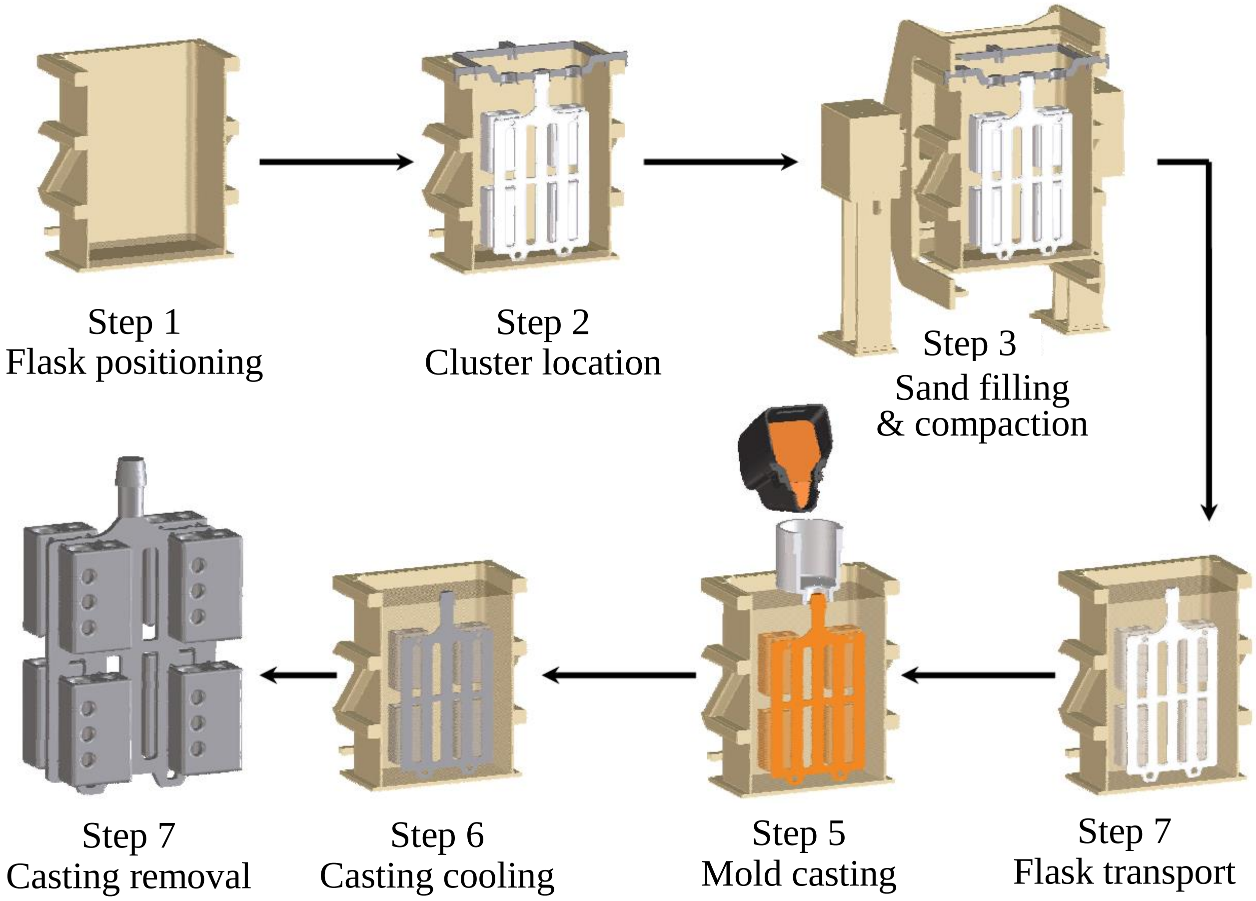


Figure 150 – Main steps in lost foam molding and casting

The first step of lost foam casting is the creation of the foam mold. A block of polystyrene foam is cut into the exact shape of the finished product using hand or power tools. For applications where the dimensions of the finished piece must be exact, power tooling is preferred for a more consistent shaping of the foam. The mold is then dipped in sheetrock mud or plaster and coated thoroughly.

After the foam mold is finished, it is buried in a container; for example, a metal drum; filled with compacted sand. The very ends of the foam shape are left exposed to facilitate the entry of the molten metal into the mold. A homemade tool can be used during this step to help the process along further. This tool, which consists of a hinged cylinder that can be opened and closed along the side by long handles, is placed on the sand so that it surrounds the foam piece. When the metal is poured, the cylinder walls contain it and allow it to build up over the piece, creating more pressure and, therefore, a more thorough casting.

Lost foam pattern.

A foam pattern and gating system are made, in most cases using the foam molding press. The process of pattern-making can vary depending on the number of items that will be replicated.

Lost foam patterns can be produced by several means. In volume production, multiple copies of patterns are prepared by molding. It is also possible to machine foam patterns on a high-speed CNC router. Both of these methods involve considerable capital investment, so most hobby casters fabricate their patterns by gluing together simple shapes to build up complex patterns.

Firstly, a pattern is designed from polystyrene foam. This type of foam plays an important role in this casting method. It is a good thermal insulator and chemical resistance, enable working normally at a temperature below 75° C.

Depending on the difficulty and details of the product, the foam pattern can be made in different manners.

For highly detailed casting patterns, the foam pattern is partly made and glued together. For the small volume, foundries often make patterns by hand-cut or machined from a solid foam block. If the pattern is simple enough, a hot wire foam cutter can be applied. In case the volume is large, the pattern can be mass-produced by a process similar to injection molding.

Polystyrene beads are injected into a pre-heated aluminum mold at low pressure. After that steam is applied leading to the polystyrene

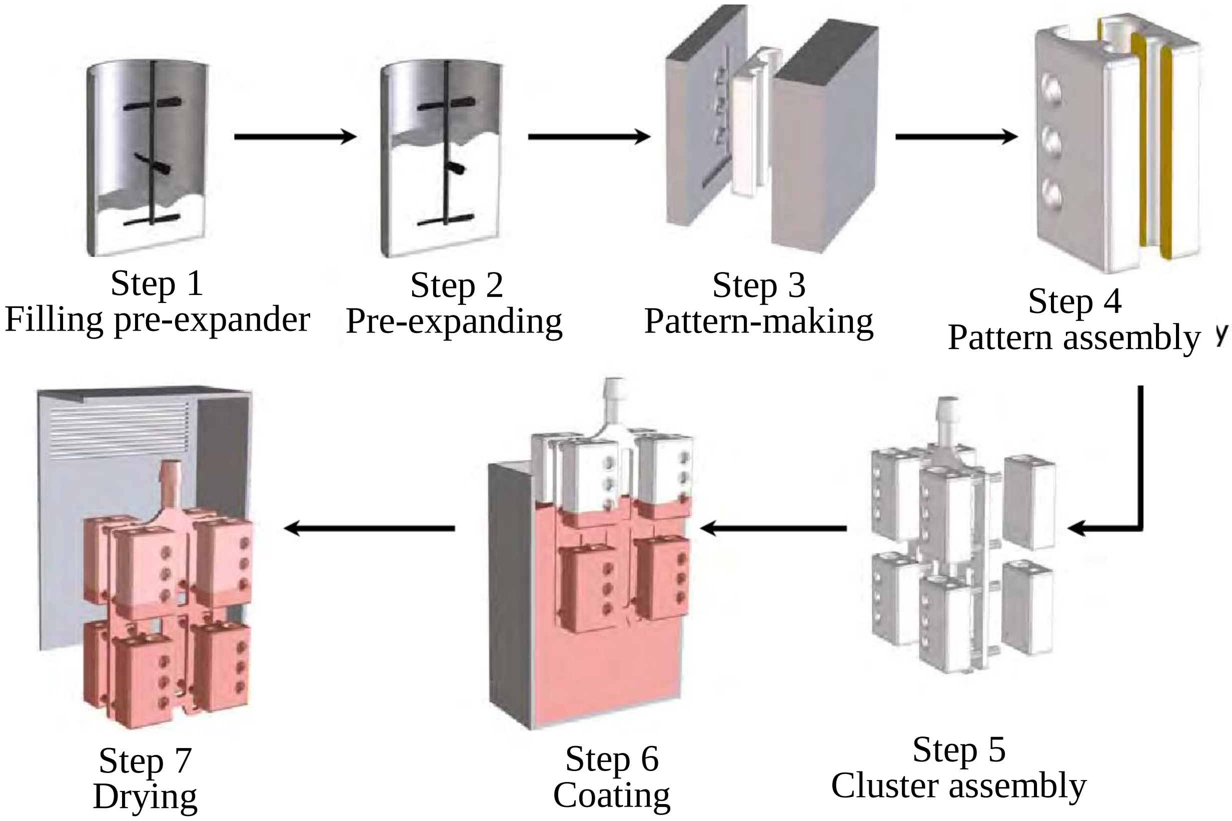


Figure 151 – Main steps in complete pattern (cluster) manufacture

expanding more to fill the empty cavity and then form the pattern or a section. The final pattern is approximately 97.5% air and 2.5% polystyrene.

The pattern can be molded with either the risers and gates already in place, or it can be assembled (usually glued) from various molded parts. In the pattern-making process, very detailed attention is needed as it will determine the quality and reliability of the final product.

Properties and considerations of manufacturing by lost foam casting:

- Lost foam casting is ideal for creating metal products in several industries, including automotive, arts, defense, agriculture, and computer technology.
- The process is suitable for a wide material range, such as cast iron, alloy steel, ferrous alloy, carbon steel, and alloy aluminum, enabling the production of different metal parts.
- Manufacturers leverage polystyrene foams to design patterns due to their exceptional thermal and chemical properties.
- Unlike other types of casting, the molten metal evaporates the polystyrene foam mold in lost foam casting, leaving metal products that require little to zero shaking.

- No draft is required as the pattern is vapourised in the pouring process.
- Lost foam is also an environmentally friendly process as emissions are low and the sand is reused.
- Lost foam casting maintains an excellent surface finish (so less finishing is required). The process is dimensionally accurate requiring less machining.
- In a nutshell the lost foam casting process is more efficient, meaning we can make more castings with better lead times.
- Minimum wall thicknesses are 2.5 mm, tolerances can be held to .3% on dimensions.
- Surface finish can be held from 2.5mm to 25mm (0.1in to 1.0 in) rms.
- Size limits are from 400 g (1 lb) to several tons. No draft allowance is required.
- Manufacturers leverage lost foam casting to fabricate products, such as cylinder blocks, valves, automotive engines, gearbox details, fire hydrants, cylinder heads, and 3D models, since the technique creates castings with high dimensional accuracy.
- This technique is also well-suited for creating highly detailed and complex products, such as lamp posts, pump housing, pan support, gas burners, and fences.
- If the designs of metal products are complicated and prioritize excellent finishing and dimensionally accurate products, lost foam casting is the most viable option.

Lost foam casting is relatively a new casting technique that has the characteristics of both investment casting and sand casting. It is similar to evaporative pattern casting, with the pattern made up of foam instead of wax. The foam pattern is coated with refractory material, as in investment casting. The casting process exhibits the quality and accuracy of investment casting with the lower costs and greater flexibility of sand casting.

Lost foam casting is applied in a variety of industries ranging from the arts, computer technology, agriculture, national defense, automotive, to civil areas. For many cast products cylinder heads, cylinder blocks, pipe fittings, valves, fire hydrants, motor starters, 3D models, gearbox details and more the lost foam casting process is the perfect match.

High-detailed and complex lamp posts, gas burners, fences, pump housing, aluminum castings, pan support, etc. are also often processed by the lost foam casting.

Table 35 – Advantages and disadvantages of lost foam casting

Advantages	Disadvantages
Lost foam casting can cast very complicated castings of many different sizes.	The castings created by lost foam casting aren’t particularly strong.
It is advantageous for guaranteeing high precision and a smooth surface finish.	The patterns are damaged or distorted easily because of their low strength.
Lost foam casting frequently becomes possible to use a single mold to generate multiple lost foam castings.	The original molten iron has high sulfur content and generates many sulfides, which promotes the formation of inclusions.
The final products maintain high precision and a good surface finish.	Wrinkle defect is due to polystyrene foam in high-temperature metal pyrolysis to form a large amount of carbon to save the ball outside the cavity.
Casting by the lost foam technique guarantees nearly no errors or defects.	
Lost foam casting is used to cast small to medium-complex products from some metal alloy materials.	Low pouring temperature is not conducive to the floating and removal of slag inclusion.
Depending upon the selection of the metal alloys, this form of casting often permits a manufacturer to generate large runs of cast parts with excellent surface finish properties.	In the pouring process of lost foam casting if the sprue cannot be filled, the air is drawn in to form pores and casting will produce porosity defects.
Lost foam casting is often preferable to cast complicated and detailed products.	Castings by the lost foam technique are naturally susceptible to damage, such as fracturing and breaking, when stressed.
This process usually does not require extensive machining.	The pattern costs can be high for low-volume applications.
This method is also more economical than investment casting because it involves a few steps.	If closed-die molding is used to create the pattern then the cost of the die can be high.
Applying the lost foam process, the foundries can save a lot of labor and production costs.	When compared to other casting processes, lost foam is typically more expensive.

7.9.2. Full mold casting

In full mold casting, foundry engineers use thermally decomposable materials such as polystyrene foam to cast patterns. This metal casting process, which is akin to lost wax casting, evaporates the foam by pouring the molten metal directly into the mold. Thus, the casting process is expendable. The polystyrene patterns in full mold casting can be designed using computer-aided software, which helps to make changes to its design prior to the actual casting process being completed.

A vacuum is applied to the flask and molten metal is poured into the pattern. Molten metal vaporizes the polystyrene material as it flows into the mold cavity. Once cooled the casting is removed.

Many products made of iron, nickel, and copper alloys, steel, and aluminum can be cast using this metal casting method. The castings with complex patterns such as manifolds, auto-brake parts, and pump housings are cast too.

Full mold casting is beneficial to complex castings that are typically made with the use of drafts and cores. It is an effective process for small-scale and large-scale mold manufacturing, and saves production time, as the polystyrene pattern does not require to be shaped such as in wood patterns.

Materials.

- All castable materials with casting temperatures above that required to vaporize the polystyrene (≃700° C).
- The vaporized polystyrene produces carbon which will diffuse into the surface of steel components, altering their composition. This is most serious for low-carbon steel components but can be avoided by coating the pattern with 2 or 3 coats of refractory slurry, then firing at approximately 1000°C. This removes the pattern, leaving a thin ceramic shell that is surrounded by sand before casting conventionally.
- Components tend to contain fewer gas defects, due to vacuum during pouring and solidification.
- Expansion defects tend to be less since the sand is unbonded, and since the metal does not come into contact with the sand there are no exogenous inclusions.
- Hot tears are reduced since the mold offers very little resistance to contraction.

The process.

The patterns are made with materials that disappear during the metal casting process. Once it is coated using a refractory material, the patterns are used in single-piece sand molds. The benefit of this process is that molds with intricate designs can be cast without having to use a draft for that. The patterns in small quantities can be handmade or produced in a machine using a solid foam block in full mold casting. As part of small quantity runs, the patterns can be cut using hand tools or automatic machines using a block of foam that is solid. For big volumes though, the material for the pattern can be inserted into an aluminum mold that is preheated and then steam is exerted on the material. After the pattern is ejected from the aluminum die, spruces and gating systems can be glued or hot glued to be precise into the polystyrene pattern.

Then, the pattern is placed into a molding box prior to ramming it for hardening the sand, and the gating systems and spruces are applied to the mold to allow molten metal enter each design and cutting made by it. Then, molten metal is poured on a pattern that is made up of polystyrene material, and once the metal in a liquid state comes in contact with the pattern, it disappears or evaporates and forms the mold cavity’s shape.

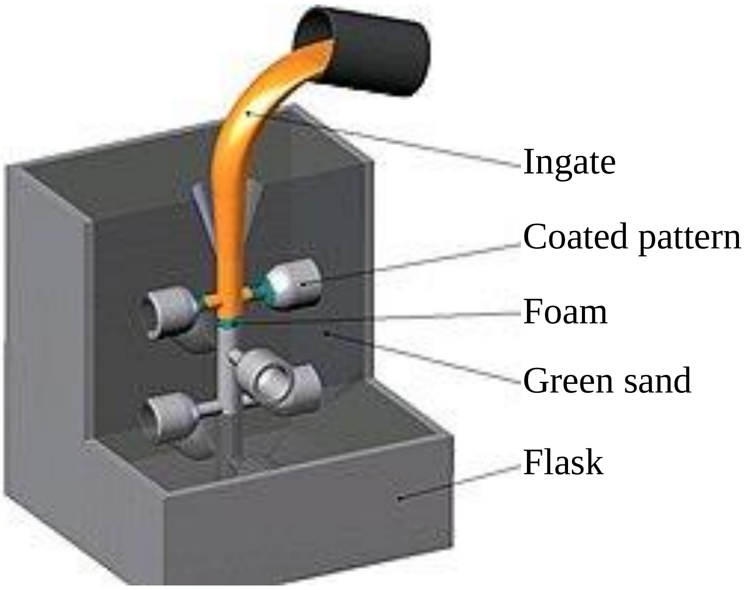


Figure 152 – Full mold casting

The full mold casting process consists of the following steps.

1. Injecting polystyrene beads into a heated aluminum die. Inject steam into the pattern, from a steam chest, to fuse and expand polystyrene beads.

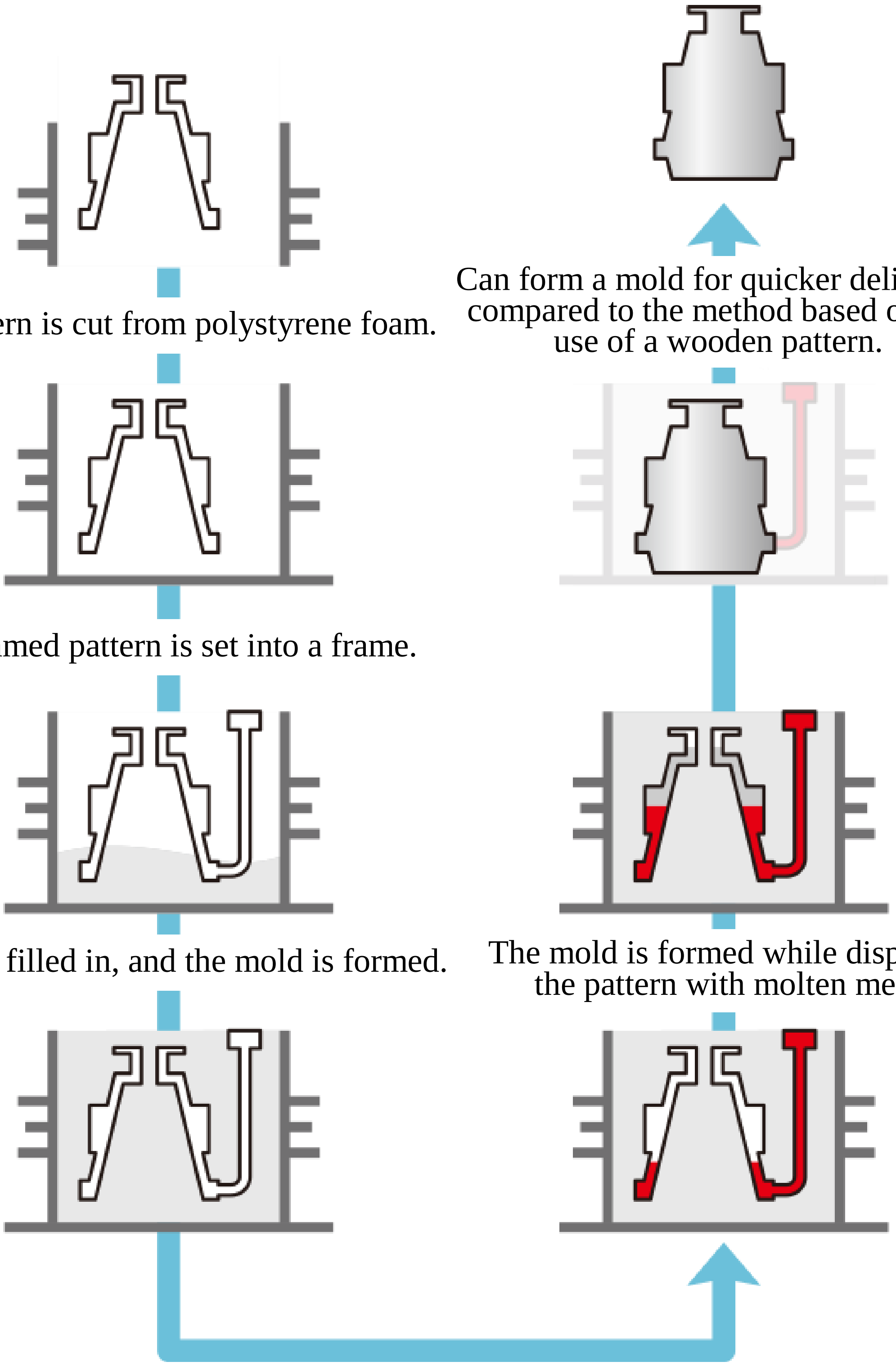


Figure 153 – Full mold casting steps

2. Cooling die, open, eject pattern and store for 30 days.

3. Glue-on runners, feeders and risers (where necessary) if not already an integral part of the pattern. Coating the pattern with a special factory coating and dry.

4. Placing the pattern in a «flask» of loose, dry, unbonded sand. Addition more sand and consolidate by vibrations. Applying the vacuum to «flask» and pour metal. Allowing to cool, remove casting and treat sand before re-use.

Properties and considerations of manufacturing by full mold casting:

- Faster start-up and delivery compared to conventional wooden patterns.
- «Vertical start-ups» with a huge production capacity of milling foamed patterns.
- No storage nor repairing costs for wooden patterns.
- Easy geometrical validation before casting.
- More flexibility for updating and revising design.
- Simple equipment and low operating costs enable savings of 10–20% to be achieved compared with conventional sand casting.
- Best suited for low to medium production runs of the order of 50–200 per day, for castings with a high sand/metal ratio that require complex cores.
- Patterns of special low-density polystyrene beads of diameter 1.25 mm are usually produced in cast aluminum dies, but for short runs and one-offs they can be machined from solid, or fabricated. The rate of pattern production in dies is approximately 1 pattern min–1.
- Patterns are initially undersize but quickly expand to die size. Shrinkage then occurs over the next 30 days, and patterns are usually used after this shrinkage.
- Ready-made patterns can easily be obtained from firms that specialize in packaging, and if patterns are small, large numbers can be assembled in one flask (molding box).
- Although conventional core and mold coatings have been used to coat the pattern, it is preferable to use coatings specifically designed for this purpose. These coatings, of zirconia, zirconia-graphite or silica, are more permeable than conventional coatings – aiding gas escape from the mold, and are more flexible – allowing contraction and expansion without chipping or cracking.
- Coarse, unbonded molding sand is used to aid permeability.
- Low-cost consumables, as the sand binder is eliminated and the sand is recycled.

- No knock-out or decoring problems, as the loose sand flows away easily.
- Tool life is excellent, since tooling does not contact either sand or liquid metal (this unusual advantage is only found elsewhere for the lost wax process).
- A vacuum is necessary to provide mold strength when the expanded polystyrene evaporates, and to remove the fumes.
- The pouring rate is critical and depends upon the density of the polystyrene, sand permeability, gating system, and the metal.
- Yields are slightly higher (50–80%) than the conventional methods since risers are seldom needed.
- Typical products include automotive castings such as camshafts, crankshafts, ball-valve casing,s and caterpillar tracks.

Design of full mold casting processes.

1. Complex 3D castings up to 2000 kg can be produced without the use of cores, but castings are usually in the range of 1–50 kg.
2. Distortion of the polystyrene pattern is possible in large castings (500 mm and above).
3. Castings have no parting lines and hence require less fettling.
4. Re-entrant angles are possible and draught angles can be minimized, with a saving in metal.
5. Minimum wall thickness is 4–5 mm (approx. 3 x bend radius), and dimensional accuracy and repeatability are better than with conventional sand casting processes. Uniform wall thickness can be maintained as there is no core displacement.
6. The surface finish usually shows a polystyrene bead pattern.

Full mold casting, on the other hand, is a type of evaporative-pattern casting that’s characterized by the use of a wax mold. Like with lost foam casting, it also uses a polystyrene foam mold that, when exposed to heat, vaporizes to fill the mold. The difference between these two evaporation-casting processes is that full mold casting includes sand as well. With full mold casting, the foam pattern is surrounded by sand. When molten metal is poured into the mold, the pattern vaporizes and hardens on the sand.

The pattern used in lost foam casting consists entirely of foam, which is placed inside a mold. The pattern used in full mold casting consists of the same foam pattern, but it’s surrounded by sand that separates it from the mold. When molten metal is poured into the mold, the foam pattern vaporizes and, therefore, fills the mold’s cavity. The casting is then allowed to cool, typically at room temperature, after which it’s removed.

Table 36 – Advantages and disadvantages of full mold casting

Advantages	Disadvantages
Full mold casting supports complex shapes.	Mold patterns are susceptible to cracking and other forms of damage.
This process provides highly accurate.	
Costs less than traditional wax-based casting processes.	While relatively inexpensive when performed for high-volume applications, such as the mass production of goods, full mold casting typically costs more than other casting processes for low-volume applications.
The full mold casting process doesn’t require draft or flash.	
This process supports a variety of sizes, ranging up to several tons.	
Can be used with molten aluminum, steel, iron, copper, alloys and many other metals.	
Highly efficient (produces little or no waste).	The density and strength of foam plastics are small and the pattern is easily deformed, which affects the dimensional accuracy of the casting.
Suitable especially for one-shot production including prototypes and artistic casting with short lead-time.	
Visual pattern check available in front of the completed foamed pattern.	Gases produced by the pattern during casting pollute the environment.
Higher flexibility for design with no sand cores needed.	
Higher technology is required as so-called “carbon residue ” needs to be connected and rumored from the casting.	As not all the manufactures of castings are fit for applying full mold casting.
Lighter casting with no draft angle and fewer design limitations.	Flashing is a thin skin created when liquid metal seeps between closed joints on the mold. If there is instability in the mold, flashing can be bad enough to deform the casting.
Good combination of CAD/CAM, 3D data, and material of the formed pattern; it is easier to work on the same shape of its real product and on formed pattern.	

7.10. Stir casting

Stir casting is currently the most popular commercial method of producing aluminum-based composites. The stir casting process was initiated in 1968. In this process, powder forms as reinforcing phases are usually distributed into molten metals by mechanical stirring. Nonuniform distribution and porosity in casted materials consider the main disadvantages of the stir casting process. Generally, the difference in density is between the liquid metal and the reinforcement and the consequent tendency to reinforce the sink or float, resulting in the nonuniform distribution of the reinforcement in the solidified composite.

Stir casting is a type of casting process in which a mechanical stirrer is introduced to form a vortex to mix reinforcement in the matrix material. It is a suitable process for the production of metal matrix composites due to its cost-effectiveness, applicability to mass production, simplicity, almost net shaping, and easier control of the composite structure.

The process.

The stir casting setup as shown in Fig. 154, consist of a furnace, reinforcement feeder and mechanical stirrer. The furnace is used to heating and melting of the materials. The bottom poring furnace is more suitable for the stir casting as after stirring the mixed slurry instant poring is required to avoid the settling of the solid particles in the bottom of the crucible. The mechanical stirrer is used to form the vortex which leads to the mixing of the reinforcement material which are introduced in the melt. The sstirrer consist of the stirring rod and the impeller blade.

The impeller blade may be of, various geometry and various number of blades. A flat blade with three number is preferred as it leads to an axial flow pattern in the crucible with less power consumption. This stirrer is connected to the variable speed motors, the rotation speed of the stirrer is controlled by the regulator attached to the motor. Further, the feeder is attached to the furnace and used to feed the reinforcement powder in the melt. A permanent mold, sand mold or a lost-wax mold can be used for pouring the mixed slurry.

Various steps involved in the stir casting process are shown in Fig. 157. In this process, the matrix material is kept in the bottom pouring furnace for melting. Simultaneously, reinforcements are preheated in a different furnace at a certain temperature to remove moisture, impurities, etc.

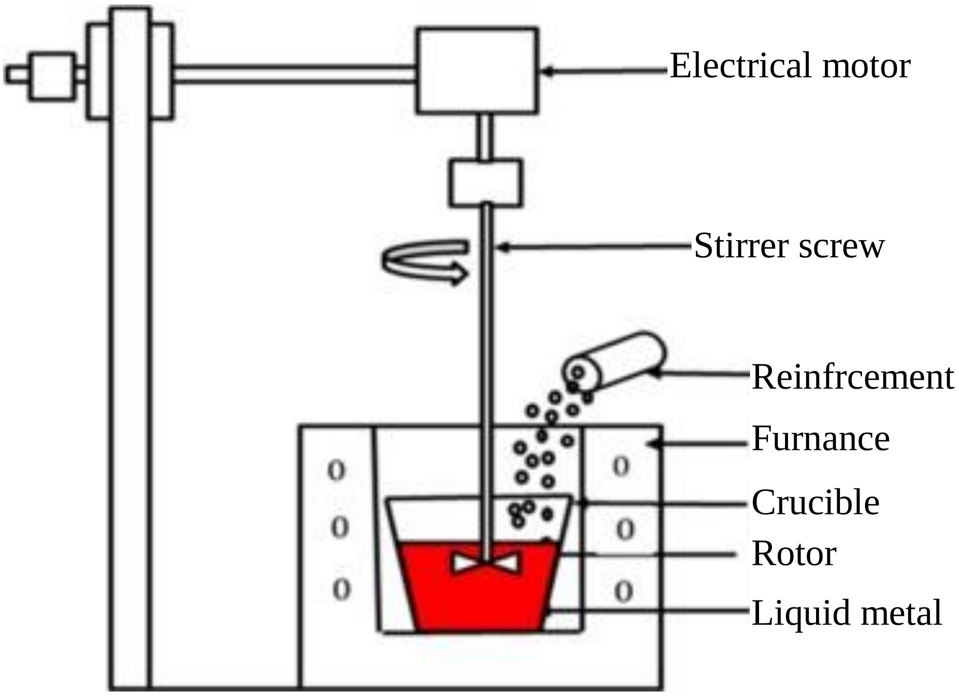


Figure 154 – Schematic of stir casting setup

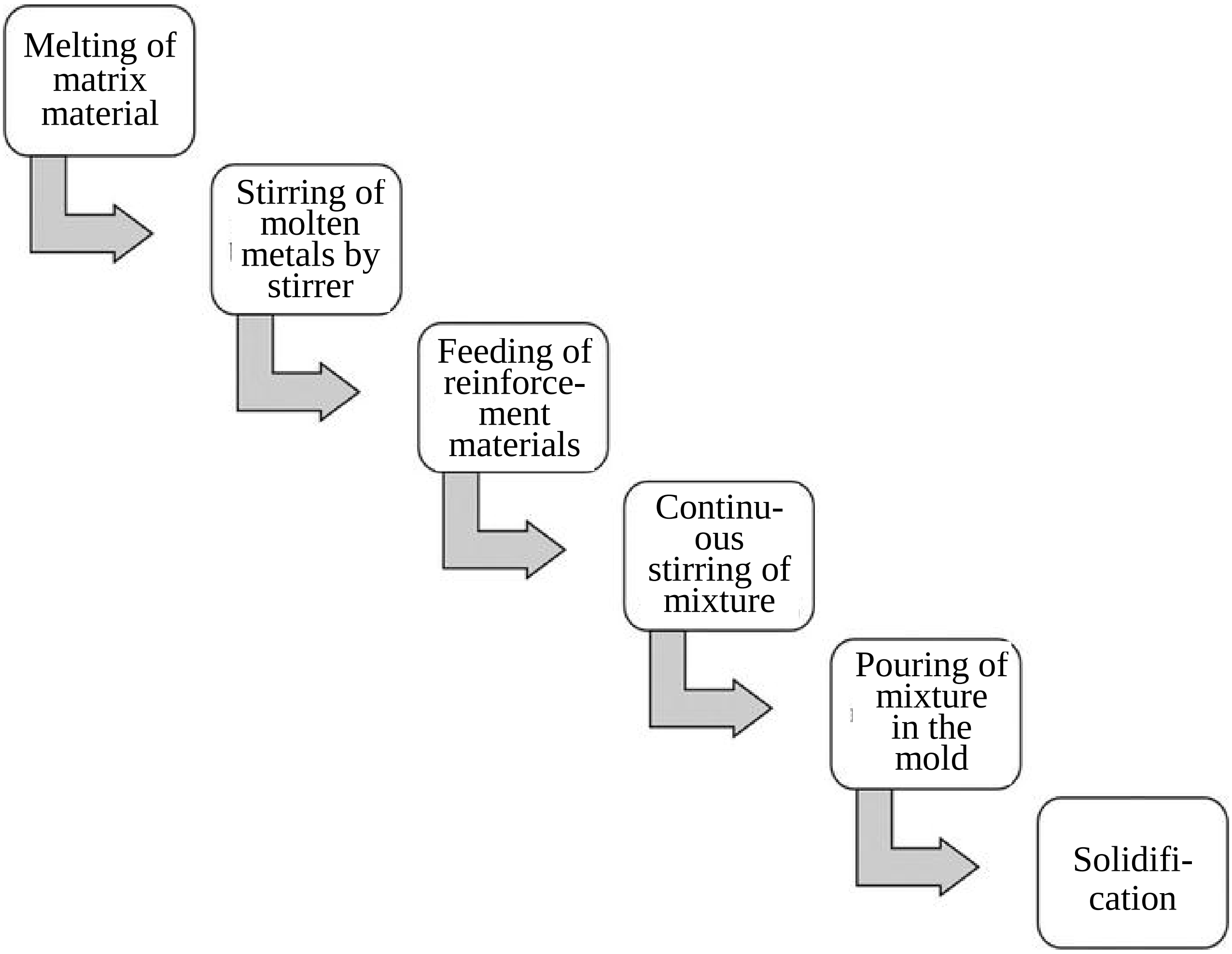


Figure 155 – Steps of stir casting process

After melting the matrix material at a certain temperature the mechanical stirring is started to form a vortex for a certain period time then reinforcements particles are poured by the feeder provided in the setup at a constant feed rate at the center of the vortex, the stirring process is continued for certain period time after complete feeding of reinforcements particles.

The molten mixture is then poured into a preheated mold and kept for natural cooling and solidification.

Further, post-casting process such as heat treatment, machining, testing, inspection, etc. has been done. There are various impeller blade geometry is available. Melting of the matrix material is a very first step that has been done during this process.

Melting of matrix material.

Out of various furnaces, the bottom pouring furnace is suitable for the fabrication of metal matrix composites in the stir casting route, this type of furnace consists of an automatic bottom pouring technique which provides instant pouring of the melt mix (matrix and reinforcement). Automatic bottom pouring is mainly used in the investment casting industry.

In this technique, a hole is created in the base of the melting crucible to provide bottom pouring and was shielded by a cylinder-shaped shell of metals. In the stir casting process, the matrix material is melted and maintained at a certain temperature for 2–3 h in this furnace.

After melting the matrix material, the stirring process has been started to form the vortex.

Mechanical stirring.

In the stir casting process, the mechanical stirrer is coupled with the varying speed motor to control the speed of the stirrer. There are various stages of impeller stirrer i.e. single stage, and double stage and multistage impeller. Double-stage and multi-stage stirrer are mainly used in chemical industries whereas single-stage impeller stirrer is commonly used for fabrication due to flexibility and to avoid excessive vortex flow. Fig. 156 shows various stages of the impeller stirrer.

Stirring plays a vital role in the final microstructure and mechanical properties of the casted composites as it controls the distribution of reinforcements within the matrix. Optimum mechanical properties can be attained by the uniform distribution of reinforcement and this problem is common to most processing techniques, including stir casting. This problem can be solved by the optimal selection of stirring parameters.

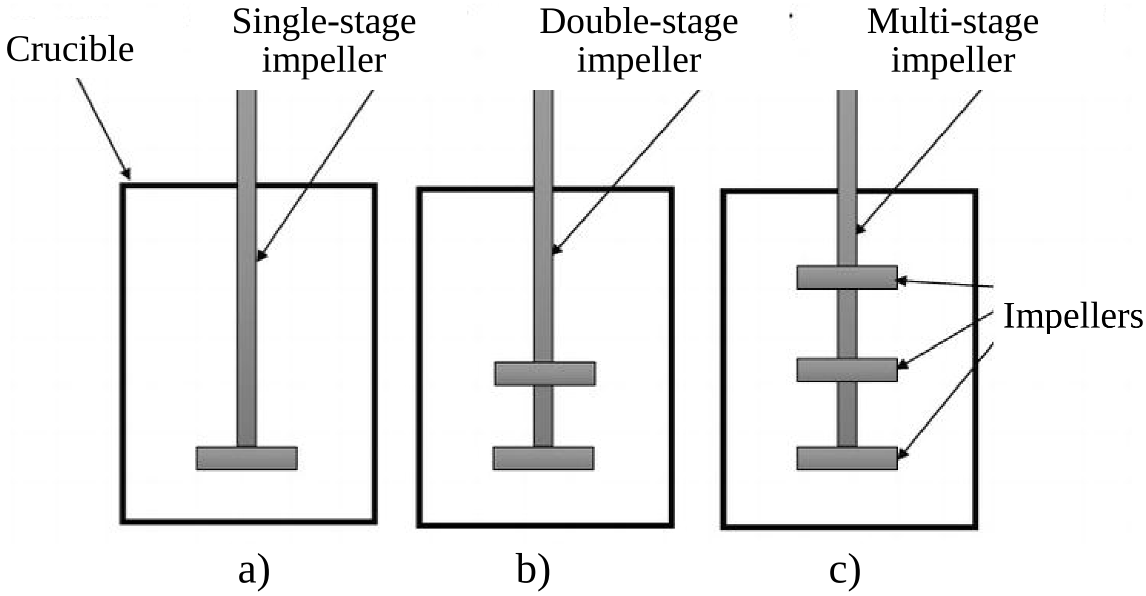


Figure 156 – Single stage impeller stirrer (a), double stage impeller stirrer (b), multistage impeller stirrer (c)

Optimum mechanical properties can be attained by the uniform distribution of reinforcement and this problem is common to most processing techniques, including stir casting. This problem can be solved by the optimal selection of stirring parameters.

Stirring time.

Stirring time is a significant process parameter in the stir casting process. Lower stirring time may lead to the clustering of particle reinforcements and results non-homogeneous distribution of reinforcement particles. Whereas, higher stirring time may lead to the deformation of the stainless steel stirrer impeller blade at very high working temperatures. The working temperature of some reinforcement such as boron carbide with aluminum matrix is very high. This temperature range is 850–950°C, which may deform the stirrer impeller.

Effect and optimization of stirring process parameters.

There are some significant stirring process parameters that affect the distribution of reinforcement at most. These parameters are stirring speed, stirring time, blade angle, stirrer size, position of the stirrer and feed rate of reinforcements. The main purpose of introducing a stirrer is to form a vortex in the melt which transfers the reinforcement particles in the matrix melt and maintains them in suspension. There are various types of stirrers are existing for this purpose but for minimizing the power requirement stirrer are designed such that it provides high degree of axial flow.

7.11. Ingot casting manufacture

Manufacturing by its nature involves the conversion of raw material to useful structures of a certain geometry. There are many types of raw materials and they come in many forms. All materials in their most basic state are in some way obtained from the Earth. Most metals are not simply found in the state that we use them in everyday life. Rather they must be processed to create the desired material. The manufacture of most metals into a raw useful material state is a well-developed process.

Typically the final result is a quantity of molten metal with the desired material consistency. The molten metal is usually either poured into large molds of basic shape, ingots, or fed into a continuous casting system. Continuous casting manufacture has the advantage of a higher rate of production, also raw metal produced can be cut into different desired lengths. A continuous casting operation can increase industrial efficiency by being fed directly into a rolling operation. Ingot casting manufacture is a more time-consuming process since it requires large molds to sit and solidify. Ingot manufacture, however, can produce very large raw-form castings and requires much less manufacturing complication than continuous casting.

Ingots are commonly round, square, or rectangular in shape. Each ingot constitutes a certain amount of metal. Numbers of ingots of known mass may be used to quantify material requirements. Often ingots may be transported over distances to move to the next manufacturing plant. Ingots vary in size from a few hundred pounds to 355 tons. Enormous ingots are produced for the unique manufacture of especially massive parts, such as turbine rotors.

A casting melt in steel making industry typically weighs around 300 tons. While not that commonly produced an ingot weighing 300 tons would take an entire casting melt. Many ingots are usually poured with each melt. Normally ingots poured are under 40 tons. Some ingots are remelted for particular casting operations, but most are subject to subsequent metal forming manufacture.

A large consideration in the process of ingot manufacture is the solidification of the part. Ingots usually take many hours to harden, the larger the ingot's mass the longer the solidification time. The outside surface of an ingot mold may be corrugated in order to speed up heat loss and cooling rate. The ingot solidifies from the outside progressing towards the center and thus the ingot's grain structure develops as columnar and points in the direction of solidification. This grain structure development is typical of cast materials.

Due to long hardening times ingots tend to also develop grains that are large. The corners of the ingot's mold are rounded in order to avoid planes of weakness corners may cause particularly concerning the columnar grain structure of castings. Shrinkage and gases liberated from the operation will cause a cast ingot to contain porosity and vacancies both large and small within the material. The large piping defect is cut from the casting, but most porosity in an ingot is acceptable since it will be removed through further processing.

The majority of ingots are hot rolled as the next step after being cast. Hot rolling will break up the large columnar cast grain structure and reform a smaller more uniform wrought grain structure. As hot rolling breaks down the grain boundaries, it pushes material, closing up and eliminating vacancies and porosity. Hot rolling further improves the quality of the ingot's material by also breaking up solid inclusions and distributing their material throughout the mass of the part.

Different molds may be used to produce ingots. The huge size of the mass of material that is solidifying makes vacancy due to shrinkage a particular problem in this process. Some molds may contain risers on the top or even gating systems to compensate for shrinkage. A very common ingot mold type used in the manufacturing industry, particularly in steel making is the big end-down mold.

This simple mold does not contain any risers or gating system and can be quite large. The big end-down mold is square, round, or rectangular, usually made of high-carbon iron, tapered from top to bottom, and sits on a base. The ingot is poured and allowed to harden. Once the casting is solid the taper allows for the mold to be lifted from the base where the ingot remains.

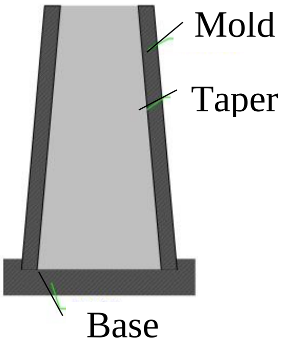


Figure 157 – Big end-down mold

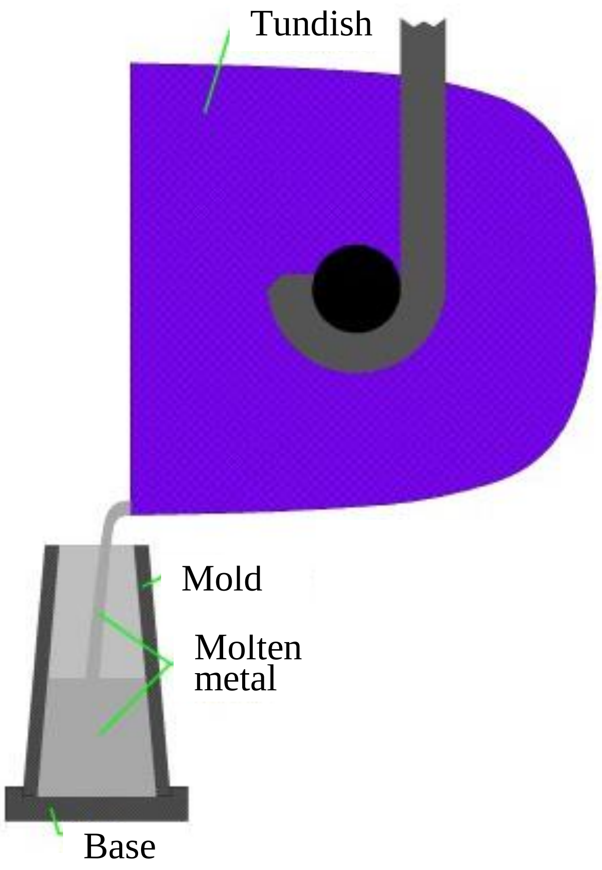


Figure 158 – Pouring of an ignot

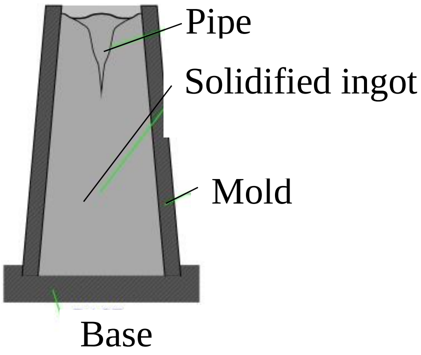


Figure 159 – Solidification of a cast ingot

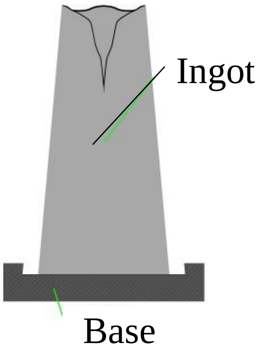


Figure 160 – Mold is lifted off leaving ingot on base

Steel production.

Steel is a fundamental and necessary part of our world. Steel comprises much of our physical civilization. The production of steel is of great importance and methods of steelmaking have been studied and refined over time. Both demand for and production of steel has also increased over time. Currently, hundreds of millions of tons of steel are produced in the world each year.

Steel ingots are of three basic types rimmed, semi-killed, and killed. Gases, particularly oxygen, trapped in the molten metal are released as the material hardens. This is facilitated by an extreme decrease in the materials solubility limit as its temperature decreases. Oxygen combines with carbon and forms carbon monoxide. Gases may not escape the melt and form spherical vacancies within the material that remain upon solidification of the steel ingot.

In order to deoxidize the steel before it starts to solidify, different elements such as silicon, vanadium, manganese, and aluminum are added to the molten metal. These elements will react readily with oxygen, forming metallic oxides. Metallic oxides float in the melt and can be removed with the slag. The three basic types of steel ingots produced in industry today represent three different degrees to which the steel melt is deoxidized.

Rimmed steel, usually low-carbon steel, is deoxidized to the least degree. In rimmed steel gases released during the process form spherical blow holes within the material, particularly along the outer rim. Impurities will tend to segregate more towards the center of the casting. Material flaws in rimmed steel due to impurities can be an issue.

The goal when producing rimmed steel is an ingot with sound outer skin. Blow holes within the metal may be closed up in later forming processes. They are acceptable as long as they do not break through the outer skin, becoming exposed to the atmosphere. Rimmed steel has little piping if any, since the space taken by the gas pockets negates the space taken by shrinkage due to solidification.

Semi-killed steel is partially deoxidized by the addition of oxygen-combining elements. Since semi-killed steel is not completely oxidized, gases still form in the melt and create blowholes. Gas porosity is much less than rimmed steel and is usually more prevalent in the upper portion of the ingot. A semi-killed steel ingot may have a little bit of piping. The semi-killed manufacturing process is an economical method of creating steel ingots.

Killed steel is produced by the full oxidation of the metal melt. Enough oxygen-combining elements are added to the melt and the formation of metal oxides eats up all of the oxygen preventing the development of gas. Metallic oxides can form solid inclusions or combine with the slag, and can be scooped out with or along side it.

The molten steel will sit quietly when the ingot is poured, hence the name killed. Killed steel has excellent chemical and mechanical properties that are uniform throughout the material. This high-quality steel is free of porosity and blow holes. A killed steel ingot does not compensate for shrinkage through porosity and hence will develop a large pipe. The pipe of a killed steel ingot is usually cut off for scrap.

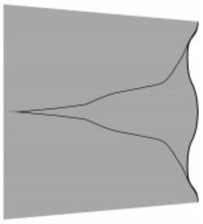


Figure 161 – Pipe

Advanced refining techniques.

In the modern manufacturing industry, there is a large demand for higher-quality metals. Parts that serve critical applications should be assured not to fail due to flaws in the material. The service life of most parts subject to stresses can be increased with the use of better-grade metal. Different additives and secondary refining of molten metal are used in industrial processes to manufacture purer metal. The purer the metal, the higher will be its quality. Cleaner metals have better mechanical properties that will be consistent throughout the part. Melting and processing in a vacuum, controlled atmospheres, and inert gas are all used in various advanced refining techniques to produce superior melts.

Steel was the most requested material all over the world during the past fast technically evolving centuries. As civilization grows and its technological development is connected with more demanding processes, it is more and more challenging to fit the required physical and mechanical properties for steel in its huge portfolio of grades for each casting steel producer. It is necessary to improve the refining and casting processes continuously to meet customer requirements and lower production costs to remain competitive.

Multiple Choice Questions

7.1. The main similarity of all permanent mold casting processes is:

1) using the disposable mold for multiple metal castings;
2) the employment of a permanent mold;
3) the employment of an investment die;
4) using the mold repeatedly for multiple metal castings;
5) the employment of an investment mold.

7.2. The mold also called a die, is commonly made of:

1) aluminum alloys;
2) ceramics;
3) nickel alloys;
4) steel or cast iron;
5) nonferrous alloys.

7.3. Permanent mold casting is a metal casting process that shares similarities to both:

1) sand casting and die casting;
2) die casting and shell molding;
3) sand casting and investment casting;
4) investment casting and plaster mold casting;
5) die casting and vacuum casting.

7.4. Because the molten metal is poured into the die and not forcibly injected, permanent mold casting is often referred to as:

1) sand casting;
2) plaster mold casting;
3) gravity die casting;
4) shell molding.

7.5. Permanent mold casting is a process for:

1) producing a large number of castings using a single reusable mold;
2) manufacturing complex castings using special molds;
3) producing a large number of castings using permanent molds;
4) manufacturing castings of small dimensions using special molds.

7.6. Basic permanent mold casting simply involves:

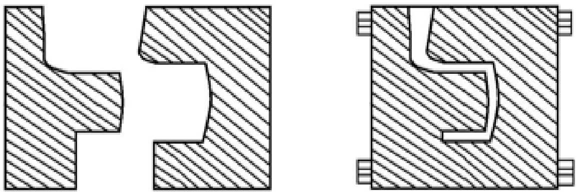
1) coating the permanent mold;
2) pouring the molten metal into a mold;

3) cooling the molten metal;
4) assembly of the prepared patterns;
5) solidification the cooled metal.

7.7. What casting materials are typically used in permanent mold casting?
1) nonferrous metals;
2) copper alloys;
3) aluminum alloys and magnesium alloys;
4) ductile irons and steels;
5) brass alloys and tin alloys.

7.8. Common permanent mold parts include:
1) gears and gear housings;
2) cylinder blocks and cylinder heads;
3) bearings and racing crankshafts;
4) pipe fittings and pistons;
5) connecting rods and gear blanks.

7.9. What is shown in the figure?
1) basic investment mold;
2) special permanent mold;
3) basic expanded mold;
4) basic permanent mold;
5) special investment mold.



Two halves of a basic permanent mold (cross-sectional) Basic permanent mold assembled (cross-sectional)

7.10. What does the mold preparation stage include in permanent mold casting?
1) the mold is pre-heated to around 300–500°F (150–260°C) and a ceramic coating is applied to the mold cavity surfaces;
2) ceramic coating is applied to the mold cavity surfaces;
3) the cores are inserted and the mold halves are clamped together;
4) each pattern half is heated and coated with a lubricant and then they are clamped to a dump box;
5) the molten metal is poured at a slow rate from a ladle into the mold through a sprue at the top of the mold.

7.11. What does the mold assembly stage include in permanent mold casting?
1) the molten metal is poured at a slow rate from a ladle into the mold through a sprue at the top of the mold;

2) ceramic coating is applied to the mold cavity surfaces;
3) the cores are inserted and the mold halves are clamped together;
4) two molds clamped to a dump box;
5) each pattern half is heated and coated with a lubricant.

7.12. What does the pouring stage include in permanent mold casting?
1) the cores are inserted and the mold halves are clamped together;
2) ceramic coating is applied to the mold cavity surfaces;
3) the molten metal is poured at a fast rate into the mold through a sprue at the bottom of the mold;
4) the molten metal is poured at a slow rate from a ladle into the mold through a sprue at the top of the mold;
5) the molten metal is poured from a ladle into the gating system and fills the mold cavity.
6) core and drag mold pieces are assembled along with any necessary cores, and poured.

7.13. What does the cooling stage include in permanent mold casting?
1) the molten metal is allowed to cool and solidify in the mold;
2) the molten metal is poured at a slow rate from a ladle into the mold through a sprue at the top of the mold;
3) ceramic coating is applied to the mold cavity surfaces;
4) the molten metal is allowed to cool and solidify into the shape of the final casting;
5) the molten metal is allowed to cool in the mold.

7.14. What does the mold opening stage include in permanent mold casting?
1) the two mold halves are opened and the casting is removed;
2) the excess material is cutting away;
3) ceramic coating is applied to the mold cavity surfaces;
4) the cores are inserted and the mold halves are clamped together;
5) the molten metal is allowed to cool and solidify in the mold.

7.15. What does the trimming stage include in permanent mold casting?
1) the two mold halves are opened and the casting is removed;
2) the excess material is cutting away;
3) the molten metal is allowed to cool and solidify in the mold;
4) the cores are inserted and the mold halves are clamped together;
5) ceramic coating is applied to the mold cavity surfaces.

7.16. What casting method is the variation of permanent mold casting?

1) slush casting;
2) vacuum permanent mold casting;
3) expanded polystyrene casting;
4) low pressure permanent mold casting;
5) gravity mold casting.

7.17. Termed mold life in permanent mold casting is:

1) the number of castings produced by each particular mold before it had to be replaced;
2) the number of castings produced by typical mold before it had to be replaced;
3) the weight of castings produced by each particular mold before it had to be replaced;
4) the weight of castings produced by typical mold before they had to be replaced.

7.18. The termed mold life depends on what factors?

1) the mold operating temperature;
2) the weight of castings;
3) mold material;
4) dimensions of castings;
5) casting metal.

7.19. What is the purpose of spraying the internal surfaces of the permanent mold with a slurry consisting of refractory materials before pouring a metal casting?

1) this coating helps to control the heat flow;
2) this coating act as a lubricant for easier removal of the cast part;
3) this coating helps to control the solidification;
4) this coating serves as a thermal gradient;
5) this coating increases the mold life of the valuable mold.

7.20. Which of the following is not the function of coating refractory materials on the permanent mold?

1) prevent the soldering of metal to the mold;
2) minimize thermal shock to the mold;
3) control the rate of casting solidification;
4) increase the heat transfer rate.

7.21. In permanent mold casting, the temperature at which the mold is used does not depend on:

1) casting weight;
2) casting wall thickness;
3) pressure in casting;
4) pouring temperature.

7.22. The metal cast part is usually removed before much cooling occurs, to prevent:

1) the solid metal casting from contracting too much in the mold;
2) cracking the casting;
3) acceleration of the heat flow;
4) cracking the permanent mold.

7.23. The removal of the part from permanent mold is accomplished by:

1) ejector cores built into the mold;
2) special hooks;
3) ejector pins built into the mold;
4) special clumps.

7.24. Semi-permanent mold is the casting process, that:

1) make steel alloy castings with re-usable metal molds and sand cores to shape internal passages in casting;
2) make steel alloy castings with sand molds and sand cores to shape internal passages in casting;
3) make aluminum alloy castings with sand molds and metal cores to shape internal passages in casting;
4) make aluminum alloy castings with re-usable metal molds and sand cores to shape internal passages in casting.

7.25. What are the features of semi-permanent mold casting?

1) the metal molds and sand cores have to be replaced each time the product is cast;
2) the molten metal flows into the mold cavity and surrounds the sand core while filling the mold cavity;
3) re-usable metal molds and metal cores haven’t to be replaced each time the product is cast;
4) molds are arranged in two halves: the sand cores are put into place before the two halves are placed together;

5) when the casting is removed from the mold the sand core is removed from the casting leaving an internal passage in the casting.

7.26. The permanent mold may be cooled by:

1) water;
2) cooling gases;
3) heat fins;
4) directed air flows;
5) cooling cores.

7.27. What are the properties and limitations of manufacturing by basic permanent mold casting?

1) more uniform properties throughout the material of the cast part may also be observed with investment mold casting;
2) due to the need to open and close the mold to remove the casting, part geometry is limited;
3) due to the nature of the mold, the metal casting will solidify slowly;
4) if the semi-permanent casting method is used, internal part geometry may be complex;
5) in industrial manufacture permanent mold casting results in a lower percentage of rejects than many expendable mold processes.

7.28. When designing and calculating permanent molds, it is necessary to take into account that:

1) the metallic mold of a permanent casting expands when it is filled with molten metal;
2) the shrinkage allowances taken in the permanent mold design are bigger than those in the sand casting;
3) external cooling can’t be used for creating desired solidification direction;
4) the shrinkage allowances taken in the permanent mold design are smaller than those in the sand casting;
5) the metallic mold of a permanent casting waists when it is filled with molten metal.

7.29. What are the advantages of permanent mold casting?

1) this process produces a fine-grained casting with an excellent surface finish and superior mechanical properties;
2) the complicated shape can not be produced;

3) only non-ferrous metals may be cast by this process;
4) reasonable piece costs resulting from the high production rates achieved with metal molds compared to sand and investment casting;
5) lower investment is required for equipment when compared to low pressure and high pressure die casting.

7.30. What are the disadvantages of permanent mold casting?
1) this process is economical for large-scale production as the labor involved in the mold preparation is reduced;
2) the use of expendable cores in semi-permanent mold casting permits great design flexibility for castings;
3) less competitive with sand casting when three or more sand cores are required;
4) close dimensional tolerance can be obtained;
5) method is limited to the production of somewhat little casting of easy exterior design.

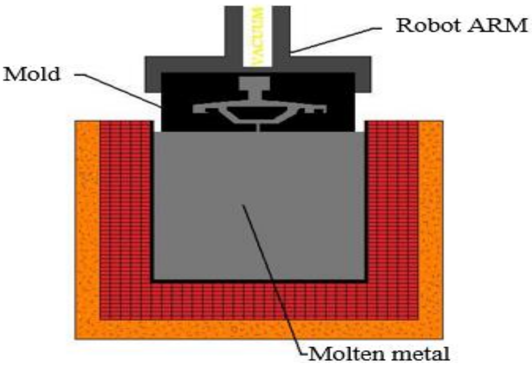
7.31. Which of the following is the main purpose of using permanent mold casting?
1) variety in production;
2) production of castings with complexities;
3) large-scale production;
4) production of highly expensive castings.

7.32. Vacuum permanent mold casting is a casting process:
1) that uses vacuum pressure to fill a mold cavity with molten metal;
2) where the material is poured into the mold and allowed to cool until a shell of material forms in the mold;
3) that uses the force caused by an applied vacuum pressure to draw molten metal into and through the mold's gating system and casting cavity;
4) similar to low pressure permanent mold casting, with both processes using pressure to fill a mold cavity with molten metal;
5) in which the metal is permitted in the mold only unit a shell of the desired thickness has formed.

7.33. What are the features of vacuum permanent mold casting?
1) the mold cavity and the metal are pulled rather than pushed into the mold;

2) this process is usually associated with larger castings and requires specialized, complex mold designs to induce the vacuum properly;
3) excellent mechanical properties and high production rates;
4) low production rates;
5) this process is usually associated with smaller castings and requires specialized, complex mold designs to induce the vacuum properly.

7.34. What casting process is the figure demonstrate?
1) low pressure die casting;
2) vacuum casting with sand mold;
3) high pressure die casting;
4) vacuum permanent mold casting;
5) basic permanent mold casting.



7.35. Combination both vacuum and pressure during vacuum casting allows:
1) controlling the flow of metal into the mold to ensure as tranquil a mold fill as possible in as all casting cycle;
2) better-controlling mold fill;
3) increasing turbulence;
4) controlling the flow of metal into the mold to ensure as tranquil a mold fill as possible in as short of a casting cycle;
5) lowering and decreasing turbulence time.

7.36. Which of the following helps in removing casting from the vacuum mold?
1) tie bar;
2) plunger;
3) platen;
4) ejector pins;
5) cores.

7.37. Which of the following problems arises in die casting that can be solved by having vacuum permanent mold casting?
1) overheating;
2) interruption in progressive solidification;
3) air in the cavity;
4) difficulty in cooling of casting;
5) gases in the cavity.

7.38. Which of the following helps in reducing the oxidation of the material in vacuum permanent mold casting?

1) mold thickness;
2) mold material;
3) tight tolerances;
4) mold coating;
5) mold mechanical properties.

7.39. The gating system in vacuum permanent mold casting is designed with the consideration that:

1) the flow of molten material starts at the bottom and flows upwards;
2) the mold is suspended over a supply of liquid metal for the casting;
3) the mold is mounted on a moving head;
4) the flow of molten material starts at the top and flows down;
5) the mold is suspended over a supply of solid metal for the casting in the mold.

7.40. A permanent mold for vacuum casting is designed taking into account:

1) design of cores;
2) part geometry;
3) dimensions of casting;
4) design of the gating system;
5) mold thickness.

7.41. The reduced pressure within the mold causes molten metal:

1) to be drawn up through the gating system;
2) to be poured slowly through the casting cavity;
3) to be mixed in the casting cavity;
4) to be drawn up through the casting cavity;
5) to be poured faster through the casting cavity.

7.42. The vacuum permanent mold casting process can produce metal castings with:

1) close dimensional accuracy;
2) good surface finish;
3) thick-walled sections;
4) superior mechanical properties;
5) gas-related defects.

7.43. Vacuum permanent mold casting is more suitable to:
1) high-volume production;
2) low-volume production;
3) small-batch manufacture;
4) large-batch manufacture.

7.44. What are the advantages of vacuum permanent mold casting?
1) the mold used in the process has a long life;
2) wide selection of alloys including heat-treatable and non-heat-treatable alloys;
3) potential hollowness issues;
4) this process is relatively inexpensive and can be automated;
5) reduced air porosity and greater strength.

7.45. What are the disadvantages of vacuum permanent mold casting?
1) thin wall castings can be made in large structures;
2) vacuum permanent mold casting is a process of higher productivity;
3) the mold used in the process has a short life;
4) the mold utilized for the job needs to be cleaned frequently, if not, the resulting pieces will have signs of mark-offs;
5) the yields are high since no risers are used.

7.46. Which of the following casting technique is an alternative to investment, shell mold, and green sand casting?
1) vacuum casting;
2) permanent mold casting;
3) evaporative pattern casting;
4) expandable mold casting;
5) plaster mold casting.

7.47. Slush casting is a traditional method of permanent mold casting process:
1) similar to low pressure permanent mold casting, with both processes using pressure to fill a mold cavity with molten metal;
2) in which the metal is permitted in the mold only unit a shell of the desired thickness has formed;
3) where the molten metal is not allowed to completely solidify in the mold;
4) which involves injecting molten metal into a die mold under high pressure;

5) where the material is poured into the mold and allowed to cool until a shell of material forms in the mold.

7.48. What casting materials are used in slush casting?
1) high-melting-point metals;
2) zinc-based alloys;
3) lead, zinc and tin;
4) low-melting point metals;
5) ferrous alloys.

7.49. In the slush casting process:
1) molten metal is fed into the cavity in the metallic mold by gravity;
2) metal is forced into a mold under low pressure;
3) metal is poured into a die cavity, and after a predetermined time the mold is inverted to permit a part of the metal still in the molten state to flow out of the cavity;
4) cavity is filled with a precalculated quantity of metal and a core or plunger is inserted to force the metal into the cavity;
5) metal is forced into a mold under high pressure.

7.50. Which of the following molds is used in slush casting, in which mold is broken to remove the castings?
1) copper mold;
2) iron mold;
3) bronze mold;
4) zinc mold;
5) aluminum mold.

7.51. What type of cores are used in the slush casting process to produce hollow castings?
1) metallic core;
2) sand core;
3) wooden core;
4) no core is used;
5) aluminum core;
6) disposable cores.

7.52. What are the features of the slush casting process?
1) consumable patterns are used;
2) plunger is used to force the molten metal to fill up cavities;

3) vacuum is applied to facilitate complete filling of casting;
4) when a solid shell of sufficient thickness has formed, the remaining liquid is poured out;
5) metal is forced into a mold under low pressure.

7.53. What does the melting stage include in the slush casting process?
1) permanent mold is heated above the melting point temperature of metal;
2) melting ingots are heated above the melting point temperature;
3) the mold cavity is heated and coated with die lubricant to improve the surface finish and reduces in the final casting;
4) permanent mold is pre-heated to the desired temperature;
5) melting ingots in the furnace lower the melting point temperature of the metal.

7.54. What does the pre-heating stage include in the slush casting process?
1) the mold cavity is heated and coated with die lubricant to improve the reduction in the final casting;
2) permanent mold is pre-heated to the desired temperature;
3) melting ingots are heated above the melting point temperature;
4) care must be taken that molten metal is free from dross, slag and other impurities before pouring molten metal;
5) the mold cavity is heated and coated with die lubricant to improve the surface finish.

7.55. What is shown in the figure?

1) mold for slush casting before pouring;
2) the liquid metal is poured out;
3) mold after solidification;
4) mold for slush casting after pouring.

7.56. What does the pouring stage include in the slush casting process?
1) molten metal is poured in the pouring gate till the cavity is full with the help of a ladle;
2) molten metal is poured till the cavity is full with the help of a ladle;
3) molten metal is poured till the cavity is full with the help of a pouring cup;
4) care must be taken that molten metal is free from dross, slag and other impurities before pouring molten metal.

7.57. What does the solidification stage include in the slush casting process?

1) metal starts solidifying at the surface of the mold wall first;
2) metal slowly starts solidifying inward the surface of the mold wall first;
3) molten metal slowly solidifying at all the surfaces of the mold;
4) molten metal gats into a slushy state, where molten metal is between a solid and a liquid state;
5) molten metal gats into a slushy state, where molten metal is between a solid and a liquid state.

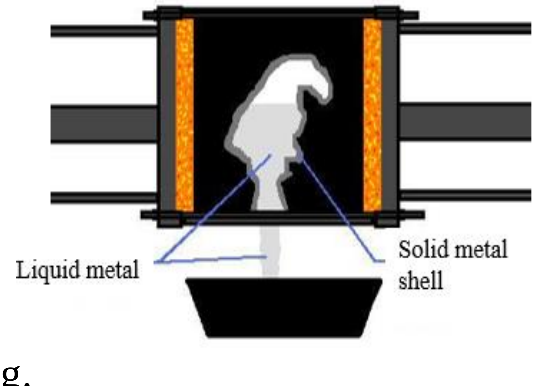
7.58. Where is the temperature lowest during the solidification of slush casting?

1) near the mold wall;
2) in areas, where molten metal solidified;
3) in the center of the mold;
4) between the solidified shell and the center of the mold;
5) in areas, where molten metal always remains in the liquid state.

7.59. What are the draining and injecting stages include in the slush casting process?

1) once the desired thickness is achieved non-solidified metal is drained out;
2) metal that is drained out is melting and pouring into the mold;
3) the mold is opened, and hollow casting is ejected out of the permanent mold;
4) the mold remains closed until the complete solidification and hollow casting are ejected after the out of the permanent mold.
5) the mold is opened until complete solidification.

7.60. What is shown in the figure?



1) mold for slush casting ready to be poured;
2) the liquid metal from the interior is poured out before the entire mass can harden leaving only the solidified outer shell;
3) mold after solidification;
4) mold for slush casting after pouring.

7.61. What are the secondary manufacturing operations in theslush casting process after the casting is taken out from the mold?

1) trimming the edges;
2) polishing the surfaces;
3) shaving the edges;
4) coating to polish the surfaces.

7.62. The exterior of slush casting has the following structure:

1) rough texture;
2) semi-rough texture;
3) semi-smooth texture;
4) smooth and shiny structure;
5) matte texture.

7.63. What are the advantages of slush casting?

1) slush casting is suitable for casting with thin thickness;
2) the desired thickness can be achieved by pouring out the leftover molten metal;
3) slush casting is suitable for only low-temperature pure metals such as lead, zinc, tin, cadmium and magnesium;
4) a variety of exquisitely designed casting can be cast for decorative and ornamental purposes;
5) both symmetrical and asymmetrical casting can be produced with high control over the external surfaces.

7.64. What are the disadvantages of slush casting?

1) large size components cannot be manufactured due to problems in inverting the mold and draining out molten metal;
2) the mold used here has only one gate, it does not have a sprue, runner or rise;
3) slush casting is a slow and time-consuming process if not done under automation;
4) casting made by slush casting process cannot sustain high-stress conditions;
5) slush casting is suitable for small to medium size production.

7.65. The slush casting process is used to produce the following products:

1) intricate castings;
2) castings of large sizes;

3) castings of the thin wall but not hollow;
4) hollow casting products;
5) solid section castings.

7.66. Die casting is a metal casting process:
1) in which the metal is permitted in the mold only unit a shell of the desired thickness has formed;
2) where the molten metal is not allowed to completely solidify in the mold;
3) that involves feeding molten nonferrous alloys into dies under high pressure and at high speed to rapidly create molded products;
4) which involves injecting molten metal into a die mold under high pressure;
5) where the material is poured into the mold and allowed to cool until a shell of material forms in the mold.

7.67. What are the main features of the die casting process?
1) molten metal is fed into the cavity in the metallic mold by gravity;
2) metal is poured into a die cavity, and after a predetermined time the mold is inverted to permit a part of the metal still in the molten state to flow out of the cavity;
3) cavity is filled with a pre-calculated quantity of metal and a core or plunger is inserted to force the metal into the cavity;
4) metal is forced into a mold under high pressure.

7.68. What are the most common metals processed using die casting?
1) zinc, tin, lead, aluminum, brass, and magnesium;
2) iron and carbon;
3) non-ferrous alloys;
4) titanium, cobalt, tungsten;
5) ductile iron and steel.

7.69. What are the main features of dies?
1) dies is the steel mold made majorly by CNC machining;
2) die consists of two halves: the fixed half, which is stationary and attached to the casting machine and the movable ejector half;
3) die is a mold, into which the liquid metal is injected;
4) die consists of two movable halves: one half, which is attached to the casting machine, and the ejector half.

7.70. Much pressure in die casting used to ensure the flow of metal through the mold occurs:

1) to produce metal castings with great surface detail;
2) to produce metal castings with small holes;
3) to produce metal castings with large holes;
4) to produce metal castings with high dimensional accuracy;
5) to produce metal castings with extremely thin walls.

7.71. Wall thickness within die castings can be manufactured as small as:

1) 1 mm;
2) 2.5 mm;
3) 0.5 mm;
4) 3 mm.

7.72. What does the clamping stage include in the die casting process?

1) each die half is cleaned, lubricated, closed and securely clamped together;
2) the molten metal, which is maintained at a set temperature in the furnace, is transferred into a chamber where it can be injected into the die;
3) excess material, along with any flash that has occurred, is trimmed from the casting either manually via cutting or sawing;
4) the molten metal that is injected into the die will begin to cool and solidify once it enters the die cavity.

7.73. What does the injection stage include in the die casting process?

1) each die half is cleaned, lubricated, closed and securely clamped together;
2) the molten metal that is injected into the die will begin to cool and solidify once it enters the die cavity;
3) the molten metal, which is maintained at a set temperature in the furnace, is transferred into a chamber where it can be injected into the die;
4) excess material, along with any flash that has occurred, is trimmed from the casting either manually via cutting or sawing.

7.74. What does the cooling stage include in the die casting process?

1) excess material, along with any flash that has occurred, is trimmed from the casting either manually via cutting or sawing;

2) the molten metal that is injected into the die will begin to cool and solidify once it enters the die cavity;
3) each die half is cleaned, lubricated, closed and securely clamped together;
4) the molten metal, which is maintained at a set temperature in the furnace, is transferred into a chamber where it can be injected into the die.

7.75. What does the trimming stage include in the die casting process?
1) excess material, along with any flash that has occurred, is trimmed from the casting either manually via cutting or sawing;
2) the molten metal, which is maintained at a set temperature in the furnace, is transferred into a chamber where it can be injected into the die;
3) each die half is cleaned, lubricated, closed and securely clamped together;
4) the molten metal that is injected into the die will begin to cool and solidify once it enters the die cavity.

7.76. How is the recycled material used after trimming?
1) it is reconditioned to the proper chemical composition;
2) it is disposed of;
3) it is combined with non-recycled metal;
4) it is used in other casting operations;
5) it is reused in the die casting process.

7.77. What is a flash in die casting?
1) is a thin portion at the inner side of a casting that results from the molten metal being squeezed into the clearances around the cores and ejector pins;
2) is a thin portion at the exterior of a casting that results from the molten metal being squeezed into the spaces between the die halves of the mold at the parting line;
3) is a thin portion at the exterior of a casting that results from the molten metal being squeezed into the clearances around the cores and ejector pins;
4) is a thin portion at the inner side of a casting that results from the molten metal being squeezed into the spaces between the die halves of the mold at the parting line.

7.78. Most alloys used in die casting are:
1) non-ferrous alloys with strong mechanical properties;
2) alloys with low melting points;
3) ferrous alloys;
4) alloys with high melting points;
5) alloys with excellent thermal conductivity.

7.79. What are the properties of aluminum alloys that make them suitable for die casting?
1) excellent thermal conductivity;
2) outstanding corrosion resistance;
3) full recyclability;
4) low electrical conductivity;
5) hard weight.

7.80. What are the properties of zinc alloys that make them suitable for die casting?
1) shortened cycle time;
2) low electrical conductivity;
3) extended die life;
4) improved castability;
5) ideal mechanical qualities.

7.81. Tin is the material used in die casting due to its:
1) high fluidity;
2) low electrical conductivity;
3) high melting point;
4) low melting point;
5) extended die life.

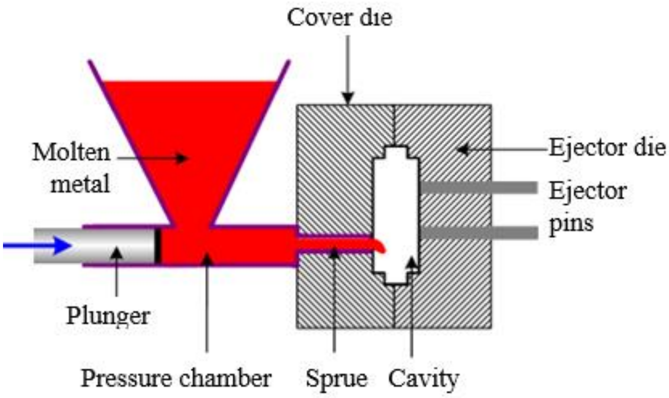
7.82. What are the characteristics of the mold in die casting?
1) contains all the components of the gating system;
2) machined from ductile iron;
3) machined from steel;
4) contains all the components of the investment mold.

7.83. How are dies classified in die casting?
1) opened and closed dies;
2) multi-cavity and unit dies;

3) symmetrical and asymmetrical dies;
4) separable and inseparable.

7.84. What is shown in the figure?

1) die casting process;
2) vacuum die casting;
3) investment casting;
4) expanded polystyrene casting;
5) slush casting.



7.85. Which of the following is true for die used in the die casting machines?

1) one part of a die is stationery and the other is moveable;
2) both parts of a die are stationary;
3) both parts of a die are moveable;
4) none of the above.

7.86. What is the main characteristic of die casting machine?

1) die casting machines are large and strong;
2) die casting machines are designed to hold the mold together against forces;
3) die casting machines are designed to hold the molten metal;
4) die casting machines are designed to hold the two halves of the mold together during the injection of the molten metal.

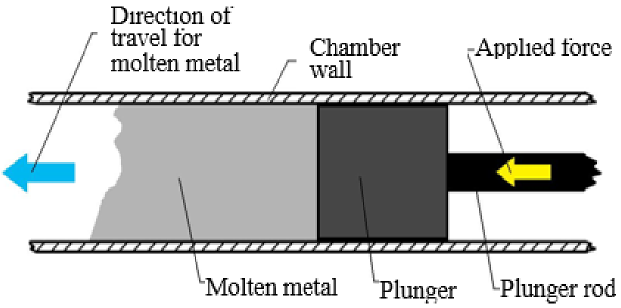
7.87. What is the purpose of spraying the internal surfaces of the die with lubricant before each cycle?

1) the lubricant will prevent the metal casting from sticking to the mold;
2) the lubricant will assist in the removal of the metal casting;
3) the lubricant will assist in cooling down the dies;
4) the lubricant will assist in the removal of the ejector pins.

7.88. Cycle times in die casting will differ depending upon:

1) rates of production;
2) the details of each specific die casting manufacturing technique;
3) dimensions of castings;
4) the pressure at which the metal is forced to flow into the mold.

7.89. What is shown in the figure?



- 1) injection of the molten metal;
- 2) the basic principle of die casting;
- 3) clamping of the two halves of the die;
- 4) unit dies which are a combination of smaller dies;
- 5) multi-cavity die.

7.90. What is the purpose of insert molding in die casting?

- 1) to prevent grooving of the part;
- 2) to help with the integration of the part into the casting,
- 3) once solidified the parts of insert molding become one with the casting;
- 4) to prevent knurling of the part.

7.91. What are the properties of die casting?

- 1) manufacturing of metal castings with close tolerances;
- 2) manufacturing of metal castings with thin intricate walls;
- 3) low rates of production;
- 4) manufacturing of metal castings with tremendous surface detail;
- 5) manufacturing castings of large sizes.

7.92. Which of the following ways of cooling is used for maintaining die temperature?

- 1) natural air cooling;
- 2) forced air cooling;
- 3) water channels cooling;
- 4) liquid nitrogen cooling;
- 5) forced nitrogen cooling.

7.93. In die casting, which of the following keeps the two halves of the die in proper alignment?

- 1) dowel pins;
- 2) ejector pins;
- 3) chaplets;
- 4) fillets;
- 5) ejector cores.

7.94. The chief advantage of die casting is:

1) possibility of incorporating thick sections in small castings;
2) high production rates are possible;
3) casting of inserts is possible;
4) wide tolerances are possible;
5) undercuts cannot be found in simple two-piece dies.

7.95. Due to the rapid cooling at the die walls in die casting:

1) smaller grain structures are formed;
2) thinner sections of the casting are formed;
3) metal castings with superior mechanical properties are cast;
4) bigger grain structures are formed.

7.96. What are the advantages of die casting?

1) fewer steps from raw material to finished part;
2) not suitable for metals with high melting points;
3) smooth surface finish for minimum mechanical finishing;
4) limited sizes of the products can be produced based on the availability of the equipment;
5) some gases may be entrapped in the form of porosity.

7.97. What are the disadvantages of die casting?

1) microporosity in the die casting products;
2) flash is present except for very small zinc die casting;
3) tighter tolerances;
4) large parts can not be cast;
5) extra quantity of material required during the process.

7.98. The hot chamber process is known as:

1) hot die casting process;
2) high pressure die casting process;
3) low pressure die casting process;
4) gooseneck casting process;
5) pressure die casting process.

7.99. Which of the following materials is not suitable to be cast by the hot chamber die casting process?

1) aluminum;
2) tin;

3) lead;
4) zinc;
5) magnesium.

7.100. In the hot chamber die casting process, which of the following parts is used for the pumping of liquid metal into the cavity?

1) accumulator;
2) slug;
3) guide pin;
4) gooseneck;
5) inject pin.

7.101. In hot chamber method of die casting:

1) the melting pot is separate from die casting machine;
2) the melting pot is integral to die casting machine;
3) melting pot location has nothing to do with such a classification;
4) high temperature and low-pressure alloys are used;
5) low temperature and high-pressure alloys are used.

7.102. What does the injection stage include in the hot chamber die casting process?

1) a hot chamber is filled with molten metal, a plunger is raised, and the metal fills the mold;
2) the plunger begins to move downward, this forces the metal into the cavity of the mold and seals it off once it is filled;
3) once the mold has been sealed off, it is cooled and the metal solidifies, taking the shape of the mold;
4) after the metal has solidified, the die opens and the casting (the cooled metal) is ejected.

7.103. What does the sealing stage include in the hot chamber die casting process?

1) a hot chamber is filled with molten metal, a plunger is raised, and the metal fills the mold;
2) the plunger begins to move downward, this forces the metal into the cavity of the mold and seals it off once it is filled;
3) after the metal has solidified, the die opens and the casting (the cooled metal) is ejected;
4) once the mold has been sealed off, it is cooled and the metal solidifies, taking the shape of the mold.

7.104. What does the cooling stage include in the hot chamber die casting process?

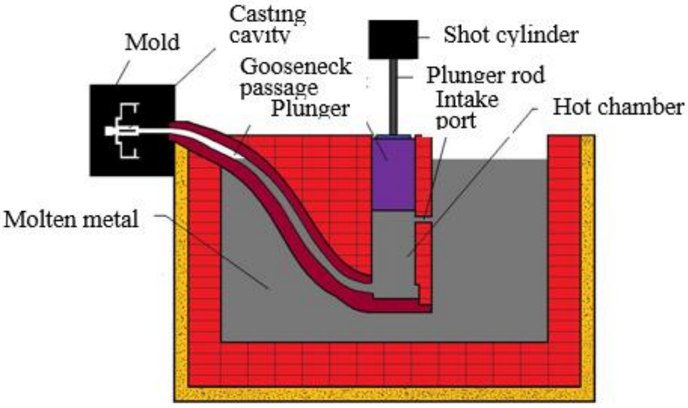
1) after the metal has solidified, the die opens and the casting (the cooled metal) is ejected;
2) the plunger begins to move downward, this forces the metal into the cavity of the mold and seals it off once it is filled;
3) a hot chamber is filled with molten metal, a plunger is raised, and the metal fills the mold;
4) once the mold has been sealed off, it is cooled and the metal solidifies, taking the shape of the mold.

7.105. What does the final stage include in the hot chamber die casting process?

1) after the metal has solidified, the die opens and the casting (the cooled metal) is ejected;
2) a hot chamber is filled with molten metal, a plunger is raised, and the metal fills the mold;
3) once the mold has been sealed off, it is cooled and the metal solidifies, taking the shape of the mold;
4) the plunger begins to move downward, this forces the metal into the cavity of the mold and seals it off once it is filled.

7.106. What is shown in the figure?

1)the hot chamber die casting process;
2) the cold chamber die casting process;
3) the pressure die casting process;
4) vacuum die casting.



7.107. What are the functions of a built-in furnace in the hot chamber die casting process?

1) it uses a hydraulic-powered piston;
2) it helps cool the metal to a solid state;
3) it helps heat the metal to a molten state;
4) it forces the molten metal into the die.

7.108. The shot cylinder provides:

1) the flow of molten metal;
2) the supply of molten metal;
3) the power for the injection stroke;
4) the injection of molten metal.

7.109. At the start of a casting cycle:

1) the power cylinder forces the plunger downward;
2) the plunger is at the top of a chamber;
3) the plunger travels past the ports, cutting off the flow of liquid metal to the hot chamber;
4) «shot» is used to fill the mold and produce the casting.

7.110. In what limits should be the pressure exerted on the liquid metal to fill the die in hot chamber die casting manufacture?

1) 5 MPa to 35 MPa;
2) 2 MPa to 5 MPa;
3) 20 MPa to 40 MPa;
4) 5 MPa to 10 MPa.

7.111. In preparation for the next cycle of casting manufacture, the plunger:

1) the plunger allows the chamber to refill with molten material;
2) the plunger travels back upward in the hot chamber;
3) the plunger exposes the intake ports again;
4) the plunger travels downward in the hot chamber.

7.112. What multiple components are used in the hot chamber die casting machine?

1) gooseneck;
2) nozzle;
3) hydraulic plunger;
4) furnace;
5) hydraulic piston.

7.113. What are the functions of the furnace in the hot chamber die casting machine?

1) it has a combustion chamber to burn fuel;
2) it produces extreme temperatures to melt the raw materials;
3) it is in close vicinity of the die;
4) it produces extreme power to melt the raw materials.

7.114. What are the characteristics of the gooseneck in the hot chamber die casting machine?

1) it links the injection mechanism to the feed line through which the molten metal travels into the die;
2) it is submerged in the molten metal pool;
3) it must have a high thermal resistance;
4) it is ideal to manufacture from high-quality cast or forged steel;
5) it contains a cylindrical lining that houses the hot chamber and the plunger.

7.115. What are the functions of the nozzle in the hot chamber die casting machine?

1) it acts as a gateway for the metal;
2) it regulates the flow of the molten metal through the gooseneck into the die;
3) any extra raw material at the end of the casting cycle travels back into the furnace through the nozzle;
4) it regulates the pressure of the molten metal through the gooseneck into the die.

7.116. What are the functions of the hydraulic plunger in the hot chamber die casting machine?

1) it transports the molten metal into the die;
2) it maintains the chamber at high pressure;
3) it traverses up and down through the hot chamber;
4) its power source is an oil or gas hydraulic cylinder;
5) it regulates the flow of the molten metal through the gooseneck into the die.

7.117. What are the advantages of hot chamber die casting?

1) the process is more difficult for castings with complex recesses;
2) compared to other die casting processing, it produces less metal scrap;
3) low cycle time, automatic run;
4) the process can create metal components with a more intricate design;
5) the process offers limited metal fluidity due to variance in alloy malleability, limiting the final product’s shape and/or complexity.

7.118. What are the disadvantages of hot chamber die casting?

1) the die can be used multiple times because of its lower melting points;
2) reduced porosity using the alloys, which do not damage or erode the machines when subjected to high temperature and pressure;
3) the high initial start-up cost required for setting up the die-casting equipment;
4) the process requires a high-pressure range that isn't always suitable for making every product;
5) hot chamber die casting has the lowest production circle.

7.119. What are the features of cold chamber die casting?

1) it operates under high pressure;
2) it can produce a wide variety of forms and components;
3) it can produce long-lasting castings;
4) it operates under low pressure;
5) higher pressure makes it possible for the parts to have thin walls, which increases the strength of the parts.

7.120. In the cold chamber method of die casting:

1) melting pot location has nothing to do with a classification of the die casting processes;
2) the melting pot is integral to the die casting machine;
3) high temperature and low-pressure alloys are used;
4) the melting pot is separate from the die casting machine.

7.121. What multiple components are used in the cold chamber die casting machine?

1) die;
2) injection mechanism;
3) piston;
4) ejector pins;
5) plunger;
6) hydraulic piston.

7.122. In the cold chamber method of die casting:

1) high melting point metals can be cast;
2) only low melting point metals can be cast;
3) die is kept hot by electrical heating;
4) die is kept cold by circulating water.

7.123. What are the functions of the cold chamber die casting machine?

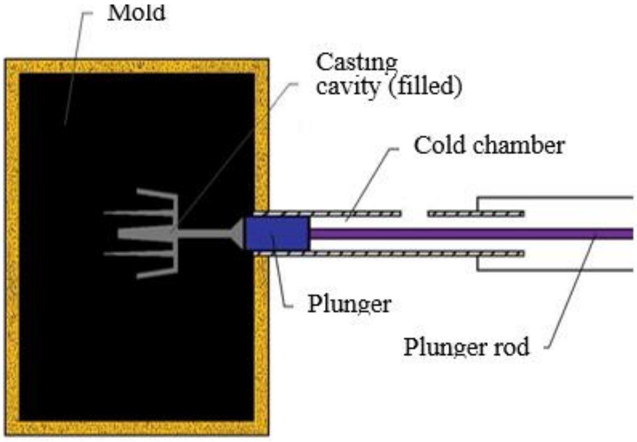
1) the metal is melted to the necessary temperature;
2) the molten metal flows into a shot chamber through an inlet;
3) the plunger, powered by hydraulic pressure, forces the molten metal through a gooseneck channel and into the die;
4) the metal is contained in an open holding pot which is placed into a furnace;
5) molten metal is injected into the die cavity;
6) the plunger remains down, holding the pressure while the casting solidifies.

7.124. In cold chamber die casting, what is the minimum pressure that can be applied?

1) 200 kg/cm^2;
2) 180 kg/cm^2;
3) 150 kg/cm^2;
4) 140 kg/cm^2;
5) 250 kg/cm^2.

7.125. What is shown in the figure?

1) the hot chamber die casting process;
2) the cold chamber die casting process;
3) pressure die casting;
4) vacuum die casting;
5) low pressure die casting.



7.126. What are the functions of the power cylinder in cold chamber die casting?

1) it forces the molten material into the casting mold with great pressure;
2) it causes the liquid metal to fill thin sections of the metal casting;
3)it forces the piston forward in the chamber, cutting off the intake port;
4) it presses the mold walls for great surface detail.

7.127. What are the functions of the plunger in cold chamber die casting?

1) it is powered by hydraulic pressure;

2) it forces the molten metal through the shot chamber and into the injection sleeve in the die;
3) it remains forward, holding the pressure while the casting solidifies;
4) it is powered by a power cylinder.

7.128. The main difference between cold-chamber die casting and hot-chamber die casting manufacture is that:

1) in the hot chamber process the source of molten material is attached to the machine;
2) in the cold chamber process the molten metal for the casting is introduced to the shot chamber from an external source;
3) in the hot-chamber process, certain machine apparatus is always in contact with molten metal;
4) in the cold chamber process the source of molten material is attached to the machine;
5) in the hot chamber process the molten metal for the casting is introduced to the shot chamber from an external source.

7.129. In the cold chamber die casting process, thematerial must be brought:

1) for every shot;
2) for every cycle of production;
3) for temperature rate;
4) for pressure rate;
5) for every furnace.

7.130. What are the methods to increase the efficiency of the cold chamber die casting process?

1) use of removal robots;
2) use of dosing furnaces;
3) use of spraying machines;
4) use of trimming presses.
5) use automatically operating casting cells.

7.131. What are the advantages of the cold chamber die casting process?

1) this method produces lighter castings with thin walls, which makes them stronger;
2) components made using this technique are more durable than parts made by other processes;
3) part geometry must allow removal from the die cavity;
4) requires a high degree of skill in operation and maintenance;

5) due to high pressure and temperature conditions, the method separates the molten metal from injector chemicals that cause corrosion, producing a corrosive-free metal.

7.132. What are the disadvantages of the cold chamber die casting process?
1) injector components in cold chamber casting machines enjoy a longer machine life;
2) complex shapes can be produced in a cold chamber with higher selectivity than many other mass manufacturing procedures;
3) molten metal can cool significantly if it sits in the chamber too long and causes defects;
4) high strength, not too difficult technically and cheap;
5) easy to have shrinkage porosity inside of parts.

7.133. Pressure die casting is a fast and reliable process:
1) in which the metal is permitted in the mold only unit a shell of the desired thickness has formed;
2) where the molten metal is not allowed to completely solidify in the mold;
3) for producing large quantities of parts that meet close dimensional tolerances;
4) that involves feeding molten nonferrous alloys into dies under high pressure and at high speed to rapidly create molded products;
5) which involves injecting molten metal into a die mold under high pressure.

7.134. What are the types of pressure die casting?
1) gravity casting;
2) low pressure die casting;
3) high pressure die casting;
4) investment casting;
5) permanent die casting.

7.135. What is gravity casting?
1) is a technique that involves pouring molten metal directly from a ladle into a semi-solid or solid mold;
2) is a metalworking process in which molten metal or metal alloy is injected into a mold at high pressure and speed;
3) is a metalworking process where the molten metal is not allowed to completely solidify in the mold;

4) casting process that uses a crucible to fill a mold at a pressure of 0.7 bar to make rotationally symmetrical parts.

7.136. What is low pressure die casting?
1) is a metalworking process in which molten metal or metal alloy is injected into a mold at high pressure and speed;
2) is a technique that involves pouring molten metal directly from a ladle into a semi-solid or solid mold;
3) casting process that uses a crucible to fill a mold at a pressure of 0.7 bar to make rotationally symmetrical parts;
4) is a metalworking process where the molten metal is not allowed to completely solidify in the mold.

7.137. What is high pressure die casting?
1) is a technique that involves pouring molten metal directly from a ladle into a semi-solid or solid mold;
2) casting process that uses a crucible to fill a mold at a pressure of 0.7 bar to make rotationally symmetrical parts;
3) is a metalworking process where the molten metal is not allowed to completely solidify in the mold;
4) is a metalworking process in which molten metal or metal alloy is injected into a mold at high pressure and speed.

7.138. Pressure die casting, also known in the manufacturing industry as:
1) pressure molding;
2) pressure pouring;
3) investment casting;
4) pressure shaping.

7.139. What are the properties of pressure die casting?
1) steel castings are cast in graphite molds using this process;
2) pressure die casting uses air pressure to force the metal through the gating system and the metal casting's cavity;
3) the molten metal is poured into the casting and allowing gravity to be the force that distributes the liquid material through the mold;
4) this process can be used to cast high-quality manufactured parts.

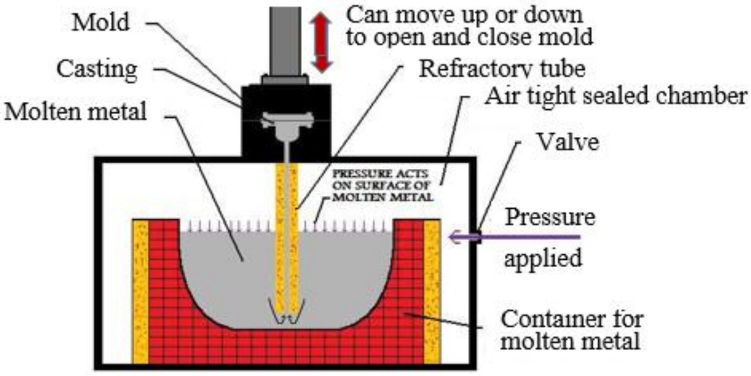
7.140. What are the properties of the gating system in pressure die casting?
1) the casting's gating system is machined into the mold;

2) the gating system is set up so that the molten material flows into the mold from the bottom instead of the top;
3) the gating system is set up so that the molten material flows into the mold from the bottom instead of the bottom;
4) the casting's gating system is machined into the pattern.

7.141. What are the main stages of the pressure die casting process?
1) the mold is set up above the supply of liquid metal to be used for the casting;
2) a refractory tube goes from the entrance of the gating system down into the molten material;
3) the chamber that the liquid material is in is kept airtight;
4) the mold is prepared and ready for the pouring of the metal casting, and air pressure is applied to the chamber.
5) this creates pressure on the surface of the liquid, that in turn forces molten material up the refractory tube and throughout the mold.

7.142. The air pressure in the die casting process is maintained until:
1) the metal casting has hardened within the mold;
2) the metal casting has solidified within the mold;
3) the metal casting has started to harden within the mold;
4) the mold is opened and the part is removed.

7.143. What is shown in the figure?
1) hot chamber die casting process;
2) vacuum die casting;
3) pressure die casting process;
4) investment casting.



7.144. Which of the following is not a pressure die casting machine?
1) cold chamber machine;
2) investment casting machine;
3) hot chamber machine;
4) gooseneck machine;
5) warm chamber machine.

7.145 The device used to increase injection pressure in pressure die casting is called:

1) compressor;
2) surge pump;
3) accumulator;
4) supercharger;
5) feed screw.

7.146. What are the main properties and considerations of manufacturing by pressure die casting?

1) since the refractory tube is submersed in the molten material, the metal drawn for the casting comes from well below the surface;
2) the metal has had less exposure to the environment than the material at the top;
3) the high setup cost makes pressure casting efficient for small runs;
4) the mold needs to be able to open and close for removal of the workpiece, therefore, very complicated casting geometry is limited;
5) the pressure die casting process results in castings with precise dimensional control and a good surface finish.

7.147. In pressure die casting, what is the minimum pressure that can be applied?

1) 50 kg/cm^2;
2) 60 kg/cm^2;
3) 70 kg/cm$^{2;}$
4) 80 kg/cm^2.

7.148. What are the advantages of the pressure die casting process?

1) this process can produce parts with superior mechanical properties;
2) the parts have a good finish and tight dimensional tolerance/accuracy;
3) it is hard to control the dimensions of the final product depending on the amount of pressure;
4) the process is mainly suitable for high-fluidity metal parts;
5) requires complex and expensive equipment.

7.149. What are the disadvantages of the pressure die casting process?

1) the final product is free from oxidation effects with no gas trapped within the metals;

2) a large capital investment is required for the setup;
3) relatively inflexible when compared to gravity die casting;
4) the limitations of the alloys used must have a low melting point;
5) pressure die casting is suitable for large-scale production of parts.

7.150. Low pressure die casting is a method of production that uses:
1) vacuum pressure to fill a mold cavity with molten metal;
2) the force caused by an applied vacuum pressure to draw molten metal into and through the mold's gating system and casting cavity;
3) air pressure to force the metal through the gating system and the metal casting's cavity;
4) pressure, rather than gravity, to fill molds with molten metal;
5) compressive pressure to fill a mold cavity with molten metal.

7.151. Low pressure die casting method is a type of:
1) semi-permanent casting process;
2) permanent mold casting process;
3) expendable mold casting process;
4) shell mold casting process;
5) vacuum permanent mold casting process.

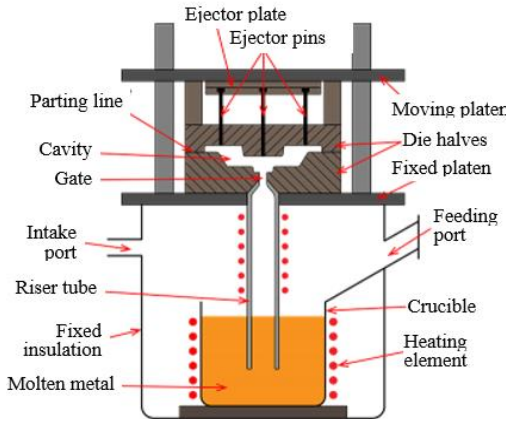
7.152. What are the main features of low pressure die casting?
1) the holding furnace is located below the cast;
2) molten metal is poured into a die-casting mold using low pressure;
3) the liquid metal is forced down through a riser tube and into the cavity;
4) the pressure is applied constantly, sometimes in increasing increments, to fill the mold and hold the metal in place within the die until it solidifies;
5) the holding furnace is located above the cast.

7.153. Due to the continual filling of the die cavity during the shrinking process low pressure die casting:
1) extremely precise (solidification) occurs;
2) oxide formation of the molten metal reduces,
3) porosity of the molten metal decreases;
4) uniformity of the molten metal decreases from top to bottom;
5) oxide formation of the molten metal increases from top to bottom.

7.154. For which workpiece materials is low pressure die casting used?
1) nickel-based alloys;
2) aluminum alloys;
3) copper-based alloys;
4) stainless steel;
5) zinc-based alloys.

7.155. What materials are used to make dies in the low pressure die casting process?
1) alloy cast iron;
2) stainless steel;
3) tool steel;
4) grey cast iron;
5) ductile iron;
6) gray iron.

7.156. What process is shown in the figure?
1) cold chamber die casting;
2) low pressure die casting;
3) hot chamber die casting;
4) high pressure die casting;
5) warm chamber die casting.



7.157. What should be the pressure range (in the bar) of the gas used in the low pressure die casting?
1) 2 to 10;
2) 10 to 30;
3) 20 to 30;
4) 0.3 to 1.5;
5) 30 to 50.

7.158. What are the main steps of the low pressure die casting process before pouring?
1) pattern manufacturing, metal smelting and metal cores making;
2) preparing the mold, injection, ejection/part removal and trimming;
3) core manufacturing, metal smelting and metal mold making;
4) mold manufacturing, metal smelting and sand cores making;
5) core manufacturing, metal smelting and riser tube cleaning up.

7.159. What does the feeding stage include in the low pressure die casting process?

1) the molten metal is fed into the crucible through the feeding port;
2) the mold is sprayed with lubricant;
3) the crucible is sealed and the molten metal is forced in to mold cavity via a riser tube under pressure;
4) the mold is sprayed with lubricant.

7.160. What does the filling stage include in the low pressure die casting process?

1) the mold is filled with lubricant,
2) the molten metal is fed into the crucible through the feeding port;
3) the crucible is sealed and the molten metal is forced in to mold cavity via a riser tube under pressure;
4) the mold is opened up and the castings are ejected out by ejector pins;
5) the mold is filled with pouring metal.

7.161. What does the solidification stage include in the low pressure die casting process?

1) the mold is opened up and the castings are solidified;
2) the pressure is kept for a certain time until the part left in the mold gets solidified;
3) the crucible is sealed and the molten metal is forced in to mold cavity via a riser tube under pressure;
4) the molten metal is fed into the crucible through the feeding port.

7.162. What does the ejection stage include in the low pressure die casting process?

1) the crucible is sealed and the molten metal is forced in to mold cavity via a riser tube under pressure;
2) the mold is sprayed with lubricant;
3) the molten metal is fed into the crucible through the feeding port;
4) the mold is opened up and the castings are ejected out by ejector pins.

7.163. What are the requirements for dies used in the low pressure die casting process?

1) venting of the die cavity, which is extremely important and achieved by allowing flash to form at the parting lines or including vents in the die itself;

2) die walls must have a constant thickness;
3) dies should have a slight taper to assist in the removal of castings;
4) the outside of the die must match the contours of the inside one;
5) die walls must have a permanent thickness.

7.164. Which of the following type of cooling is used for the cooling of top and bottom dies in low pressure die casting?

1) air jets cooling;
2) water cooling;
3) cooling with fins;
4) convective cooling;
5) liquid nitrogen cooling.

7.165. Which of the following products is most suitable to cast by the low pressure die casting method?

1) blades of the turbine;
2) surgical instruments;
3) crankcases;
4) connecting rods;
5) cylinder heads.

7.166. What are the advantages of the low pressure die casting process?

1) the life of the lift tube is short, and the metal fluid is easy to oxidize and produces slag in the process of heat preservation;
2) mainly used for casting some high-quality requirements of aluminum alloy and magnesium alloy castings;
3) the low pressure die casting method is not economical for small-scale production;
4) the rising speed of metal liquid and crystallization pressure can be adjusted during pouring;
5) the casting can not be heat treated.

7.167. What are the disadvantages of the low pressure die casting process?

1) size of casting is limited by machine size;
2) low pressure die casting has a fairly high metal part production rate;
3) the life of the lift tube is short, and the metal fluid is easy to oxidize and produces slag in the process of heat preservation;
4) mainly used for casting some high-quality requirements of aluminum alloy and magnesium alloy castings;

5) improved surface finish thus, reduced finishing operation, the surfaces produced through high pressure die casting are better.

7.168. High pressure die casting is a method of production:

1) whereby the molten metal is fed into a die and solidified to obtain the desired component;
2) in which the metal is permitted in the mold only unit a shell of the desired thickness has formed;
3) that uses the force caused by an applied vacuum pressure to draw molten metal into and through the mold's gating system and casting cavity;
4) whereby the molten metal is forced, under high pressure (generally hydraulic pressure), within the die cavity and a powerful press secures it inside;
5) where the molten metal is not allowed to completely solidify in the mold.

7.169. What systems are used in the high pressure die casting process?

1) opened and closed chambers;
2) cold and hot chambers;
3) opened and closed dies;
4) cold and hot dies;
5) cold, warm and hot chambers.

7.170. What components are not included in the high pressure die casting machine?

1) ejector pins;
2) piston;
3) die-cast mold;
4) pattern;
5) riser tube.

7.171. What are the features of the die-cast molds in high pressure die casting?

1) they have two halves (movable and fixed) attached to the machine, which clamp under force when the operator injects molten metal;
2) these components function in the ejection of the die cast after solidification;
3) they act as a passageway for the molten metal into the die-cast mold;

4) they function in heating metal while storing and maintaining the temperature of the molten metal;
5) they produce the pressure that injects molten metal from the blow chamber into the mold.

7.172. What are the features of the ejector pins in high pressure die casting?
1) they function in heating metal while storing and maintaining the temperature of the molten metal;
2) they produce the pressure that injects molten metal from the blow chamber into the mold;
3) these components function in the ejection of the die cast after solidification;
4) they act as a passageway for the molten metal into the die-cast mold.

7.173. What are the features of pistons in high pressure die casting?
1) they act as a passageway for the molten metal into the die-cast mold;
2) they function in heating metal while storing and maintaining the temperature of the molten metal;
3) they produce the pressure that injects molten metal from the blow chamber into the mold;
4) these components function in the ejection of the die cast after solidification.

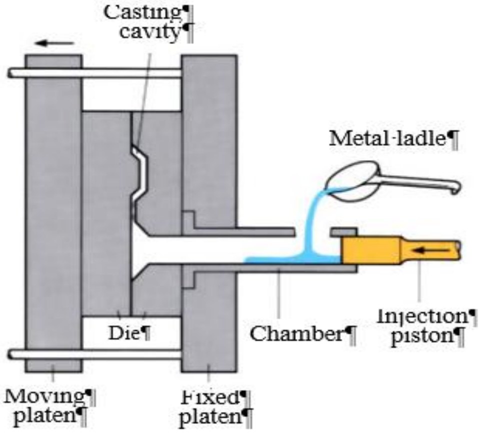
7.174. What are the features of heating components in high pressure die casting?
1) they produce the pressure that injects molten metal from the blow chamber into the mold;
2) they function in heating metal while storing and maintaining the temperature of the molten metal;
3) these components function in the ejection of the die cast after solidification;
4) they act as a passageway for the molten metal into the die-cast mold.

7.175. What are the features of riser tubes in high pressure die casting?
1) they function in heating metal while storing and maintaining the temperature of the molten metal;
2) they produce the pressure that injects molten metal from the blow chamber into the mold;
3) they act as a passageway for the molten metal into the die-cast mold;

4) these components function in the ejection of the die cast after solidification.

7.176. What materials are not used in high pressure die casting?
1) magnesium-based alloys;
2) zinc-based alloys;
3) aluminum-based alloys;
4) carbon steels;
5) magnesium-based alloys.

7.177. What process is shown in the figure?
1) cold chamber high pressure die casting;
2) hot chamber high pressure die casting;
3) low pressure die casting;
4) hot chamber die casting;
5) warm chamber die casting.



7.178. What are the main steps of the high pressure die casting process before pouring?
1) pattern manufacturing, metal smelting and metal cores making;
2) mold manufacturing, metal smelting and sand cores making;
3) core manufacturing, metal smelting and metal mold making;
4) preparing the mold, injection, ejection/part removal and trimming;
5) core manufacturing, metal smelting and riser tube cleaning up.

7.179. What does the mold-preparing stage include in the high pressure die casting process?
1) separating any scrap or waste metal that forms during the process from the freshly manufactured cavity;
2) pouring the molten metal into the blow chamber before injecting it into the mold;
3) applying a specific lubricant to the inner walls of the mold to control and regulate its temperature;
4) removing the plunger and opening the die to eject the cavity;
5) cleaning the die cast mold to remove impurities.

7.180. What does the injection stage include in the cold chamber high pressure die casting process?
1) the entire mold bust is shut tight and sealed;

2) immersing the injection system into the melting furnace;
3) the molten metal makes its way through the shot plunger into the nozzle and, thereafter, the die;
4) pouring the molten metal into the blow chamber before injecting it into the mold;
5) forcing a hydraulic plunger through the sleeve.

7.181. What does the injection stage include in the hot chamber high pressure die casting process?
1) immersing the injection system into the melting furnace;
2) removing the plunger and opening the die to eject the cavity;
3) the entire mold bust is shut tight and sealed;
4) the molten metal makes its way through the shot plunger into the nozzle and, thereafter, the die;
5) pouring the molten metal into the blow chamber before injecting it into the mold.

7.182. What does the enjection/removal stage include in the high pressure die casting process?
1) enjection when the formed cavity is in a solid state;
2) removing the cavity from the mold;
3) separating any scrap or waste metal that forms during the process from the freshly manufactured cavity;
4) pushing out the solidified casting part from the cavity;
5) removing extra material from the part and the mold.

7.183. What does the trimming stage include in the high pressure die casting process?
1) trimming the part by trim die, saw, etc;
2) removing the cavity from the mold;
3) separating any scrap or waste metal that forms during the process from the freshly manufactured cavity;
4) removing extra material from the part and the mold.

7.184. Which statements about the two injection systems in high pressure die casting are incorrect?
1) the hot chamber injection system is quicker due to the cold chamber system’s extra step of heating the metal;
2) the cold chamber system can use horizontal or vertical injection, while the hot chamber system uses only horizontal injection;

3) the hot chamber injection system is suitable for solids with high melting points like aluminum, brass and magnesium;
4) the hot chamber uses less pressure (1,000 – 5,000 psi), unlike the cold chamber's 1500 to 25000 psi;
5) the hot chamber injection system is suitable for making small, intricate parts due to the machine's size restrictions.

7.185. What is the maximum pressure, which can be applied in high pressure die casting?
1) 4530 kg/cm^2;
2) 4980 kg/cm^2;
3) 5000 kg/cm^2;
4) 5100 kg/cm^2;
5) 5500 kg/cm^2.

7.186. What operations are not included in the vertical high pressure die casting process?
1) molten metal is ladled into the shot chamber drive cylinder when the mechanism is tilted to a slight angle from the vertical;
2) drive cylinder is adjusted back to the vertical position;
3) vacuum is applied to inject the molten metal into the die cavity
4) shot chamber is raised to the lower die position;
5) pressure is applied to inject the molten metal into the die cavity.

7.187. What are the advantages of the high pressure die casting process?
1) the die-cast parts have a superior finish i.e. they have a smooth surface with a fine-grain finish;
2) complicated and expensive dies are used in high pressure die casting;
3) high pressure die casting is suitable for high-volume production of parts;
4) components produced by high pressure die casting typically can be thoroughly heat treated because of the existence of these pores;
5) this process is not suitable to achieve parts with very tight tolerances.

7.188. What are the disadvantages of the high pressure die casting process?
1) only hard parts may be manufactured through this process;
2) only for die-cast parts without under-cuts, as sand cores cannot be used;

3) the die-cast parts have a superior finish i.e. they have a smooth surface with a fine grain finish;
4) components produced by high pressure die casting typically cannot be thoroughly heat treated because of the existence of these pores;
5) high pressure die casting is suitable for the high-volume production of parts.

7.189. Gravity die casting is a permanent mold casting process:
1) in which the molten metal flows by the force of gravity without the use of external pressure;
2) in which the metal is permitted in the mold only unit a shell of the desired thickness has formed;
3) that uses the force caused by an applied vacuum pressure to draw molten metal into and through the mold's gating system and casting cavity;
4) where the molten metal is not allowed to completely solidify in the mold;
5) in which molten metal is injected into the mold under the action of the earth's gravity.

7.190. What materials are not used in gravity die casting?
1) copper-based alloys;
2) zinc-based alloys;
3) aluminum-based alloys;
4) nickel-based alloys;
5) steels and cast irons.

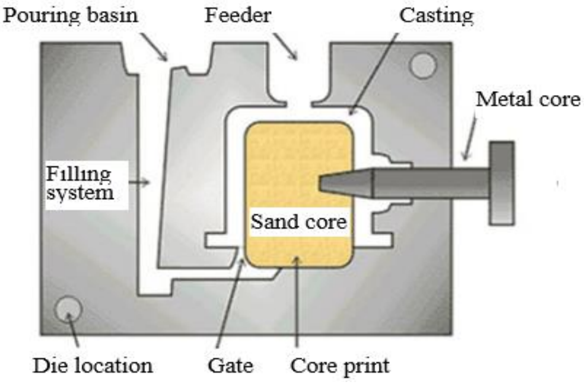
7.191. What are the functions of mold down sprue in gravity die casting?
1) it reduces the formation of turbulence in the finished part;
2) it increases the formation of inclusions in the finished part;
3) it allows the alloy to enter the mold cavity from the lower part of the die;
4) it reduces the formation of subsequent porosity in the finished part.

7.192. What components are not used in gating and risering systems of gravity die casting?
1) the gate;
2) runners;
3) sprues;

4) the pattern;
5) the flash.

7.193. What are the features of automatic filling in gravity die casting for smaller ferrous castings?
1) increases the formation of inclusions in the finished part;
2) both ladle and molds are tilted throughout pouring;
3) minimizes turbulence;
4) both ladle and molds are controlled throughout pouring.

7.194. What process is shown in the figure?
1) high pressure die casting;
2) gravity die casting;
3) low pressure die casting;
4) hot chamber die casting;
5) cold chamber die casting.



7.195. What are the advantages of the gravity die casting process?
1) the cooling ability of the metal type to the casting is strong, which makes the casting dense and has high mechanical properties;
2) aor low-volume production, the cost to be allocated to each product is obvious;
3) gravity die casting offers good dimensional accuracy and a smoother cast surface finish than sand casting;
4) mainly applicable to the mass production of non-ferrous alloy castings;
5) gravity die casting provides slower production times compared to the other processes.

7.196. What are the disadvantages of the gravity die casting process?
1) gravity die casting is not suitable for casting made of metals with a high melting point;
2) thinner walls can not be cast compared to sand casting;
3) because the heat-resistant alloy and its hollow cavity are more expensive to process, the molds are expensive to manufacture;
4) the cycle time is long, and the process requirements are strict, so it is not suitable for the production of single-piece small batch castings;
5) automatic injection molding parts are more precise than manual injection molding parts.

7.197. The centrifugal casting process is a method in which:

1) the molten metal is poured into a rapidly rotating cylindrical mold where the centrifugal force of rotation exerts pressure on the molten metal;
2) the molten metal or metal alloy is injected into a mold at high pressure and speed;
3) the molten metal is poured into the casting and allowing gravity to be the force that distributes the liquid material through the mold;
4) the liquid metal is forced down through a riser tube and into the cavity.

7.198. In centrifugal casting, the permanent mold is usually made of:

1) steel;
2) cast iron;
3) graphite;
4) ceramics.

7.199. What are the types of centrifugal casting?

1) true centrifugal casting and centrifuge casting;
2) true centrifugal casting and semi-centrifugal;
3) semi-centrifugal casting and centrifuge casting;
4) true centrifugal casting, semi-centrifugal casting and centrifuge casting.

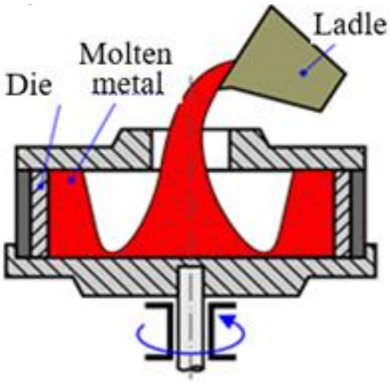
7.200. What principle is inherent in all types of centrifugal casting?

1) the mold is rotated around an axis and molten metal is poured into the pouring cup, from where it is forced into the mold by centrifugal force;
2) the molten metal is poured into a mold that rotates only while it is being poured;
3) the mold is rotated around an axis and molten metal is poured into the pouring cup, from where it is forced into the mold by pressure;
4) the molten metal is poured into a preheated mold which is kept rotating even during solidification of the casting.

7.201. The core in the centrifugal casting is made of:

1) carbon steel;
2) properly treated sand;
3) plastic;
4) no core is used.

7.202. What casting process is the figure demonstrate:



1) low pressure die casting;
2) vertical centrifugal casting;
3) high pressure die casting;
4) horizontal centrifugal casting;
5) basic permanent mold casting.

7.203. Depending on the construction centrifugal casting is divided into principles:

1) opened and closed;
2) high-speed and low-speed mold rotating;
3) vertical and horizontal;
4) high and low centrifugal force.

7.204. Vertical centrifugal castings as compared to horizontal centrifugal castings are spun at:

1) lower speeds;
2) higher speeds;
3) same speed;
4) varying speeds.

7.205. What components are not used in the centrifugal casting process?

1) ladle, metal mold;
2) pouring basin;
3) core, rollers;
4) hydraulic plunger.

7.206. Which of the following are the most likely characteristics in centrifugal casting?

1) fine grain size and high porosity;
2) coarse gain size and high porosity;
3) fine grain size and high porosity;
4) coarse grain size with a high density;
5) carrier grain size and high density.

7.207. The centrifugal casting method is used for casting articles of:

1) symmetrical shape about the horizontal axis;
2) symmetrical shape about the vertical axis;

3) irregular shape;
4) sphere shape.

7.208. What are the advantages of the centrifugal casting process?
1) the centrifugal casting cast only symmetrical shapes therefore;
2) directional solidification, starting from the outer face in contact with the metal mold, realizes a sound cast metal quality, free of cavity and inclusions;
3) the temperature distribution and solidification time are possible to determine;
4) parts produced using centrifugal casting have a fine-grained microstructure that can easily resist atmospheric corrosion.

7.209. What are the disadvantages of the centrifugal casting process?
1) centrifugal casting is not suitable for both low-volume and high-volume production
2) when casting other than cylindrical structure there is a loss in structural and purity benefits;
3) more machining is required when casting components other than cylindrical and there is more chance of making the process more costly;
4) effective for shapes that don’t have a circular profile.

7.210. In true centrifugal casting manufacture the mold will be rotated about:
1) horizontal axis;
2) as horizontal so vertical axis;
3) vertical axis;
4) none of the above.

7.211. Which of the following is true for centrifugal casting?
1) core is made of any metal;
2) no core is used;
3) core is made of sand;
4) core is made of ferrous metal.

7.212. True centrifugal casting doesn’t include the following steps:
1) molten metal is poured straight into the mold without any gating mechanism;

2) once within the hollow, the centrifugal forces of the spinning mold propel the molten material to the cavity’s exterior wall;
3) after the necessary amount of molten metal has been poured, the mold is rotated until the part is hardened;
4) after the necessary amount of molten metal has been poured, the mold is rotated until the part is cooled;
5) after the casting has been set, the mold is removed, opened, and the part removed for post-processing.

7.213. What are the features of true centrifugal casting?
1) once inside the cavity, the centripetal forces from the spinning mold force the molten material to the outer wall;
2) the molten material for the cast part is introduced to the mold using a spout;
3) the molten material for the casting is poured into a spinning mold;
4) the molten material for the cast part is poured into the mold from an external channel;
5) the molten material for the casting is poured into an immobile mold.

7.214. Centripetal forces in true centrifugal casting are:
1) greater in regions of the metal casting nearer the inner surface;
2) greater in regions, outermost axis of rotation;
3) smaller in regions of the metal casting nearer the outer surface;
4) smaller in regions, outermost axis of rotation.

7.215. True centrifugal casting is used to:
1) get accurate castings;
2) get chilled castings;
3) get dynamically balanced castings;
4) cast objects symmetrical about an axis;
5) get statistically balanced castings.

7.216. The true centrifugal casting process is very well suited for the manufacture of:
1) hollow casting with thin walls;
2) thin and hollow casting products;
3) hollow cylindrical tubes;
4) hollow casting with thick sections.

7.217. What are the advantages of the true centrifugal casting process?

1) the true centrifugal casting process is limited to cylindrical parts;
2) castings have a high density, high mechanical strength and an excellent outer surface finish;
3) proper directional solidification obtained except for castings with greater wall thickness;
4) no risers are used in the true centrifugal casting process.

7.218. What are the disadvantages of the true centrifugal casting process?

1) this method is not suitable for all alloys;
2) true centrifugal casting process does not require any core;
3) this process can not be used for mass production;
4) the quality of true centrifugal and cost savings in post-processing including machining must be balanced with the tooling cost.

7.219. The main feature of semi-centrifugal casting consists in:

1) a permanent mold can not be employed in this process;
2) industrial manufacturing processes utilize an expendable sand mold;
3) the mold is filled completely with molten metal, which is supplied to the casting through a central sprue;
4) if the rotational rate of the mold is too slow, the molten material for the casting will not stay adhered to the surface of the cavity.

7.220. In semi-centrifugal casting, the molten material for the metal casting is poured into a pouring basin and is distributed through:

1) a lateral sprue to all regions of the mold;
2) a central sprue to the inner surface of the mold;
3) a lateral sprue to the outer surface of the mold;
4) a central sprue to all regions of the mold.

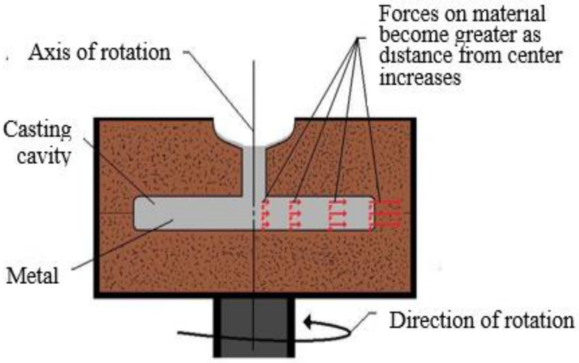
7.221. In semi-centrifugal casting as the metal casting solidifies in a rotating mold,

1) the centripetal forces act to fill vacancies as they form, thus avoiding shrinkage areas;
2) the centripetal forces constantly push material out from the central sprue;
3) the centripetal forces push in a direction that is directly away from the center of the axis of rotation;
4) the centripetal forces constantly push material out from the riser.

7.222. In semi-centrifugal casting when the metal casting solidifies,

1) the outer region of the cast part forms of dense material;
2) density of a cast part increases as travels radially outward from the center;
3) the inner region of the cast part forms dense material;
4) density of a cast part diminishes as travels radially outward from the center.

7.223. What casting process is the figure demonstrate:



1) true centrifugal casting;
2) semi-centrifugal casting;
3) centrifuge casting;
4) horizontal centrifugal casting;
5) vertical centrifugal casting.

7.224. What are the features of the semi-centrifugal casting process?

1) the low forces in the outer section that push the molten material against the mold wall ensure a great surface finish of cast parts;
2) impurities within the metal, (such as solid inclusions and trapped air), will form towards the inner regions of the casting;
3) once inside the cavity, the centripetal forces from the spinning mold force the molten material to the inner wall;
4) denser material subject to centripetal forces will tend to move toward the rim;
5) the molten material for the casting is poured into an immobile mold.

7.225. The quality of the final casting is not affected by factors such as:

1) component diameter;
2) rotating speed;
3) production rate;
4) mold temperature;
5) pouring temperature.

7.226. Semi-centrifugal casting is:

1) used to ensure purity and density at extremities of castings;
2) used to cast symmetrical objects;
3) used to obtain high density and pure casting;
4) not used for any purpose.

7.227. What are the advantages of the semi-centrifugal casting process?

1) all metals and alloys are compatible with this process;

2) the mold rotating too slowly or the pouring rate too fast can result in the metal falling from the top of the rotation onto the bottom;

3) this process is miles apart when it comes to mechanical strength and delivers the best-performing products;

4) the semi-centrifugal casting process allows modifications of the shape of the hollowed interior of a cast ring or cylinder.

7.228. What are the disadvantages of the semi-centrifugal casting process?

1) semi-centrifugal casting is limited to cylindrical and circular objects;

2) the diameter of the inner surface is incorrect in this casting;

3) the equipment can be used for multiple types of metals without sacrificing quality;

4) semi-centrifugal casting is not a cost-effective process.

7.229. The main feature of centrifuge casting consists in:

1) a permanent mold cannot be employed in this process;

2) castings of desired shapes can be manufactured with all the distinct benefits of castings produced by the semi-centrifugal casting process;

3) castings manufactured by the centrifuge casting process need not have rotational symmetry;

4) if the rotational rate of the mold is too slow, the molten material for the casting will not stay adhered to the surface of the cavity.

7.230. Which statement about the centrifuge casting process is incorrect?

1) in centrifuge casting manufacture molds employed to produce the desired castings are arranged around a central sprue;

2) molds contain all the necessary geometry for the cast part, as well as the gating system;

3) runners travel from the central sprue to the mold entrances;

4) in centrifuge casting molds employed to produce the desired castings are arranged along a sprue.

7.231. Centripetal force is not only utilized to distribute molten material through a mold but:

1) to help control the dimensions of a cast part;

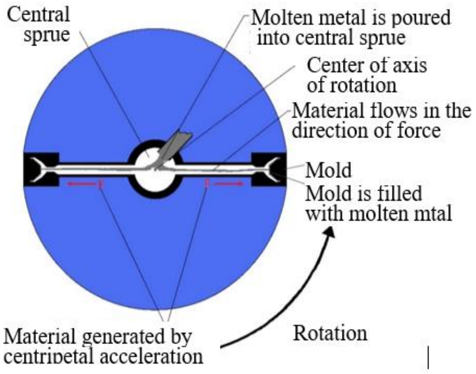
2) to help control the material properties of a cast part;

3) to help control the material properties of the molten metal;
4) to help control the hardness of a cast part.

7.232. What are the main features of the centrifuge casting process?
1) the entire system is rotated about an axis with the central sprue at the center of rotation;
2) the centripetal forces from the rotating apparatus push the material inward to the center through the runners;
3) when an object is rotated, forces have produced that act directly away from the center of the axis of rotation;
4) the centripetal forces from the rotating apparatus push the material outward from the center through the runners and into the molds.

7.233. In the centrifuge casting process when the correct amount of molten metal to manufacture the casting is poured and distributed completely into the molds,
1) the apparatus will stop rotating and the casting has completely solidified;
2) the apparatus will continue to rotate as solidification is occurring;
3) the centripetal forces from the rotating apparatus push the material inward to the center through the runners;
4) the centripetal forces from the rotating apparatus push the material outward from the inner area through the runners and into the molds.

7.234. What is shown in the figure?
1) the set-up stage of centrifuge casting;
2) the pouring stage of centrifuge casting;
3) the solidification stage of centrifuge casting;
4) the part removing stage of centrifuge casting.



7.235. In the centrifuge casting process:
1) since the metal is forced into the mold, the mold cavity fills completely and cast parts with thick walled sections are possible;
2) great surfaces can be produced;
3) since the metal is forced into the mold, the mold cavity fills completely and cast parts with thin walled sections are possible;

4) molten material that solidified under greater force will be denser than the same material that solidified under less force.

8.236. The centripetal forces used in the centrifugal casting methods have on the material of a cast part is that impurities, such as inclusions and trapped air,

1) tend to collect and solidify in more dense material closer to the center of the axis of rotation;
2) tend to collect and solidify in the less dense material closer to the center of the axis of rotation;
3) tend to collect and solidify in more dense material;
4) tend to solidify in more dense material a little rather from the center of the axis of rotation.

7.237. What are the advantages of the centrifuge casting process?

1) good surface finish due to the amount of forces imparted on the molten metal;
2) radial symmetry of part is required as in other centrifugal casting methods;
3) due to low density, impurities such as trapped gases and inclusions will be near the axis, away from the desired part;
4) sprue and runner will have to be machined.

7.238. What are the disadvantages of the centrifuge casting process?

1) since the cast parts are further away from the rotational axis, the part is denser;
2) the biggest downside of centrifuge casting is that it is limited only to rotationally symmetrical parts;
3) the same die cannot be used even for parts with different wall thickness values;
4) the centrifuge casting process is used only for smaller parts.

7.239. The squeeze casting is a process:

1) in which the molten metal is poured into a rapidly rotating cylindrical mold where the centrifugal force of rotation exerts pressure on the molten metal;
2) in which molten metal solidifies under pressure within closed dies positioned between the plates of a hydraulic press;
3) in which the molten metal or metal alloy is injected into a mold at high pressure and speed;

4) which combines both die casting and metal forging;
5) in which the molten metal is poured into the casting and allowing gravity to be the force that distributes the liquid material through the mold.

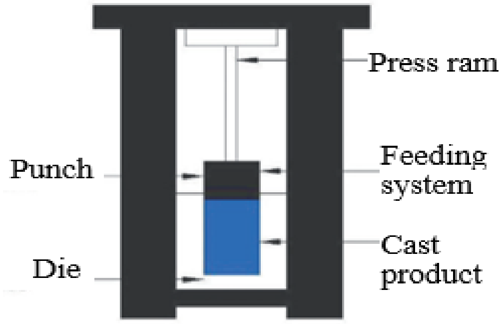
7.240. What properties of castings can increase as a result of the application of the squeeze casting process?
1) thermal;
2) mechanical;
3) thermodynamic;
4) chemical.

7.241. Which statement about the squeeze casting process is incorrect?
1) in the squeeze casting method, extreme care is taken while pouring molten metal into the die cavity;
2) the method of squeeze casting is very expensive to use because of its high productivity;
3) an intermediate feeding component takes part in the in-direct type of squeeze casting;
4) the main purpose of squeeze casting is to produce castings of large volume with high segregation;
5) in squeeze casting, the instant contact between the melt and the die results in the formation of ductile castings of the coarse structure due to the slow rate of cooling.

7.242. Squeeze casting is used for manufacturing components of:
1) aluminum alloys;
2) iron alloys;
3) chromium alloys;
4) carbon alloys.

7.243. Which statement about the direct squeeze casting process is incorrect?
1) the pressure for preform penetration is provided directly to the melt in the direct squeeze casting method;
2) the oxide residue in the composite is stopped by the gating system;
3) the existence of oxide residue in the composite is another difference;
4) there is no gate mechanism, direct squeeze casting tooling is relatively easy.

7.244. What process is shown in the figure?



1) indirect squeeze casting;
2) semi-squeeze casting;
3) direct squeeze casting;
4) centrifuge casting;
5) horizontal squeeze casting.

7.245. Which statement about the indirect squeeze casting process is incorrect?

1) the pressure for preform penetration is provided directly to the melt in the indirect squeeze casting method;
2) the melt is forced into the preform by a gate system in indirect squeeze casting;
3) the tooling is complicated, and a gating mechanism is present;
4) the oxide residue in the composite is stopped by the gating system.

7.246. What should be the range of pressure (in MPa) under which molten metal is pressed to form the castings by the squeeze casting method?

1) 10 to 50;
2) 50 to 140;
3) 140 to 240;
4) 240 to 300.

7.247. Which of the following factors is not considered for the determination of pressure level in squeeze casting?

1) shape of the casting;
2) fluidity of the alloy;
3) freezing range of alloy;
4) molding material.

7.248. What are the advantages of the squeeze casting process?

1) squeeze casting tooling has no versatility;
2) this process needs to be accurately controlled which shows the cycle time down and increases process costs;
3) squeeze casting is done with tightly sealed dies and high pressure, so the parts have low shrinkage;
4) it is great for mass production because the process saves energy by operating through software programming.

7.249. What are the disadvantages of the squeeze casting process?

1) while materials such as plastic can melt at high temperatures, this technique will not be suitable to cast plastic;
2) the squeeze casting process is limited to high-fluidity metal and alloys;
3) this process is suitable only for non-ferrous metals;
4) manufacturers can use automatic machines for this process.

7.250. Continuous casting is the process:

1) in which the molten metal is poured into a rapidly rotating cylindrical mold where the centrifugal force of rotation exerts pressure on the molten metal;
2) in which molten metal solidifies under pressure within closed dies positioned between the plates of a hydraulic press;
3) in which the molten metal or metal alloy is injected into a mold at high pressure and speed;
4) in which molten metal is cast through a mold, the casting takes the two-dimensional profile of the mold but its length is indeterminate;
5) in which the molten metal is poured into the casting and allowing gravity to be the force that distributes the liquid material through the mold.

7.251. The process of continuous casting is not comprised of the following sections:

1) primary cooling zone;
2) heating zone;
3) secondary cooling zone;
4) section for the unbending and straightening of steel strands;
5) cutting section.

7.252. Which statement about the continuous casting process is incorrect?

1) before starting of the casting process, a dummy starter bar is used in the continuous casting method;
2) continuously cast products in the continuous casting show very less segregation;
3) the higher extent of automation can be possible in a continuous casting method;
4) in continuous casting, different cooling rates provide different properties to the castings;

5) the rolling process is an essential part of the continuous casting for the production of castings.

7.253. Which of the following parts is used for the support of steel shell in continuous casting?

1) steel balls;
2) conveyor belt;
3) steel rollers;
4) steel frame.

7.254. What are the advantages of the continuous casting process?

1) continuous cast material is consistently dense and homogeneous in structure;
2) complex shapes can be cast, which must have a constant cross-section;
3) continuous casting requires large ground space;
4) continuous cast bars require appreciably less machining stock.

7.255. What are the disadvantages of the continuous casting process?

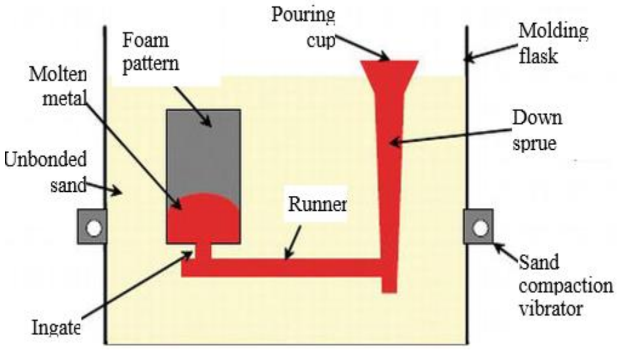
1) continuous casting allows manufacturing metal slabs or bars in large amounts to be shot time;
2) continuous cast material is consistently dense and homogeneous in structure;
3) only simple shapes can be cast, which must have a constant cross-section;
4) the continuous casting process is proper only for small amount of production.

7.256. Evaporative pattern casting is:

1) a process in which molten metal solidifies under pressure within closed dies positioned between the plates of a hydraulic press;
2) a sand casting process where the foam pattern evaporates into the sand mold;
3) a process in which the molten metal or metal alloy is injected into a mold at high pressure and speed;
4) an investment casting process where the molten metal is poured into the casting and allowing gravity to be the force that distributes the liquid material through the mold.

7.257. What is shown in the figure?

1) the squeeze casting process;
2) the lost foam casting process;
3) the high pressure die casting process;
4) the evaporative pattern casting process.



7.258. What are the types of the evaporative pattern casting process?

1) unbonded sand casting and green sand casting;
2) bonded sand casting and gray sand casting;
3) lost foam casting and full mold casting;
4) full mold casting and bonded sand casting.

7.259. What classes of systems exist for making castings by the evaporative pattern casting process?

1) evaporative pattern production, assembly and inspection;
2) inspection of the patterns produced industrially or manually;
3) casting production and inspection;
4) compaction of the coated patterns in the sand mold and inspection.

7.260. What are the advantages of the evaporative pattern casting process?

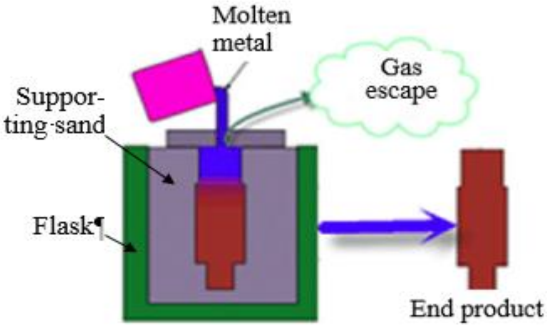
1) complicated shapes can be cast without using cores or drafts;
2) the pattern density has a significant effect on the quality of casting produced with it;
3) porosity defects are created when a fast-moving metal front engulfs portions of the foam pattern which form voids in the solidified castings;
4) this process offers high dimensional accuracy and superior casting surface smoothness.

7.261. What are the disadvantages of the evaporative pattern casting process?

1) the process offers a good surface finish but it is subject to the surface of the pattern;
2) evaporative pattern casting hasn’t improved heat resistance and also abrasion resistance and other cast steel properties;
3) the density values of the patterns vary due to the level of compaction of the beads by steam molding;
4) high material and operational costs.

7.262. Lost foam casting is:
1) a process in which molten metal solidifies under pressure within closed dies positioned between the plates of a hydraulic press;
2) a sand casting process where the foam pattern evaporates into the sand mold;
3) a process in which the molten metal or metal alloy is injected into a mold at high pressure and speed;
4) a process used to create complex metal pieces and parts in which molten metal evaporates a foam mold being held still with sand.

7.263. What process is shown in the figure?
1) lost foam casting;
2) evaporative pattern casting;
3) squeeze casting;
4) full mold casting;
5) stir casting.



7.264. The lost foam casting technology doesn’t include the following steps:
1) designing the pattern;
2) pouring the molten metal;
3) placing the pattern into the sand mold;
4) collecting the castings.

7.265. What are the advantages of the lost foam casting process?
1) lost foam casting can cast very complicated castings of many different sizes;
2) if closed-die molding is used to create the pattern then the cost of the die can be low;
3) the final products maintain high precision and good surface finish;
4) the pattern costs can be low for high-volume applications.

7.266. What are the disadvantages of the lost foam casting process?
1) castings by the lost foam technique are naturally susceptible to damage, such as fracturing and breaking, when stressed;
2) lost foam casting frequently becomes impossible to use a single mold to generate multiple lost foam castings;
3) casting by the lost foam technique guarantees errors or defects;
4) the patterns in lost foam casting are damaged or distorted easily because of their low strength.

7.267. The full mold casting is an evaporative-pattern casting process:

1) which is a combination of sand casting and lost-foam casting;

2) in which molten metal solidifies under pressure within closed dies positioned between the plates of a hydraulic press;

3) which uses an expanded polystyrene foam pattern which is then surrounded by sand;

4) where the foam pattern evaporates into the sand mold.

7.268. What process is shown in the figure?

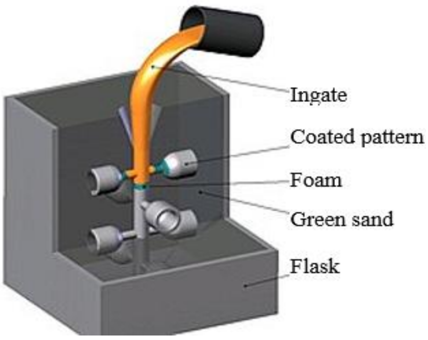
1) lost foam casting;

2) evaporative pattern casting;

3) squeeze casting;

4) full mold casting;

5) stir casting.



7.269. What are the main features of the full mold casting process?

1) the liquid metal is forced down through a riser tube and into the cavity;

2) cavity is filled with a pre-calculated quantity of metal and a core or plunger is inserted to force the metal into the cavity;

3) the patterns in small quantities can be handmade or produced in a machine using a solid foam block in full mold casting;

4) for big volumes the material for the pattern can be inserted into an aluminum mold that is preheated and then steam is exerted on the material.

7.270. What are the advantages of the full mold casting process?

1) full mold casting typically costs less than other casting processes for low-volume applications;

2) this process supports a variety of sizes, ranging up to several tons;

3) full mold casting is not suitable, especially for one-shot production including prototypes and artistic casting with short lead-time;

4) full mold casting process doesn’t require draft or flash.

7.271. What are the disadvantages of the full mold casting process?

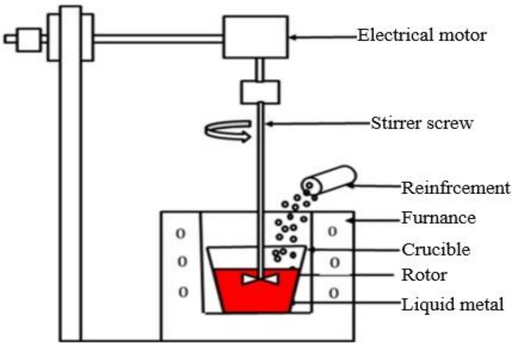
1) mold patterns in full mold casting are susceptible to cracking and other forms of damage;

2) higher flexibility for design with no sand cores needed;

3) the density and strength of foam plastics are small and the pattern is easily deformed;
4) can not be used with molten aluminum, steel, iron, copper, alloys and many other metals.

7.272. Stir casting is a type of casting process:
1) in which molten metal solidifies under pressure within closed dies positioned between the plates of a hydraulic press;
2) which uses an expanded polystyrene foam pattern that is then surrounded by sand;
3) in which a mechanical stirrer is introduced to form a vortex to mix reinforcement in the matrix material;
4) where the foam pattern evaporates into the sand mold.

7.273. What is shown in the figure?
1) schematic of lost foam casting setup;
2) schematic of stir casting setup;
3) schematic of evaporative pattern casting setup;
4) schematic of squeeze casting setup.



7.274. What are the advantages of the stir casting process?
1) stir casting is suitable for the production of metal matrix composites due to its cost-effectiveness;
2) stir casting is not suitable for mass production;
3) this process has easy control of composite structure;
4) nonuniform distribution of the reinforcement in the solidified composite;
5) non-uniform distribution, and porosity in casted materials.

7.275. What are the advantages of die casting over sand casting?
1) fewer steps from raw material to finished part;
2) not suitable for metals with high melting points;
3) smooth surface finish for minimum mechanical finishing;
4) limited sizes of the products can be produced based on the availability of the equipment;
5) some gases may be entrapped in the form of porosity.

7.276. Which of the following qualifies as a precision casting process?

1) ingot casting and sand casting;
2) investment casting and plaster mold casting;
3) plaster mold casting and sand casting;
4) sand casting and shell molding;
5) pressure die casting.

7.277. Which of the following casting methods utilizes wax pattern?

1) shell molding;
2) plaster molding;
3) slush casting;
4) investment casting;
5) pressure die casting.

7.278. Large and heavy castings are made by:

1) green sand molding;
2) pit molding;
3) dry sand molding;
4) pressure molding;
5) vacuum molding.

7.279. Water pipes of large length and diameter are made by:

1) semi-centrifugal casting;
2) continuous casting;
3) sand casting;
4) forging;
5) pressure die casting.

7.280. Which of the following process would produce the strongest components?

1) die casting;
2) hot rolling;
3) forging;
4) cold rolling;
5) vacuum casting.

7.281. Which casting process has no size and shape limits?

1) sand casting;
2) shell-mold casting;

3) plaster-mold casting;
4) slush casting;
5) none of the above.

7.282. Which of the following statement is not correct about die casting?
1) it has close dimensional accuracy;
2) die has a good life;
3) it is very economical for large-scale production;
4) no need for removing the entrapped gases.

7.283. Which type of casting is preferred for making hollow pipes and tubes which are axisymmetric with concentric holes?
1) centrifuging;
2) true centrifugal casting;
3) semi-centrifugal casting;
4) pressure die casting;
5) none of the mentioned.

7.284. Which casting is used to make the hollow casting with thin walls?
1) die casting;
2) centrifugal casting;
3) pressure die casting;
4) slush casting;
5) shell molding;
6) plastic mold casting.

7.285. Which of the following is not an example of a precision casting process?
1) plastic mold casting;
2) ceramic mold casting;
3) slush casting;
4) investment casting;
5) centrifugal casting.

7.286. In which of the following casting method, the molten metal is poured and allowed to solidify while the mold is revolving?
1) die casting method;
2) slush casting method;
3) centrifugal casting method;

4) plastic mold casting method;
5) investment casting method.

7.287. In which of the following casting technique, the metal is heated to just above its solidus temperature and poured into a vessel to cool it down to the semisolid state?

1) vacuum casting;
2) rheocasting;
3) pressure casting;
4) investment casting;
5) evaporative-pattern casting.

7.288. Cast iron and steel pipes are produced by:

1) slush casting;
2) investment casting;
3) true centrifugal casting;
4) die casting;
5) plastic mold casting.

7.289. In which of the following technique, sand is compacted by a controlled explosion or instantaneous release of compressed gases?

1) vacuum molding;
2) impact molding;
3) blow molding;
4) rotational molding;
5) pouring molding.

7.290. Typical parts such as impellers and cutters for machining operations are made by:

1) plaster-molding process;
2) ceramic-mold casting process;
3) shell-molding process;
4) metallic-mold casting process;
5) true centrifugal casting process.

7.291. Which of the following casting process uses a polystyrene pattern?

1) investment casting;
2) ceramic-shell casting;
3) evaporative-pattern casting;

4) slush casting;
5) ceramic-mold casting.

7.292. Which of the following are made of two or more different materials?
1) composite molds;
2) centrifuging;
3) die casting;
4) investment casting;
5) permanent mold casting.

7.293. Which of the following casting process is used to make typical parts such as gears, cams, valves, etc.?
1) investment casting;
2) ceramic-shell casting;
3) evaporative-pattern casting;
4) slush casting;
5) metallic-mold casting.

7.294. In which of the following casting technique, the molten metal is forced upward by gas pressure into a graphite or metal mold?
1) vacuum casting;
2) slush casting;
3) pressure casting;
4) investment casting;
5) pressure die casting.

7.295. Which of the following casting technique has a greater impact in the semi-conductor industry?
1) conventional casting;
2) directional solidification;
3) single crystal;
4) induction melting;
5) induction solidification.

7.296. Which of the following statement is wrong?
1) the hot chamber die casting machine is used for casting zinc, tin, lead and other low-melting alloys;
2) the castings produced by high pressure die casting method have open and coarse-grained structures;

3) the cold chamber die casting machine is used for casting aluminum, magnesium, copper base alloys and other high melting alloys;
4) the castings produced by the centrifugal casting method have open and coarse-grained structures;
5) all of the above.

7.297. In which of the following casting method, alloy is melted by induction in a ceramic crucible?
1) conventional casting;
2) melt spinning;
3) pressure die casting;
4) vacuum arc melting;
5) induction melting.

7.298. Which of the following casting technique, a seed crystal is dipped into the molten metal and then pulled out slowly?
1) crystal pulling method;
2) melt spinning;
3) induction melting;
4) single crystal;
5) Ramasamy method.

7.299. Match the correct answer from group B with the manufacturing process given in group A.

Group A (manufacturing process)	Group B (product)
A. Pressure die casting	1. Automobile piston in aluminum alloy.
B. Gravity die casting	2. Engine crankshaft in spheroidal graphite iron.
C. Sand casting	3. Carburetor housing in aluminum alloys.
D. Shell molding	4. Cast titanium baldes.
E. Centrifugal casting	5. Jet engine compressor cases and hydro wear rings.

1) A – 1; 3) C – 2; 5) B – 5;
2) B – 3; 4) D – 4; 6) E – 3.

8. CASTING DEFECTS

Casting is a manufacturing process, in which a hot molten metal is used to pour into a mold box, which contains a hollow cavity of the desired shape, and then allowed to solidify. That solidified part is known as casting, Casting is most often used for making complex shapes that would be otherwise difficult or uneconomical to make by other methods. Casting is a process that carries a risk of failure occurrence during the process of accomplishing of the finished product.

The casting process is associated with some casting defects that degrade the quality of the foundry product. To upgrade the productivity of the organization the casting defects should be minimized.

Hence necessary action should be taken while manufacturing cast products so that defect-free parts are obtained. During the process of casting, there is always a chance that defects will occur. A defect may arise due to a single cause or may be due to the presence of some more causes it depends on the foundry shop and its resources available.

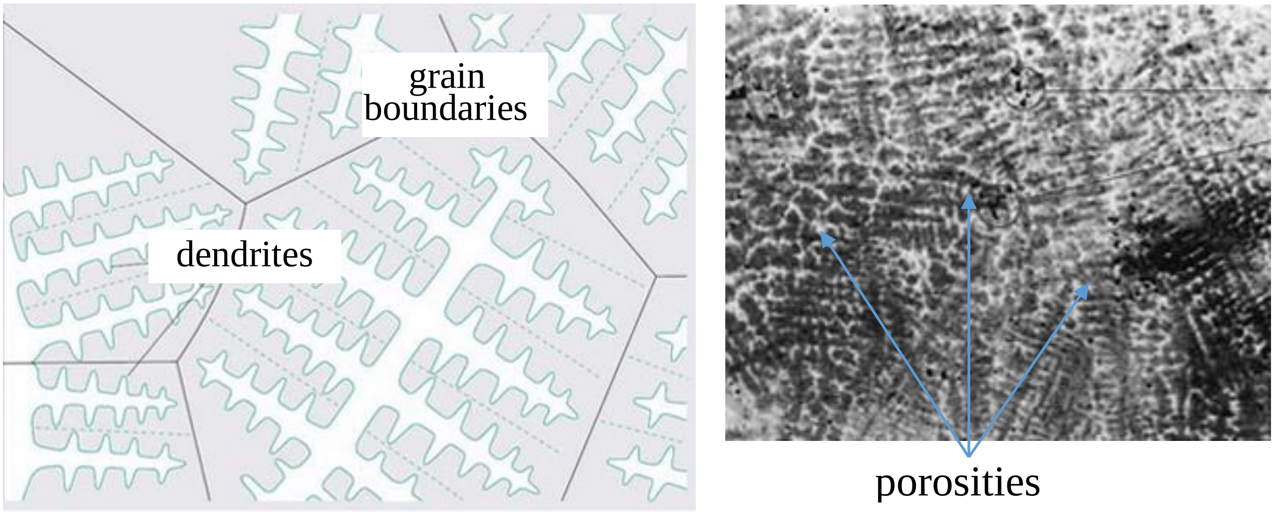
The minor defects can be adjusted easily but high rejected rates could lead to significant change at a high cost. Therefore die caster needs to have knowledge of the type of defect and be able to identify the exact root cause and their remedies.

In a casting process, the material is first heated to completely melt and then poured into a cavity of the mold. As soon as the molten metal is in the mold, it begins to cool. When the temperature drops below the freezing point (melting point) of the material, solidification starts. Solidification involves a change of phase of the material and differs depending on whether the material is a pure element or an alloy. A pure metal solidifies at a constant temperature, which is its melting point (freezing point).

8.1. Casting microstructure

Metal castings have very specific microstructures. When a liquid metal cools and begins to solidify in a mold, grains (crystals) of the metal start to form, both on the mold walls and in the bulk of the liquid metal. The way they grow is shown schematically in Fig. 162 (a).

As the metal solidifies, it forms curious tree-like dendrites. This structure is maintained after the casting is fully solidified, as can be seen in Fig. 162 (b), which shows a typical casting microstructure. The image is created by polishing the surface of the metal, immersing it for a short while in a dilute acid, and viewing it under an optical microscope. In addition to the dendritic structure, two other common defects can be found in a cast microstructure: particles of impurities known as inclusions, and porosity which is small holes in the casting.



a) b)

Figure 162 – Castings (a) dendritic formation (b) a typical cast microstructure

Some inclusions can be removed by heating the casting to a temperature somewhat below its melting point to anneal it and 'dissolve' the inclusions in the metal but the porosity is more difficult to remove. The porosity occurs because the casting has shrunk on solidification. Most materials contract on solidification (water is one of the few liquids that expands on solidification so that ice floats on water; bad news for the Titanic, but good news for polar bears) and this shrinkage is not always uniform so that substantial holes and voids can be left in the casting.

This reduces the load-bearing capability of the component, and in highly stressed products, where the full strength of the material is being utilized, voids can lead to failure. The shrinkage on solidification can be large and is generally a greater effect than the thermal contraction of the solid material as it cools to room temperature.

In many casting processes, runners and risers are used as reservoirs of molten metal to prevent voids from developing in the casting as it solidifies. The runners and risers are parts of the casting that contain a 'reserve' of extra liquid to feed into the mold as the cast product contracts during cooling. However, if a volume of liquid material becomes surrounded by solid material, then a void is formed when the liquid solidifies and contracts.

Fig.163 shows a section through a gravity-die casting in which the effects of this contraction can be seen. The chimney-like feature is the runner, down which liquid aluminum alloy was poured into the mold. There is a hollow in the top of the runner caused by liquid flowing from the runner into the mold as the casting solidified. As well as the hollow at the top, some holes can be seen in the runner and one hole within the casting itself. The runners and risers will later be cut off and discarded.

Figure 163 – Section through a gravity die-cast microscope body

When we are using casting to form the final shape of a product, we have to live with the microstructure of our casting, including its defects. But if we are casting ingots to produce sheet or bar metal for further processing, then a mixture of large deformations and high temperatures is typically used to 'break down the cast structure, remove the porosity, and create a far more uniform microstructure. Such material is the typical raw material for the forming processes we will look at in the next section.

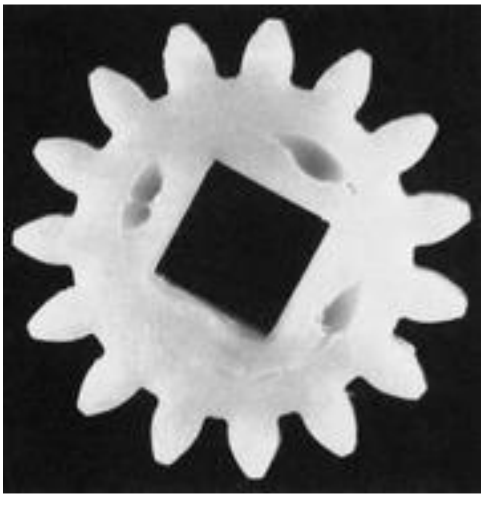


Figure 164 – Section through a molded nylon gear showing three large shrinkage holes

Polymers do not produce the same cast microstructures as are seen in metals, as they are composed of long-chain molecules, rather than grains built up from an atomic lattice of metal atoms. However, polymers do shrink on solidification, and in injection-molded products, shrinkage holes can form, particularly within thick sections.

Fig. 164 shows such holes in an injection-molded nylon gear. Alternatively, the contraction may take the form of depressions on the surface ('sink marks'). Tto 'feed' shrinkage holes with liquid, the pressure is maintained for a short time after the thermoplastic has been injected. Similar holes are found in pressure-die castings.

8.2. Casting defects and remedies

The undesired irregularity in a metal casting process is called a casting defect. Casting defects may be defined as characteristics that create a deficiency or imperfection to quality specification imposed by design and service requirements. Casting defects are caused by non-optimized processes, failure of the material and casting equipment (Table 36). So the defects can be tolerated and repaired. The three general origins of defects are:

1. Casting design.
2. Technique of manufacture or the method.
3. Application of technique- workmanship.

Categories of defects are the following:

1. Shaping faults in pouring.
2. Inclusions and sand defects.
3. Gas defects.
4. Shrinkage defects.
5. Contraction defects.
6. Dimensional defects.
7. Compositional errors.
8. Segregation.

A properly designed casting, a properly prepared mold and correctly malted metal should result in a defect-free casting. However, if proper control is not exercised in the foundry-sometimes it is too expensive. Casting defects can be also classified as follows:

1. Filling related defects.
2. Shape related defects.
3. Thermal related defects.

Filling related defects.

1. Blowhole. During solidifying metal on the surface of metal, a rounded or oval-shaped hole cavity on the smooth or clean surface is associated with oxides. It collects into a bubble at the high points of a mold cavity ad prevents the liquid metal from filling that space. Blowhole is a kind of cavities defect, which is also divided into the pinhole and subsurface blowhole. Pinhole is a very tiny hole. Subsurface blowholes only can be seen after machining. The defects are nearly always located in the core part of the mold in poorly vented pockets and undercuts.

2. Inclusions. Inclusions are due to the presence of forging, non-metallic particles in cast metal. These are may in the form of oxides, slag, dirt, sand or nails. These inclusions can limit mechanical properties and fatigue performance as well as lead to cosmetic defects.

Sand inclusion is nothing but a sand hole or blacking scab, it looks like small or middle holes with sand grain in the internal or on the surface of castings. Inclusion defects look like there is slag inside of metal castings. Sand inclusions are one of the most common casting defects. This casting defect is formed during abrasion of the mold surface by the metal flowing past and the associated thermomechanical stresses.

The considerable compressive and shear stresses acting on the mold and core sections can lead to the breakage of individual sand grains (erosions) or the tearing off of larger mold sections (erosion scabs). This causes interruptions in smooth mold and core surfaces, thickening zones on individual casting sections and sand crusts (sand inclusions) in remote casting areas. Irregularly formed sand inclusions, it is often difficult to diagnose, as these defects generally occur at widely varying positions and are therefore very difficult to attribute to a local cause.

Areas of sand are often torn away by the metal stream and then float to the surface of the casting because they cannot be wetted by the molten metal. Sand inclusions can also be trapped under the casting surface in combination with metal oxides and slag, and only become visible during machining.

3. Cold lap or cold shut. A cold shut is caused when two streams while meeting in the mold cavity, do not fuse properly thus forming a discontinuity in the casting. When the molten metal is poured into the mold cavity through a more-than-one gate, multiple liquid fronts will have to flow together and become one solid. If the flowing metal fronts are too cool, they may not flow together but will leave a seam in the part.

Such a seam is called a cold shut, It is a crack with round edges. Cold lap is because of low melting temperature or poor gating system.

4. Misrun. A misrun defect is a kind of incomplete casting defect, which causes the casting uncompleted. The edge of the defect is round and smooth. When the metal is unable to fill the mold cavity completely and thus leaving an unfilled portion called a misrun. A cold shunt is called when two metal streams do not fuse properly.

5. Porosity. Porosity in castings is due to bubbles being trapped during solidification. Porosity describes the presence of voids inside casting of different sizes, shapes and surface constituents.

Porosity can be divided into two types: gas porosity and shrinkage porosity. The gas can be from trapped air, hydrogen dissolved in aluminum alloys, moisture from water-based die lubricants or steam from cracked cooling lines, usually internal, caused by trapped gases of various kinds in the die. Gas porosity comes from three main sources in die casting, namely trapped air steam and burned lubricant.

Air is present in the cavity before the shot. It can easily be trapped as the metal starts to fill the cavity. The air is then compressed as more and more metal streams into the cavity and the pressure rises. When the cavity is full it becomes dispersed as small spheres of high pressure air. The swirling flow can cause them to become elongated.

Shrinkage porosity is one of the most common defects in the rejection of metal casting. It can be described as internal cracks in casting which comes from several sources.

6. Sinks. Sinks form when there is the presence of a sub-surface cavity. A sink is a depression impacting of the surface of a part that does not mimic the mold surface. Sinks are often visible because they reflect light.

Shape defects.

1. Blister. In blister the thin film of a small surface blows up from the part surface when the internal pressure of surface gas-related porosity plastically deforms the metallic surface. Blister represents an example of defect of metallurgical defects.

2. Mismatch defect. Mismatch in mold defect is because of the shifting molding flashes. It will cause a dislocation at the parting line.

3. Distortion or warp. Warped casting—distortion due to warp age is known as warp defect.

4. Flash defect. Flash can be described as any unwanted, excess metal which comes out of the die attached to the cavity or runner. Typically it forms a thin sheet of metal at the parting faces. There are many different causes of flash and the amount and severity can vary from a minor inconvenience to a major quality issue. At the very least, flash is waste material, which mainly turns into dross when re-melted, and therefore is a hidden cost to the business.

5. Segregation. Segregation occurs due to changes in the chemical composition of the metal. Segregation is distinguished between two types: microsegregation and macrosegregation. Microsegregation refers to localize differences between dendrite arms. The distance involved is about 10 to

100μm which is small for diffusion to be a significant mechanism and this is not in the case of microsegregation.

6. Mechanically induced defects. Mechanically induced defects such as surface marks, undercuts and bending occur during ejection of casting and due to insufficient draft angle. Undercuts are formed due to erosion of sand by the stream of molten metal. It shows the pattern around the gates and causes dirt in casting. Bending and surface marks are caused by external pressure loads and improper ejection methods. These defects can be avoided by giving the proper draft angles and using standard ejection methods and modified casting designs.

Thermal defects.

1. Cracks or tears. Cracks can appear in die castings from many causes. Some cracks are very obvious and can easily be seen with the naked eye. Other cracks are very difficult to see without magnification.

2. Shrinkage. Shrinkage defects occur when feed metal is not available to compensate for shrinkage as the metal solidifies. Shrinkage defects can be split into two different types: open shrinkage defects and closed shrinkage defects. Open shrinkage defects are open to the atmosphere, therefore as the shrinkage cavity forms air compensates. There are two types of open-air defects: pipes and caved surfaces. Pipes form at the surface of the casting and burrow into the casting, while caved surfaces are shallow cavities that form across the surface of the casting.

Closed shrinkage defects, also known as shrinkage porosity, are defects that form within the casting. Isolated pools of liquid form inside solidified metal, which are called hot spots. The shrinkage defect usually forms at the top of the hot spots. They require a nucleation point, so impurities and dissolved gas can induce closed shrinkage defects. The defects are broken up into macro porosity and microporosity (or micro shrinkage), where macro porosity can be seen by the naked eye and microporosity cannot.

3. Soldering. Soldering is one of the main and major casting defects in the metal die casting process. Soldering occurs when molten metal sticks to the surface of die steel and remains there after the ejection of casting. Soldering occurs after just a few casting cycles.

4. Cold shut. Cold shut forms when small droplets of metal fall into the casting mold. Solidify and fail to combine when remaining metal is introduced to mold. Cold shut is a crack with round edges. In cold shut two different metal streams do not forge together.

Defect of gating system.

A proper runner and gating framework are essential to secure the quality of the casting. With the use of the casting simulation technique design of the gating framework of the casting defect has been measured. In this manner, the casting simulation technique has become an essential tool for casting defect troubleshooting and optimization method. It helps in enhancing product quality and upgrading the yielding of casting, reducing cost and spare time among other optimization techniques.

Careful control of a large number of variables is needed:

1. Characteristics of metals & alloys cast.
2. Method of casting.
3. Mold and die materials.
4. Mold design.
5. Process parameters – pouring, temperature.
6. Gating system.
7. Rate of cooling.

Design modifications to avoid defects are the following:

1. Avoid sharp corners.
2. Maintain uniform cross-sections.
3. Avoid shrinkage cavities.
4. Use chills to increase the rate of cooling.
5. Stagger intersecting regions for uniform cross sections.
6. Redesign by making the parting lines straight.
7. Avoid the use of cores, if possible.
8. Maintain section thickness uniformity by redesigning.
9. Allowances for shrinkage to be provided.
10. Parting line to be along a flat plane-good at corners or edges of casting.
11. Draft to be provided.
12. Permissible tolerances to be used.
13. Machining allowances to be made.
14. Residual stresses to be avoided.
15. Large flat areas to be avoided – warping due to temperature gradient.

The metal casting process is complex and can result in various surface defects. A better understanding of these casting defects will give better chances for quality control in castings.

Examples of the most commonly casting defects, their causes and suggested remedies are presented in Table 37.

Table 36 – Probable causes and suggested remedies for casting defects

Name of casting defects	Probable causes	Suggested remedies
1	2	3
Blow holes	1. Excess moisture content in molding sand. 2. Rust and moisture on Chills, chaplets and inserts. 3. Cores not sufficiently baked. 4. Excessive use of organic binders. 5. Molds not adequately vented. 6. Molds not adequately vented. 7. Molds rammed very hard.	1. Control of moisture content. 2. Use of rust-free chills, chaplets and clean inserts. 3. Bake cores properly. 4. Ram the mold s less hard. 5. Provide adequate venting in mold and cores.
Shrinkage	1. Faulty gating and risering system. 2. Improper chilling.	1. Ensure proper directional solidification by modifying gating, risering and chilling.
Porosity	1. High pouring temperature. 2. Gas dissolved in metal charge. 3. Less flux is used. 4. Molten metal not properly degassed. 5. Slow solidification of casting. 6. High moisture and low permeability in mold.	1. Regulate pouring temperature 2. Control metal composition. 3. Increase flux proportions. 4. Ensure effective degassing. 5. Modify gating and risering. 6. Reduce moisture and increase the permeability of mold.
Misruns	1. Lack of fluidity ill molten metal. 2. Faulty design. 3. Faulty gating.	1. Adjust the proper pouring temperature. 2. Modify design. 3. Modify the gating system.

Continue Table 36

1	2	3
Hot Tears	1. Lack of collapsibility of core. 2. Lack of collapsibility of mold. 3. Faulty design. 4. Hard Ramming of mold.	1. Improve core collapsibility. 2. Improve mold collapsibility. 3. Modify casting design. 4. Provide softer ramming.
Metal penetration	1. Large grain size and used. 2. Soft ramming of mold. 3. Molding sand or core has low strength. 4. Molding sand or core has high permeability. 5. Pouring temperature of metal is too high.	1. Use sand having a finer grain size. 2. Provide hard ramming. 3. Suitably adjust the pouring temperature.
Cold shuts	1. Lack of fluidity in molten metal. 2. Faulty design. 3. Faulty gating.	1. Adjust the proper pouring temperature. 2. Modify design. 3. Modify the gating system.
Cuts and washes	1. Low strength of mold and core. 2. Lack of binders in facing and core sand. 3. Faulty gating.	1. Improve mold and core strength. 2. Add more binders to the facing and stand. 3. Improve gating.
Inclusions	1. Faulty gating. 2. Faulty pouring. 3. Inferior molding or core sand. 4. Soft ramming of mold. 5. Rough handling of mold and core.	1. Modify the gating system. 2. Improve pouring to minimize turbulence. 3. Use superior sand of good strength. 4. Provide hard, ramming.
Fusion	1. Low refractoriness in molding sand 2. Faulty gating. 3. Too high the pouring temperature of the metal. 4. Poor facing sand.	1. Improve the refractoriness of sand. 2. Modify the gating system. 3. Use a lower pouring temperature. 4. Improve the quality of facing sand.

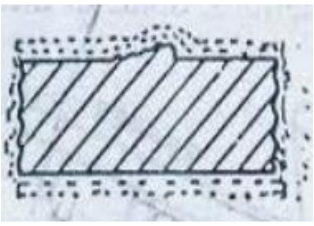
Continue Table 36

1	2	3
Drops	1. Low green strength in molding sand and core. 2. Too soft ramming. 3. Inadequate reinforcement of sand.	1. Increase the green strength of the sand mold. 2. Provide harder ramming. 3. Provide adequate reinforcement to and core projections sand projections and cope by using nails and gaggers.
Shot Metal	1. Too low pouring temperature. 2. Excess sulphur content in the metal. 3. Faulty gating. 4. High moisture content in molding sand.	1. Use proper pouring temperature. 2. Reduce sulphur content. 3. Modify the gating system.
Shift	1. Worn-out or bent clamping pins. 2. Misalignment of two halves of the pattern. 3. Improper support of core. 4. Improper location of core. 5. Faulty core boxes and cores. 6. Insufficient strength of molding sand and core.	1. Repair or replace the pins, for removing defects. 2. Repair or replace dowels that cause misalignment. 3. Provide adequate support to the core. 4. Increase the strength of both molds.
Crushes	1. Defective core boxes produce oversized cores. 2. Worn out core prints on patterns producing undersized seats for cores in the mold. 3. Careless assembly of cores in the mold.	1. Repair or replace the pins, for removing defects. 2. Repair or replace dowels that cause misalignment. 3. Provide adequate support to the core. 4. Increase the strength of both mold and core.
Hard Spot	1. Faulty metal composition. 2. Faulty casting design.	1. Suitably charge metal composition. 2. Modify casting design.

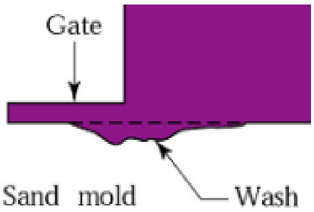
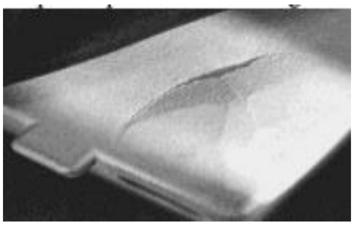
Continue Table 36

1	2	3
Swells	1. Too soft ramming of mold. 2. Low strength of mold and core. 3. Mold not properly supported.	1. Provide hard ramming. 2. Increase the strength of both mold and core.
Rat-tails or buckles	1. Continuous large flat surfaces on casting. 2. Excessive mold hardness. 3. Lack of combustible additives in the molding sand.	1. Break the continuity of large flat groves and depressions. 2. Reduce mold hardness. 3. Add combustible additives to sand.
Run out, fins and fash	1. Faulty molding. 2. Defective molding boxes.	1. Improving molding technique. 2. Change the defective molding boxes. 3. Keep weights on mold boxes.
Spongings	1. Availability of dirt and swarf held in molten metal. 2. Improper skimming. 3. Because of more impurities in molten metal.	1. Remove the dirt swarf held in molten metal. 2. Skimming should be perfect. 3. Fewer impurities in molten metal should be there.
Warpage	1. Continuous large flat surfaces on castings indicate a poor design. 2. No directional solidification of metal castings.	1. Follow the principle of sufficient directional solidification. 2. Make a good casting design.

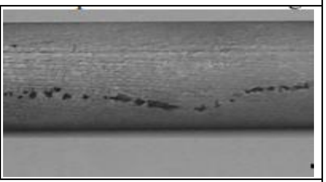
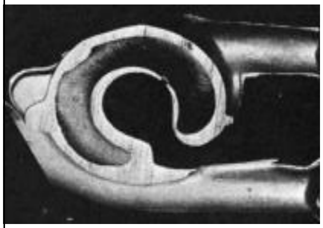
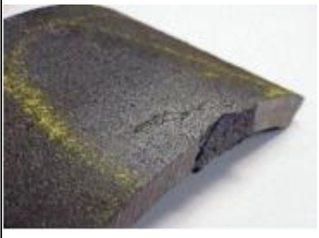
Table 37 – Examples of the most commonly casting defects

Features	Causes	Remedies	Example
1	2	3	4
Blow			
It is a large well – rounded cavity produced by the gases which displace the molten metal at the cope surface of a casting. Generally occurs on the convex casting surface.	1. Excessive moisture content in the mold. 2. Rust and moisture in the chill. 3. Cores are not sufficiently baked. 4. Excessive use of the organic binder. 5. Mold rammed very hard.	1. Can be avoided by having proper venting and adequate permeability. 2. Controlled content of moisture and volatile constituents in the sand – mix. 3. Ram the mold less.	
Pin Holes			
These are tiny blowholes. Occur either at or just below the casting surface.	1. Occurs due to gas dissolved in the alloy & the alloy not properly degasses.	1. Maintaining pouring temperature.	
Drop			
An irregularly – shaped projection on the cope surface of a casting is called a drop.	1. By dropping sand from the cope or other overhanging projections into the mold. 2. Inadequate reinforcement of sand and core projection.	1. Adequate strength of the sand and the use of gaggers can avoid the drops. 2. Provide a harder rammer. 3. Increase green strength of green sand.	
Dirt			
Sand particles dropping out of the cope get embedded on the top surface of the casting when removed leaving small angular – holes.	1. Hydrogen in the molten metal.	1. Pattern should have little part as possible in the cope and the most critical surface should be placed in the drag.	

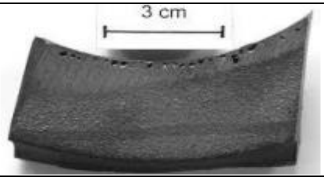
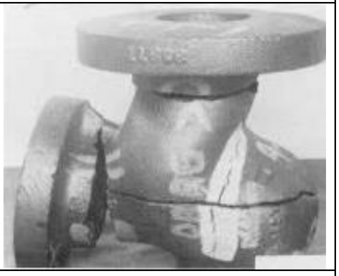
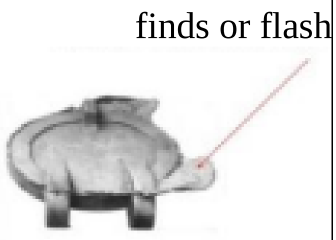
Continue Table 37

1	2	3	4
Wash			
Low projection on the drag surface commencing near the surface.	1. By the erosion of sand due to high-velocity jet of liquid metal in the bottom gate. 2. Lack of binders in facing and core stand. 3. Low strength of mold and core.	1. Improve the gating system. 2. Add more binders to the facing and core sand.	
Bluckle			
Long, fairly shallow, broad, vee-shaped depression occurring in the surface of the flat casting.	1. Expansion of the thin layer of sand at the mold face takes place before the liquid metal at the mold face solidifies.	1. Proper amount of volatile additives in the sand–mix is essential to make room for this expansion and to avoid buckles.	
Scab			
A rough, thin layer of metal, protrudes above the casting surface on top of a thin layer of sand.	1. When the upheaved sand is separated from the mold surface and the liquid metal flows into the space between the mold and the displaced sand.	Lower the moisture content of the molding sand, which increases the overall mold strength. 2. Lower the pouring temperature of the metal (eliminate excess superheat), which reduces the amount of sand expansion. 3. Lower the temperature of the molding sand from the return sand system to increase the strength properties of the sand.	

Continue Table 37

1	2	3	4
Dross			
Lighter impurities appear on the top surface of a casting.	1. Very high temperature. 2. Composition of molten metal.	1. Using strainer and skim bob at the pouring stage.	
Penetration			
Rough, porous projection on casting.	1. If the mold surface is too soft and porous the liquid metal flows between the sand particles up to the distance into the mold. 2. Large grain size. 3. Mold sand and core have low strength.	1. Suitable adjustable pouring temperature. 2. Sand having fine grain size. 3. Provide hard ramming.	
Swell			
A defect is found on the vertical surfaces of a casting.	1. Deformed by the hydrostatic pressure caused by the high moisture content in the sand. 2. Improper ramming of the mold.	1. Proper choice of the riser.	
Misrun			
Insufficient filling of molten metal in a mold cavity.	1. Due to insufficient superheat, the material starts freezing before reaching the farthest point of the mold cavity. 2. Faulty design of the gating system.	1. Adjust the proper pouring temperature. 2. Improve the design and the gating system.	
Wrap			
Distortion due to warp age is known as warp defect.	1. Distortion due to warp age can occur over time in casting that partially or completely liberates residual stresses.	1. Common practice in iron casting is normalizing heat treatment to remove residual stress.	

Continue Table 37

1	2	3	4
Shift			
Misalignment between two halves of the mold.	1. Worn out or bend clamping pin. 2. Misalignment of two halves of patterns. 3. Improper support of core.	1. Repair or replace the support pins. 2. Provide adequate support to the core. 3. Increase the strength of both mold and core.	
Srhinkage			
Reduction in required dimension.	1. Faulty gating and riser system. 2. Improper chilling.	1. Proper directional solidification by gating system, riser and chilling.	
Porosity			
Very small holes uniformly dispersed throughout the casting.	1. Due to a decrease in gas solubility during solidification. 2. High pouring temperature. 3. High moisture and low permeability. 4. Less flux is used.	1. Control metal composition. 2. Increase flux proportion. 3. Reduce moisture and increase the permeability of mold. 4. Effective degassing.	
Hot Tear			
A crack that develops in casting due to high residual stresses.	1. Lack of collapsibility in mold. 2. Hard ramming of mold. 3. Lack of collapsebility in the core.	1. Improve collapsibility of core and mold. 2. Modify casting design.	
Flash			
Flash is an excess material projecting from casting, generally visible as a thin metallic sheet, perpendicular to the casting face.	1. High pouring temperature. 2. Pattern having cavities as the end. 3. Improper clamping of top and bottom parts.	1. Ensure end cavities are filled to avoid metal leakage. 2. Dimensions to be controlled. 3. Sealing of mold box near parting line. 4. Proper core setting.	

Multiple Choice Questions

8.1 The major defects of casting are:
1) gas defects;
2) shrinkage cavities;
3) molding material defects;
4) pouring defects;
5) all of the mentioned.

8.2. Defect which occurs due to the solidification of casting is known as:
1) swell;
2) misrun;
3) metal penetration;
4) shrinkage cavity;
5) gas defect.

8.3. The defects caused by trapping gas in molten metal or by mold gases while pouring the melt are known as:
1) gas defects;
2) shrinkage cavities;
3) molding material defects;
4) pouring defects;
5) all of the mentioned.

8.4. The causes of gas defects are:
1) metal contains gas;
2) mold is too hot;
3) poor mold burnout;
4) shrinkage cavities;
5) all of the mentioned.

8.5. The defects caused by liquid shrinkage during the solidification of the casting are:
1) gas defects;
2) shrinkage cavities;
3) molding material defects;
4) hot tears;
5) pouring defects.

8.6. In casting, which of the following are not material defects?
1) cut and wash;
2) metal penetration;
3) fusion;
4) hot tears;
5) pouring defects.

8.7. The defect caused when the melt is unable to fill the mold cavity completely and thus leaves cavities is termed as:
1) cold shut;
2) misrun;
3) hot tear;
4) porosity;
5) fusion.

8.8. The defect caused when two streams do not fuse (while melting), thus forming discontinuity in casting is termed as:
1) cold shut;
2) misrun;
3) hot tear;
4) porosity;
5) metal penetration.

8.9. A casting defect that occurs near the ingates as rough lumps on the surface of a casting is:
1) shift;
2) sand wash;
3) swell;
4) hot tear;
5) shrinkage cavity.

8.10. A casting defect that occurs due to improper venting of sand is known as:
1) cold shuts;
2) blow holes;
3) shift;
4) hot tear;
5) shrinkage cavity.

8.11. Scabs are casting defects that:

1) result in a mismatch of the top and bottom parts of a casting;
2) result near the ingates as rough lumps on the surface of a casting;
3) occur as rough and irregular projections on the surface of the casting;
4) occur as smooth and regular projections on the surface of the casting.

8.12. Which gas defect is caused by hydrogen in molten metal?

1) blow holes;
2) air inclusions;
3) open blows;
4) pinhole porosity;
5) cold shut.

8.13. Which defect is caused due to the conversion of moisture to steam because of the heat of the molten metal?

1) blow holes;
2) open blows;
3) air inclusions;
4) cold shut;
5) pinhole porosity.

8.14. What is a condition existing in a casting caused by the trapping of gas in the molten metal or by mold gases evolved during the pouring of the casting?

1) gas defects;
2) shrinkage cavities;
3) molding material defects;
4) metal penetration;
5) none of the mentioned.

8.15. Cold ducts are:

1) forging defects due to insufficient filling;
2) pores in welds;
3) casting defects due to two streams not being able to fuse due to being cool;
4) casting defects due to moisture;
5) molding material defects.

8.16. Misrun is which one of the following defects in casting?

1) globules of metal becoming entrapped in the casting;
2) metal is not properly poured into the down sprue;
3) metal solidifies before filling the cavity;
4) microporosity;
5) result in a mismatch of the top and bottom parts of a casting.

8.17. Misrun is a casting defect that occurs due to:

1) very high pouring temperature of the metal;
2) insufficient fluidity of the molten metal;
3) absorption of gases by the liquid metal;
4) improper alignment of the mold flasks.

8.18. Cuts, washes, swell, drop, etc. are examples of which of the following casting defects?

1) gas defect;
2) pouring material defect;
3) molding material defect;
4) casting defect due to two streams not being able to fuse due to being cool;
5) metallurgical defect.

8.19. Which of the following defects is not an example of type "pouring material defects"?

1) misrun;
2) cold shut;
3) slag inclusion;
4) hot tear;
5) misrun & cold shut.

8.20. The lower fluidity of molten material causes:

1) misrun;
2) cold shut;
3) misrun & cold shut;
4) fusion;
5) slag inclusion.

8.21. The low permeability in the sand can cause which of the following defects in casting?

1) blow holes;

2) rough surface;
3) hot tears;
4) drop;
5) slag inclusion.

8.22. Defects caused by the chilling of the casting are known as:
1) hot spots;
2) hot tears;
3) shrinkage cavity;
4) swell;
5) misrun.

8.23. During the melting process flux is added to react with impurities to form:
1) cavity;
2) slag;
3) cold shut;
4) blow holes;
5) shrinkage cavity.

8.24. Which of the following parameter is used to determine the nature of cast components by sealing the opening in casting?
1) surface defects;
2) pressure tightness;
3) ductility;
4) brittleness;
5) planer defects.

8.25. Which of the following test allows us to remove specimens form various casting sections?
1) surface defects;
2) pressure tightness;
3) brittleness;
4) destructive;
5) non-destructive.

8.26. Which of the following defects is not an example of type “vacancies”?
1) planer defects;
2) line defects;
3) point defects;

4) volume defects;
5) material pouring defects.

8.27. What are the examples of line defects?
1) vacancies;
2) dislocations;
3) twins;
4) stacking faults;
5) pressure tightness.

8.28. Following is the casting defect in which there are thin projections of metal not intended as a part of casting:
1) hot tears;
2) swells;
3) pin holes;
4) fin;
5) stacking faults.

8.29. The defect in the casting which results in mismatching of the top and bottom parts of a casting:
1) drop;
2) cold shut;
3) shift;
4) misrun;
5) hot tears.

8.30. Blow holes occur due to:
1) low pouring rate of molten metal;
2) low temperature of molten metal;
3) improper venting of sand;
4) all of the above.

8.31. The defect which results in general enlargement of casting is known as:
1) scab;
2) swell;
3) shift;
4) drop;
5) cold shut.

9. COMPUTER SYSTEMS FOR CASTING PROCESSES SIMULATION

Foundry is the main base of the mechanical engineering and metallurgical complex, and its development depends on the pace of development of these industries as a whole. However, manufacturing cast parts with improved physical-chemical characteristics is a very important production task, which scientists and industrialists are aiming to solve.

Metallurgy and foundry are science-intensive, complex and interconnected industries. Metallurgists and foundry workers, in addition to the tasks of direct control of technological processes, in their activities are often faced with the need to perform rather complex technological and engineering-economical evaluations.

From the analysis of the current circumstance and prospects for the development of innovative technologies, it follows that to modernize the foundry, first of all, it is necessary to significantly increase the volume of investments in science: research and development; design of new machines, equipment and technologies; development efforts, the acquisition of patents or licenses, software products; education and training. A whole range of technological solutions is needed to most effectively implement the priority areas.

Information technologies are such innovative technologies that can make the greatest contribution to accelerating economic growth and increasing the competitiveness of products. They are realized through computer design, an electronic archive, which contains all the information and from where it goes to the technologists, designers, and from them – to the design objects. At the same time, a large number of shortcomings in the organization of national production are revealed and there is an opportunity for their elimination [59].

At present, one of the main ideas for the development of industry should be neo-industrialization, which is a process of large-scale modernization based on waste-free technologies of automated, computerized, and robotic production [26].

The listed factors make it possible to define the main reference direction of the strategy for the further development of the foundry. These areas covered almost the entire range of problems of modern industrial production, namely [76]:

– the maintenance and development directions of the world and national foundry production;

- modern technologies, materials, and equipment;
- diagnostics, certification and quality management of castings;
- computer technologies in the foundry.

As seen from the above, one of the main strategic tendencies of the foundry at the present stage is the development of simulation and computer technologies.

Mathematical simulation of casting processes is the most effective, reliable, and widespread method of manufacturing casting technology development in the world, which allows reducing the costs of both process engineering and production of castings.

Computer analysis at the stage of virtual design of the casting technology (before the manufacture of castings) allows: to minimize of possible miscalculations and errors that inevitably arise in the development process; to reduce financial and time costs; to increase efficiency, competitiveness, quality, and reliability of products being developed. There is a saving of materials, energy carriers, operating time and equipment is saved, and in return, a lot of unique information about the technological process is obtained.

Only computer simulation of the technology allows to look inside the product and see the nature of the processes taking place in it and understand the causes of defects.

The introduction of computer technologies also makes it possible to increase the efficiency of operations for creating and processing information – there is a real transition from paper to electronic document flow. At the same time, costs and the labor intensity of designing and mastering the production of new complex products are reduced. For example, the costs of preparing technical documentation are reduced by 30...40% and the lead time of the release of new complex products is reduced by more than 35% [26].

The development of simulation and computer technologies in foundry production involves:

- automated design of foundry technology;
- modeling the cast molding – a synthesis system for all elements of the process;
- design of foundry technology and tooling in a CAD system with its subsequent manufacture on CNC machines;
- development of a rapid prototyping system;
- computer control of technological equipment.

Computer programs for the simulation of the casting processes are designed to solve the following tasks:

– development of complex or essential casting technologies and operations;

– determination of the parameters that are most important in influencing the quality and yield of suitable products;

– finding the causes of defects in already used technologies;

– determining the technology's resistance to changes in external parameters;

– searching for new technological solutions for obtaining complex castings.

The ability to correctly solve these problems acquires an important, and often decisive, competitive advantage. One of the reasons for this is that the use of computer modeling involves a high culture of design, modeling, and manufacturing.

Currently, dozens of different software products are used in foundry production aimed at solving the problems facing casting technologists. They differ in their characteristics and use various computational methods, mathematical algorithms and physical models, which, to varying degrees, satisfy the needs of a particular consumer. Only a comparison of the results of computer simulation with the results of industrial and experimental research allows for assessing the objectivity and adequacy of the software product used.

Today in the world there are a large number of programs for computer simulation of foundry processes. In world practice, the programs presented in Table 38 have received the main distribution.

Currently, in the USA, England, and Europe, the most common are two modeling systems: ProCast and MagmaSoft. In addition, a certain market segment in Europe is occupied by WinCast, SolidCast, and Nova-Solid/Flow systems. In Eastern Europe and the countries of the former CIS, the most popular software systems are Polygon and LVMFlow.

Modern programs for casting process simulation are based on physical theories of thermal, diffusion, hydrodynamic, and deformation phenomena. They can adequately simulate many processes occurring during the filling of a mold with liquid metal, crystallization of a multi-component alloy, and further cooling of the casting.

Possibilities of the programs include hydrodynamic calculation of filling molds, analysis of temperature fields during crystallization and formation of shrinkage defects, calculation of stresses and residual deformations in castings and optimization of gating systems.

Table 38 – Casting simulation software [76]

Country-Vendor	Casting Simulation Software	Country-Vendor	Casting Simulation Software
Australia	CastFlow	Japan	JSCAST
	Castherm	Korea	AnyCasting
China	InteCast Huashu CAE	Sweden	Nova-Solid/Flow
France	ProCast	Finland	CastCAE
	QuikCast	Spain	Vulcan
	PAM-Cast	USA	PowerCast
	CalcoSo		SolidCast
	Ther		CAPCast
Germany	MagmaSoft		Flow3DCast
	WinCast		RAPIDCast
Great Britain	MavisFlow		SolidThincking
India	AutoCast		Cliick2Cast

All programs mainly differ in purpose, functionality, the number of simulated technological operations, the degree of completeness of the factors taken into account in the simulation and the equipment used. The main problems when choosing a specific program for modeling casting technological processes are the lack of reliable information about the capabilities of the program itself, the principles of working with it, as well as the absence of highly qualified specialists. A significant factor for national enterprises when choosing a program for modeling foundry processes is its cost.

The main distinguishing feature of software products is the use of numerical method for solving problems of differential equations in the simulation of the cast molding (Table 39).

Table 39 – Casting processes simulated by the selected software

Casting process	Auto Cast	CAP Cast	Cast CAE	Flow 3D Cast	Magma Soft	Nova Solid/ Flow	Pro Cast	Solid Cast	Polygon
Sand casting	+	+	+	—	+	+	+	+	+
High pressure die casting	—	+	+	+	+	+	+	—	+
Low pressure die casting	—	+	+	—	+	+	+	+	+
Continuous casting	—	—	—	+	—	—	+	—	—
Gravity die casting	+	—	+	+	+	+	+	+	+
Investment casting	+	+	+	—	+	+	+	+	+
Lost foam casting	—	—	—	+	+	+	+	—	—
Centrifugal casting	—	—	—	+	+	+	+	—	+
Tilt pouring	—	—	—	+	+	+	+	—	+
Squeeze casting	—	+	—	+	—	—	+	—	—

The finite Difference Method (FDM), used in programs such as Magmasoft, SolidCast, CastCAE, JSCAST, AnyCasting and others, allows one to quickly obtain the stress pattern of shrinkage defects in the designed casting and correct the casting technology in time. It is based on differential equations, in which the differential operators are replaced by finite-difference relations of varying degrees of accuracy. As a rule, they are built on orthogonal meshes, which makes it possible to factorize operators and reduce the solution of a multidimensional problem to a sequence of one-dimensional problems, which means much simplifying and speeding up the solution of the general system of equations. The disadvantages include the poor boundary approximation of complex areas, which is not too fundamental for the heat-conduction equations, but rather essential for the hydrodynamic equations.

Table 40 – Numerical methods in selected casting simulation software

Solution method	Auto Cast	CAP Cast	Cast CAE	Flow 3D Cast	Magma Soft	Nova-Solid/Flow	Pro Cast	Solid Cast	Poly-gon
Finite Element Method	—	—	—	—	—	—	+	—	+
Finite Difference Method	—	—	—	+	+	—	—	+	—
Finite Volume Method	—	—	+	+	—	—	—	—	—
Vector Finite Element Method	+	—	—	—	—	—	—	—	—

To eliminate internal shrinkage in critical castings, such a method is not suitable, since the applied mathematical tool does not work well enough in the case of rangy castings when the wall thickness becomes comparable to the mesh spacing. This is because the splitting of the original geometric model occurs by imposing a rectangular mesh with a constant step, which leads to a sharp increase in the number of computational cells in the case of obtaining rangy castings of large overall dimensions.

The Finite Element Method (FEM) used in programs such as WinCast, CAPCast, and others, allows maximum consideration of the casting geometry and reveals even minor defects. It is based on heat and mass transfer integral equations [6]. The solution region in which the equations are solved is divided into finite elements (most often – tetrahedrons), within which approximants of functions are constructed based on the system of basis functions defined on the element. By projecting the integral equations onto these bases, we obtain a system of finite-difference equations. This system is much more complicated than the one adopted in FDM; its solution requires large memory resources and considerable time.

The advantage of FEM is a proper boundary approximation, the disadvantages include the need for a high-quality generator of finite elements; the complexity of equations, and the impossibility of factorization. The built-in generators of the mesh model give large errors in the programs. The problem is solved by using an external finite element mesh generator, which leads to an increase in the cost of purchased software and operating time, and also requires highly qualified personnel.

At first glance, FDM and FEM differ in the representation of geometry, in the FDM the geometry is represented by bricks (parallelepipeds), and the FEM uses a fairly smooth mesh of finite elements (tetrahedra) of arbitrary sizes and configuration. This difference is not always clearly visible, because the visualization does not necessarily show a distorted brick geometry on the computer screen. It is possible to visualize the different solutions on smooth surface meshes of the original geometric models so that the bricks were not visible. However, it is not a question of the modeled casting configuration, but a significant difference in the basic postulates of these methods and, as a consequence, in the different reliability of the solution.

FEM has a fundamentally more complex and adequate mathematical apparatus and more accurately describes the processes occurring in the considered geometric model. When simulating foundry processes FDM and FEM can have significant differences in the adequacy of the solution. It should be noted that currently almost all universal modeling packages, such as ANSYS, Nastran, Patran, etc. have long ago waived the deprecated FDM and use only FEM.

More advanced foundry packages, such as ProCast, WinCast, etc. have followed the same path. The fact is that FDM is not suitable for complex geometries in problems with a significant influence on boundary flows. For casting conditions, this means that finite-difference methods can be adequately used for casting in disposable molds with low thermal conductivity when there is no jump in the simulated function (eg temperature) at the casting mold boundary.

For pressure die casting, especially for complex shaped geometries, FDM will always give a fundamental systematic inaccuracy that is absent in FEM. In addition, FEM is a less resource-intensive and faster method. For the same geometries, both methods give the same solution, but the FEM, when requiring equal adequacy with FDM, always requires about an order of magnitude less computational resources and the calculation time will be several times less. The use of FDM in the foundry processes simulation is now justified only for solving hydrodynamic problems during pouring since the magnitudes and directions of the velocity vectors change with greater discreteness than can be described by a finite-element mesh without losing the advantages of FEM in terms of calculation speed.

In software packages such as ProCast, Flow3D Cast, and Polygon, all major foundry problems are solved based on FEM, and especially for hydrodynamic problems, either FDM or intermediate methods are used. Often, the visualization of the conditional-difference solution in such basic-element packages is performed on a finite-element mesh, which is faster and more convenient.

The disadvantage is that most FEM-based programs have a very complex user interface, which in combination with the lack of experience with software products of foundry technologists reduces the benefits of using any simulation program to zero.

The Finite Volume Method (FVM) used in Nova-Solid/Flow and CastCAE programs is an integrated circuit. In a sense, it is a development of FDM, although sometimes it is considered as some intermediate stage between FDM and FEM. This is probably not entirely true, although FVM takes into account arbitrarily oriented boundaries within the difference cell, but assumes orthogonal difference subdivision (sampling) into rectangular parallelepipeds and has several other features inherent in FDM. FVM is a convenient method for using integral formulations when considering boundary conditions, it allows to control of mesh elements at the casting-mold boundary and simulates the processes of pouring and solidification of casting. FVM successfully solves filling problems, where the use of FEM is difficult, and FDM does not give the necessary conformity in the geometry of the filled cavity.

The software products Flow3DCast and LVMFlow also use FVM, which combines the simplicity and factorization of FDM, as well as a good approximation of the boundaries between different materials and phases It allows simulations to be carried out as quickly as possible without losing the accuracy of the calculations and provides reliable results even with coarse meshes.

In any case, FVM has not yet become widespread for modeling casting processes, this is probably due precisely to the intermediate nature of the method. In those cases when arbitrarily oriented boundaries are required, it is better to use FEM itself, and when it is permissible to represent the geometry by a set of parallelepipeds, it is easier to solve the problem with classical FDM.

The Vector Element Method (VEM) used in the AutoCast program is based on determining the greatest thermal gradient at any point inside the casting, which is set by the vector sum of the flux vectors in all directions from this point. The volume of the casting is divided into numerous pyramidal sectors from the considered point. Heat content and the surface area or cooling are calculated for each sector to determine the flux vector. The calculation is carried out in the direction of the resulting vector until the resulting one becomes zero. The feed line path is considered the curve along which the repetitions are done. It is possible to identify different hot spots in casting if the calculation starts with a plurality of starting points located in different areas of the casting.

VEM is relatively simple when compared to other numerical techniques but provides reliable and robust results. Unlike FEM or FDM methods, VEM rectifies small errors while computing flux vectors at any point by automatically correcting them in subsequent repetitions. Moreover, VEM requires less memory and is also faster.

The boundary element method (BEM) is the most «strong» method since in its basic formulation it assumes within the boundary element the approximation of the distribution of the desired excosecant (for example, the temperature excosecant) directly according to the original differential equation, which describes the simulated process. In addition, when using BEM, spatial ordering occurs, which theoretically speeds up the solution and reduces the requirements for computing resources. However, for modeling casting processes, BEM is practically not used, because, despite its advantages, it requires uniformity of physical properties in the areas of large boundary elements. This does not correspond to the physics of most casting processes associated with a significant change in the process parameters in local arbitrary areas, for example, in the area of heat output during solidification.

Practice shows that the optimal approach is not to choose a single numerical method to simulate casting processes but to use a combination of different methods, which makes it possible to increase the speed, accuracy, and adequacy of the results obtained from experimental data.

MagmaSoft – is a multifunctional specialized program that allows to simulatation of a variety of casting processes. This is one of the first commercial foundry packages, actually demonstrating for the first time that complex casting processes can be broadly simulated at a sufficiently high level. Thermal, hydrodynamic, and deformation processes are solved by numerical methods in MagmaSoft.

The problem of predicting macroporosity and cavities is also numerically solved, although the models used in this case are simplified and do not fully take into account the complex and dynamic nature of the structuring of alloys during solidification. A forecast of microporosity, structural, mechanical, and other characteristics of casting is carried out at the level of criterion analysis.

The advantage of MagmaSoft is the presence of a sufficiently large number of empirical criteria, which at the level of criteria analysis allow for predicting various properties, including the structure and mechanical characteristics of castings. In addition, the program implicitly integrates into the system various superimposed coefficients for a variety of casting methods, alloys, and materials, which to some extent compensates for the simplification of models and algorithms.

MagmaSoft has a convenient generator of difference meshes. If the initial geometry of the castings is relatively simple or the task of exact adherence to the ratios of different wall thicknesses and a sufficient number of finite-difference elements along the wall thickness is not posed, then the generation of the calculated difference geometric model does not present any particular difficulties.

The disadvantage of this system is that the criteria used are hidden and it is impossible to edit, customize and supplement them, which significantly reduces the possibility of their adequate application. The above is also true of the choice of initial conditions, which are closed to the user and are determined by the casting method. This approach is acceptable for typical, widely used technologies. However, the lack of information on the choice of production parameters laid down in the system leads to the fact that the calculation results are often conditional.

In general, MagmaSoft is a system focused on solving typical casting tasks, except for special casting methods and technologies for producing castings of complex geometry. The program has good accuracy of the results obtained and a rich set of parameters for the simulation. MagmaSoft's long experience with foundries around the world has earned it a reputation for being a simple, reliable, and accurate package.

ProCast computer system, unlike MagmaSoft, is an extensive set of complex and physically universal models for solving serious production problems in the foundry industry, which significantly increases the adequacy of calculations. This system simulates thermal, hydrodynamic, and deformation processes, as well as processes of structurization and crystallization.

The program can forecast the occurrence of deformations and residual stresses in the casting and can be used to analyze such processes as core making, centrifugal casting, cavityless casting, and continuous casting. An accurate description of the geometry, due to the applied FEM, allows the

ProCast system to simulate the filling of a mold with supernatant liquid and obtain reliable information about the erosion of a sand mold, air pockets, oxides, and turbulent flow, material age, non-spillages, and cold junctions, flow length and, overflows over-pours.

ProCast provides a complete solution for the simulation of the continuous and semi-continuous casting of billets. The program can simulate the steady-state mode, the initial and final stages of the process. The inverse calculation module automatically calculates the parameters of a material or process based on temperatures measured at targeted points or at predetermined times.

Primary and secondary cooling can be determined by inverse calculation. This computer system has its own finite element mesh generator, which can be successfully used for geometries of medium complexity. For complex geometry models, specialized external generators are commonly used, which are currently available on the market.

A large database of materials for foundry models comes with ProCast. Its content is constantly updated with reliable data, verified in the conditions of existing foundry production. It includes a unique thermodynamic database that allows the user (by entering the chemical composition of the alloy) to automatically obtain the temperature curves of the properties necessary for an accurate calculation of the casting process.

The main advantages of this package include the ability to take into account complex thermal boundary conditions and direction of solidification, complex rheology in deformation calculations, the ability to simulate complex processes and numerically calculate the structure in castings. To carry out numerical calculations of the structure in ProCast, it is necessary to select the correct crystallization model and its parameters.

The disadvantage of the program is a too low level of solving the shrinkage problem, as well as the high cost, but it is justified by the capabilities of the program.

Thus, ProCast can be recommended as a basic system for castings and technologies of any complexity, excluding those cases where it is required to simulate the formation of shrinkage defects, taking into account the real dynamic nature of the structuring of the two-phase zone and the pressure drop due to filtration flow in the two-phase zone during shrinkage. This package is effective when technologists need to solve deformation problems with complex rheology and structure in the casting.

WinCast is a software package for casting processes simulation capable of calculating metal pouring (hydrodynamic and thermal analysis), metal crystallization (location of heat units and shrinkage defects), the tension of a casting (forecasts technological and operational stresses), structure-forming processes, heat treatment, and welding. The basis of the modular system is made up of basic and additional modules for sequential or parallel passage of various stages of modeling, and the solution of problems can be carried out jointly, taking into account their cross-impact.

Compared to Procast, WinCast has a more convenient process for building mesh models, not inferior in the accuracy of calculations. The advantages of this model are the following: more accurate approximation of complex surfaces; more accurate representation of thin walls and complex sections with fewer elements; the ability to carry out thermal, hydrodynamic, and strength analysis on one mesh; fewer heat units reduce the calculation time.

The accuracy of thermal calculations is ensured by the correct approximation of surfaces by finite elements and by taking into account the temperature dependence of the properties of alloys and auxiliary materials. The reliability of hydrodynamic and strength analyses is guaranteed by the compatible calculation of temperature fields on the same finite element pentahedral mesh with a high level of regularity. Generation of an accurate finite element mesh for 3D geometry of any complexity, built in an external CAD system or using the program's tools, provides accurate engineering forecasts in a short time.

The advantage of WinCast is that the database, organized in text format, is easy to edit and supplement. It contains the properties of alloys and materials in the form of a tabular function of temperature. Thanks to a flexible preprocessor, the program provides an accurate geometry display and the availability of automatic mesh generation.

Among the disadvantages, it should be noted is an inconvenient interface, as well as the use of simplified models when solving the heat problem (solidification) and the shrinkage-filtration problem (the formation of micro-and macroporosity). The inability to automatically generate the computational grid requires additional spadework to create it. However, in WinCast, deformation processes are simulated at a sufficiently high level as a result of casting cooling.

SolidCast is an entry-level computer system that is designed to solve current production and technological problems, as well as to optimize the technology for each casting based on the geometry optimization of the gating-feeding system and the technological parameters of the casting process. The computational capabilities of the package allow the user to trace the dynamics of filling the mold with metal and the crystallization process of the casting in the mold; to obtain information about the time of crystallization, the rate of cooling, shrinkage defects; to determine the possible areas of defect occurrences in the casting. The built-in hydrodynamic module allows for simulation of the flow of the melt in the mold, as a result of which it is possible to identify and forecast such defects as mold erosion, cast seams, surface contaminations, and misruns in the casting.

As a result of the calculation, the technologist receives information about the allocation of temperature fields in the casting and the mold, the values of the melt flow rate, and the pressure of the melt on the mold walls at any point.

SolidCast has a built-in mesh generator in two versions and an automatic generator of graphs and diagrams in the postprocessor, which allows for comparing the simulation results of several variants of manufacturing technologies for the same casting. The availability in the SolidCast computer system of the possibility of automatic generation of the computational mesh permits optimizing the casting mold depending on scrap yield and the size of the flask. In addition, this software product allows to the creation of a unique database on the used technological processes for casting production. The built-in database of molding materials and alloys is open to the user, it is constantly changing and supplemented.

The disadvantages of SolidCast are as follows: inconvenient interface, inability to take into account preliminary mold filling; inconvenient display of calculation results for visual analysis; excessive duration of computer calculations. The extensive functionality and unique pricing policy of developers make SolidCast the best in terms of price-functionalities-productivity since one acquired licensed program can be used at five workplaces within one enterprise.

With the rapid development of computer technology, the simulation software of the casting process is also applied. The application of casting simulation technology is not limited to the simulation and analysis in the process of product development, and the process simulation of production and manufacturing also plays a pivotal role. That is, before casting, the simulation experiment is carried out on the computer for the established process. It can ensure the success of the process, design, and mold manufacturing.

GLOSSARY

A

acid – a term applied to slags, refractories and minerals containing a high percentage of silica;

acidity – the degree to which a material is acid, furnace refractories are ranked by their acidity;

acid process – a steelmaking method using an acid refractory-lined furnace; neither sulfur nor phosphorus is removed;

acid refractory – siliceous ceramic materials of a high melting temperature, such as silica brick, used for metallurgical furnace linings; compare with basic refractory;

addition agent – (1) any material added to a charge of molten metal in a bath or ladle to bring the alloy to specifications; (2) reagent added to plating bath;

additive – any material added to molding sand for reasons other than bonding, for example, seacoal, pitch, graphite, cereals;

aerate – to fluff up molding sand to reduce its density;

airblasting – see blasting or blast cleaning;

air channel – a groove or hole that carries the vent from a core to the outside of a mold;

air dried – refers to the air drying of a core or mold without the application of heat;

air-dried strength – **s**trength (compressive, shear or tensile) of a refractory (sand) mixture after being air dried at room temperature;

air furnace – reverberatory-type furnace in which metal is melted by heat from fuel burning at one end of the hearth, passing over the bath toward the stack at the other end; heat is also reflected from the roof and sidewalls;

air hole – a hole in a casting caused by air or gas trapped in the metal during solidification;

air setting – the characteristic of some materials, such as refractory cements, core pastes, binders and plastics, to take permanent set at normal air temperature**s;**

allowance – in a foundry, the specified clearance; the difference in limiting sizes, such as minimum clearance or maximum interference between mating parts, as computed arithmetically;

alloy – a material exhibiting metallic properties and composed of two or more chemical elements;

alpha process – a shell molding and coremaking method in which a thin resinbonded shell is baked with a less expensive, highly permeable material;

alumina – the mineral aluminum oxide (Al_2O_3) with a high melting point (refractory) that is sometimes used as a molding sand;

Antioch process – a plaster molding process comprising 50% sand, 40% gypsum, and 8% fibrous talc mixed with water in the ratio of 100 parts material to 50 parts water;

angularity – the angular relationship of one surface to another; specifically, the dimensional tolerance associated with such features on a casting;

arbitration bar – a test bar, cast with a heat of material, used to determine chemical composition, hardness, tensile strength and deflection and strength under transverse loading in order to establish the state of acceptability of the casting;

arbor – a metal shape embedded in and used to support green or dry sand cores in the mold;

arc furnace – a furnace in which metal is melted either directly by an electric arc between an electrode and the work or indirectly by an arc between two electrodes adjacent to the metal;

arc melting – melting metal in an electric arc furnace;

as-cast condition – **c**astings as removed from the mold without subsequent heat treatment;

atmospheric riser – a riser that uses atmospheric pressure to aid feeding; essentially, a blind riser into which a small core or rod protrudes; the function of the core or rod is to provide an open passage so that the molten interior of the riser will not be under a partial vacuum when metal is withdrawn to feed the casting but will always be under atmospheric pressure;

austenite – a solid solution of one or more elements in face-centered cubic iron (gamma iron); unless otherwise designated (such as nickel austenite), the solute is generally assumed to be carbon.

austenite steel – any steel containing sufficient alloy to produce a stable austenitic (gamma iron) crystalline structure at ambient temperatures.

B

back draft – a reverse taper that prevents removal of a pattern from a mold or a core from a core box;

backing board (backing plate) – a second bottom board on which molds are opened;

back draft – a reverse taper from the designed direction of draw from a pattern or corebox; prevents removal of a pattern from a mold without damage to the mold-tear ups;

backing sand – the bulk of the sand in the flask, the sand compacted on top of the facing sand that covers the pattern;

backup coat – the ceramic slurry of dip coat that is applied in multiple layers to provide a ceramic shell of the desired thickness and strength for use as a mold;

bake – heating in an oven to a low controlled temperature to remove gases or to harden a binder;

baked core – a core that has been heated through sufficient time and temperature to produce the desired physical properties attainable from its oxidizing or thermal-setting binders;

bank sand – sedimentary deposits, usually containing less than 5% clay, occurring in banks or pits, used in coremaking and in synthetic molding sands;

bar – metal supports placed in a flask, usually the cope to reinforce sand;

basic refractory – a lime- or magnesia-base ceramic material of high melting temperature used for furnace linings;

basin – a cavity on top of the cope into which metal is poured before it enters the sprue;

batch – an amount of core or mold sand or other material prepared at one time;

bath – molten metal on the hearth of a furnace, in a crucible or in a ladle;

bead – (1) half-round cavity in a mold or half-round projection or molding on a casting; (2) a single deposit of weld metal produced by fusion;

bedding – sinking a pattern down into the sand to the desired position and ramming the sand around it;

bedding a core – placing an irregularly shaped core on a bed of sand for drying;

bench molding – making sand molds by hand tamping loose or production patterns at a bench without the assistance of air or hydraulic action;

bentonite – a colloidal claylike substance derived from the decomposition of volcanic ash composed chiefly of the minerals of the montmorillonite family; it is used for bonding molding sand;

bimetal – a casting made of two different metals, usually produced by centrifugal casting;

binder – a material used to hold the grains of sand together in molds or cores; it may be cereal, oil, clay or natural or organic resins;

blacking – carbonaceous materials, such as graphite or powdered carbon, usually mixed with a binder and frequently carried in suspension in water or other liquid used as a thin facing applied to surfaces of molds or cores to improve casting finish;

blasting or blast cleaning – a process for cleaning or finishing metal objects with an air blast or centrifugal wheel that throws abrasive particles against the surface of the workpiece; small, irregular particles of metal are used as the abrasive in gritblasting; sand, in sandblasting; and steel balls, in shotblasting;

bleed – refers to molten metal oozing out of a casting; it is stripped or removed from the mold before complete solidification;

blended sand – a mixture of sands of different grain size and clay content that provides suitable characteristics for foundry use;

blind riser – a riser that does not extend through the top of the mold;

blister – a defect in metal, on or near the surface, resulting from the expansion of gas in a subsurface zone; it is characterized by a smooth bump on the surface of the casting and a hole inside the casting directly below the bump;

blow – a term that describes the trapping of gas in castings, causing voids in the metal;

blowhole – a void or large pore that may occur because of entrapped air, gas or shrinkage; usually evident in heavy sections;

blow holes – holes in the head plate or blow plate of a core blowing machine through which sand is blown from the reservoir into the core box;

bond clay – any clay suitable for use as a bonding agent in molding sand;

bond strength – the degree of cohesiveness that the bonding agent exhibits in holding sand grains together;

bonding agent – any material other than water that, when added to foundry sands, imparts strength either in the green, dry or fired state;

boss – a relatively short protrusion or projection from the surface of a forging or casting, often cylindrical in shape; usually intended for drilling and tapping for attaching parts;

bottom board – a flat base for holding the flask in making sand molds;

bottom-pour ladle – a ladle from which metal, usually steel, flows through a nozzle located at the bottom;

bottom running or pouring – filling of the mold cavity from the bottom by means of gates from the runner;

brazing – this process is used for joining metals and alloys by fusion of nonferrous alloys that have melting points above 800 degree F, but lower than those of the metals being joined;

bridging – (1) premature solidification of metal across a mold section before the metal below or beyond solidifies; (2) solidification of slag within a cupola at or just above the tuyeres;

buckle – (1) bulging of a large, flat face of a casting; in investment casting, caused by dip coat peeling from the pattern; (2) an indentation in a casting, resulting from expansion of the sand, can be termed the start of an expansion defect;

bumper – a machine used for packing molding sand in a flask by repeated jarring or jolting;

burned-in sand – a defect consisting of a mixture of sand and metal cohering to the surface of a casting;

burned-on sand – a misnomer usually indicating metal penetration into sand resulting in a mixture of sand and metal adhering to the surface of a casting;

burnout – firing a mold at a high temperature to remove pattern material residue;

burned sand – sand in which the binder or bond has been removed or impaired by contact with molten metal.

C

calcium silicon – an alloy of calcium, silicon and iron containing 28 to 35% Ca, 60 to 65% Si and 6% Fe (max), used as a deoxidizer and degasser for steel and cast iron; sometimes called calcium silicide;

carbonaceous – a material that contains carbon in any or all of its several allotropic forms;

carbon dioxide process (sodium silicate/CO_2) – a process for hardening molds or cores in which carbon dioxide gas is blown through dry clay- free silica sand to precipitate silica in the form of a gel from the sodium silicate binder;

carbon refractory – a manufactured refractory comprised substantially or entirely of carbon (including graphite);

carbon steel – a kind of steel that owes its properties mainly to various percentages of carbon but without substantial quantities of other alloying elements;

castability – (1) a complex combination of liquid-metal properties and solidification characteristics that promotes accurate and sound final castings; (2) the relative ease with which a molten metal flows through a mold or casting die;

castable – a combination of refractory grain and suitable bonding agent that, after the addition of a proper liquid, is generally poured into place to form a refractory shape or structure that becomes rigid because of chemical action;

casting – (1) metal object cast to the required shape by pouring or injecting liquid metal into a mold, as distinct from one shaped by a mechanical process; (2) pouring molten metal into a mold to produce an object of desired shape;

casting defect – any imperfection in a casting that does not satisfy one or more of the required design or quality specifications; this term is often used in a limited sense for those flaws formed by improper casting solidification;

casting section thickness – the wall thickness of the casting; because the casting may not have a uniform thickness, the section thickness may be specified at a specific place on the casting; also, it is sometimes useful to use the average, minimum or typical wall thickness to describe a casting;

casting shrinkage – the amount of dimensional change per unit length of the casting as it solidifies in the mold or die and cools to room temperature after removal from the mold or die. There are three distinct types of casting shrinkage; liquid shrinkage refers to the reduction in volume of liquid metal as it cools to the liquidus; solidification shrinkage is the reduction in volume of metal from the beginning to the end of solidification; solid shrinkage involves the reduction in volume of metal from the solidus to room temperature;

casting stresses – stresses set up in a casting because of geometry and casting shrinkage;

casting thickness – see casting section thickness;

casting volume – the total cubic units (mm^3 or in^3) of cast metal in the casting;

casting yield – the weight of a casting(s) divided by the total weight of metal poured into the mold, expressed as a percentage;

cast iron – a generic term for a large family of cast ferrous alloys in which the carbon content exceeds the solubility of carbon in austenite at the eutectic temperature; most cast irons contain at least 2% C, plus silicon and sulfur and may or may not contain other alloying elements, for the various forms, the word cast is often left out, resulting in compacted graphite iron, gray iron, white iron, malleable iron and ductile iron;

cast structure – the internal physical structure of a casting evidenced by the shape and orientation of crystals and the segregation of impurities;

cavity – the mold or die impression that gives a casting its external shape;

cementite – a very hard and brittle compound of iron and carbon corresponding to the empirical formula Fe_3C, commonly known as iron carbide;

centerline shrinkage – shrinkage or porosity occurring along the central plane or axis of a cast part;

centrifugal casting – the process of filling molds by (1) pouring metal into a sand or permanent mold that is revolving about either its horizontal or its vertical axis or (2) pouring metal into a mold that is subsequently revolved before solidification of the metal is complete;

centrifuge casting – a casting technique in which mold cavities are spaced symmetrically about a vertical axial common downgate; the entire assembly is rotated about that axis during pouring and solidification;

ceramic – material of a nonmetallic nature, usually refractory, made from fused, sintered or cemented metallic oxides;

ceramic molding – a precision casting process that employs permanent patterns and fine-grain slurry for making molds; unlike monolithic investment molds, which are similar in composition, ceramic molds consist of a cope and a drag or, if the casting shape permits, a drag only;

CG iron – same as compacted graphite iron;

chaplet – metal support that holds a core in place within a mold; molten metal solidifies around a chaplet and fuses it into the finished casting;

charge – (1) the materials placed in a melting furnace; (2) castings placed in a heat-treating furnace;

check – a minute crack in the surface of a casting caused by unequal expansion or contraction during cooling;

chill – (1) a metal or graphite insert embedded in the surface of a sand mold or core or placed in a mold cavity to increase the cooling rate at that point; (2) white iron occurring on a gray or ductile iron casting, such as the chill in the wedge test;

chill coating – applying a coating to a chill that forms part of the mold cavity so that the metal does not adhere – to it or applying a special coating to the sand surface of the mold that causes the iron to undercool;

chilled iron – cast iron that is poured into a metal mold or against a mold insert so as to cause the rapid solidification that often tends to produce a white iron structure in the casting;

clay – a natural, earthy, fine-grain material that develops plasticity when mixed with a limited amount of water; foundry clays, which consist essentially of hydrous silicates of alumina, are used in molds and cores;

CO_2 process – see carbon dioxide process;

coining – (1) the process of straightening and sizing castings by die pressing; (2) a press metalworking operation that establishes accurate dimensions of flat surfaces or depressions under predominantly compressive loading;

coke – a porous, gray, infusible product resulting from the dry distillation of bituminous coal, petroleum or coal tar pitch that drives off most of the volatile matter;

coke bed – the first layer of coke placed in the cupola; also the coke used as the foundation in constructing a large mold in a flask or pit;

coke breeze – fines from coke screenings, used in blacking mixes after grinding; also briquetted for cupola use;

coke furnace – type of pot or crucible furnace that uses coke as the fuel;

cold box process – a two-part organic resin binder system mixed in conventional mixers and blown into shell or solid core shapes at room temperature; a vapor mixed with air is blown into the core, permitting instant setting and immediate pouring of metal around it;

cold chamber machine – a die casting machine with an injection system that is charged with liquid metal from a separate furnace;

cold cracking – cracks in cold or nearly cold metal due to excessive internal stress caused by contraction; often brought about when the mold is too hard or the casting is of unsuitable design;

cold lap – wrinkled markings on the surface of an ingot or casting from incipient freezing of the surface and too low a casting temperature;

cold-setting process – any of several systems for bonding mold or core aggregates by means of organic binders, relying on the use of catalysts rather than heat for polymerization (setting);

cold shot – (1) a portion of the surface of an ingot or casting showing premature solidification; caused by splashing of molten metal onto a cold mold wall during pouring; (2) small globule of metal embedded in, but not entirely fused with, the casting;

cold shut – (1) a discontinuity that appears on the surface of cast metal as a result of two streams of liquid meeting and failing to unite; (2) a lap on the surface of a forging or billet that was closed without fusion during deformation; (3) freezing of the top surface of an ingot before the mold is full;

collapsibility – the tendency of a sand mixture to break down under the pressures and temperatures developed during casting;

columnar structure – a coarse structure of parallel columns of grains, that is caused by highly directional solidification resulting from sharp thermal gradients;

combination die (multiple-cavity die) – in die casting, a die with two or more different cavities for different castings;

combined carbon – carbon in iron that is combined chemically with other elements; not in the free state as graphite or temper carbon; the difference between the total carbon and the graphite carbon analyses;

compacted graphite iron – cast iron having a graphite shape intermediate between the flake form typical of gray iron and the spherical form of fully spherulitic ductile iron, also known as CG iron or vermicular iron, compacted graphite iron is produced in a manner similar to that for ductile iron but with a technique that inhibits the formation of fully spherulitic graphite nodules;

constraint – any restriction that limits the transverse contraction normally associated with a longitudinal tension and therefore causes a secondary tension in the transverse direction;

consumable-electrode remelting – a process for refining metals in which an electric current passes between an electrode made of the metal to be refined and an ingot of the refined metal, which is contained in a water-cooled mold. As a result of the passage of electric current, droplets of molten metal form on the electrode and fall to the ingot. The refining action occurs from contact with the atmosphere, vacuum or slag through which the drop falls;

continuous casting – a process for forming a bar of constant cross section directly from molten metal by gradually withdrawing the bar from a die as the metal flowing into the die solidifies;

contraction – the volume change that occurs in metals and alloys upon solidification and cooling to room temperature;

convection – the motion resulting in a fluid from the differences in density and the action of gravity. In heat transmission, this meaning has been extended to include both forced and natural motion or circulation;

cooling stresses – stresses developed during cooling by the uneven contraction of metal, generally due to nonuniform cooling;

cope – the upper or topmost section of a flask , mold or pattern;

core – (1) a specially formed material inserted in a mold to shape the interior or other part of a casting that cannot be shaped as easily by the pattern; (2) in a ferrous alloy prepared for case hardening, that portion of the alloy that is not part of the case. Typically considered to be the portion that (a) appears light on an etched cross section; (b) has an essentially unaltered chemical composition or (c) has a hardness, after hardening, less than a specified value;

core assembly – a complex core consisting of a number of sections;

core binder – any material used to hold the grains of core sand together;

core blow – a gas pocket in a casting adjacent to a cored cavity and caused by entrapped gases from the core;

core blower – a machine for making foundry cores using compressed air to blow and pack the sand into the core box;

core box – a wood, metal or plastic structure containing a shaped cavity into which sand is packed to make a core;

core dryers – supports used to hold cores in shape during baking; constructed from metal or sand for conventional baking or from plastic material for use with dielectric core-baking equipment;

core filler – material, such as coke, cinder and sawdust, used in place of sand in the interiors of large cores; usually added to aid collapsibility;

coring – a variable composition between the center and the surface of a unit of structure (such as a dendrite, grain or carbide particle) resulting from the none quilibrium growth that occurs over a range of temperature;

core knockout machine – a mechanical device for removing cores from castings;

coreless induction furnace – an electric induction furnace for melting or holding molten die casting metals that does not utilize a steel core to direct the magnetic field;

core oil – a binder for core sand that sets when baked and is destroyed by the heat from the cooling casting;

core plates – heat-resistant plates used to support cores during baking; may be metallic or nonmetallic, the latter being a requisite for dielectric core baking;

core print – projections attached to a pattern in order to form recesses in the mold at points where cores are to be supported;

core sand – sand for making cores to which a binding material has been added to obtain good cohesion and permeability after drying; usually low in clays;

core shift – a variation from the specified dimensions of a cored casting section due to a change in position of the core or misalignment of cores in assembly;

core vents – (1) a wax product, round or oval in form, used to form the vent passage in a core; also, a metal screen or slotted piece used to form the vent passage in the core box used in a core blowing machine; (2) holes made in the core for the escape of gas;

core wash – a suspension of a fine refractory applied to cores by brushing, dipping or spraying to improve the surface of the cored portion of the casting;

core wires or rods – reinforcing wires or rods for fragile cores, often preformed into special shapes;

corrosion – a continual chemical or electrochemical attack on a metal surface, triggered by atmosphere, moisture or other agents;

corundum – native alumina or aluminum oxide, Al_2O_3, occurring as rhombohedral crystals and also in masses and variously colored grains; It is the hardest mineral except for the diamond; corundum and its artificial counterparts are abrasives especially suited to the grinding of metals;

coupon – a piece of metal from which a test specimen is to be prepared; often an extra piece (as on a casting or forging) or a separate piece made for test purposes (such as a test weldment);

cover core – (1) a core set in place during the ramming of a mold to cover and complete a cavity partly formed by the withdrawal of a loose part of the pattern; also used to form part or all of the cope surface of the mold cavity; (2) a core placed over another core to create a flat parting line;

critical dimension – a dimension on a part that must be held within the specified tolerance for the part to function in its application; A noncritical tolerance may be for cost or weight savings or for manufacturing convenience, but is not essential for the products;

croning process – a shell molding process that uses a phenolic resin binder; Sometimes referred to as C process or chronizing;

cross-sectional area – the area measured at right angles to the molten metal flow stream at any specified portion of the gating system;

crucible – a vessel or pot, made of a refractory substance or of a metal with a high melting point, used for melting metals or other substances;

crucible furnace – a melting or holding furnace in which the molten metal is contained in a pot-shaped (hemispherical) shell; electric heaters or fuel-fired burners outside the shell generate the heat that passes through the shell (crucible) to the molten metal;

crush – (1) buckling or breaking of a section of a casting mold due to incorrect register when the mold is closed; (2) an indentation in the surface of a casting due to displacement of sand when the mold was closed;

crush strip or bead – an indentation in the parting line of a pattern plate that ensures that cope and drag will have good contact by producing a ridge of sand that crushes against the other surface of the mold or core;

cupola – a cylindrical vertical furnace for melting metal, especially cast iron, by having the charge come in contact with the hot fuel, usually metallurgical coke;

curing time (no bake) – the period of time needed before a sand mass reaches maximum hardness;

cut – (1) to recondition molding sand by mixing on the floor with a shovel or blade-type machine; (2) to form the sprue cavity in a mold; (3) defect in a casting resulting from erosion of the sand by metal flowing over the mold or cored surface;

cut off – removing a casting from the sprue by refractory wheel or saw, arc-air torch or gas torch.

D

daubing – filling of cracks in molds or cores by specially prepared pastes or coatings to prevent penetration of metal into these cracks during pouring;

dead-burned – term applied to materials that have been fired to a temperature sufficiently high to render them relatively resistant to moisture and contraction;

defect – a discontinuity whose size, shape, orientation or location makes it detrimental to the useful service of the part in which it occurs;

defective – a quality control term describing a unit of product or service containing at least one defect or having several lesser imperfections that, in combination, cause the unit not to fulfill its anticipated function;

degasification – see degassing;

degasifier – a substance that can be added to molten metal to remove soluble gases that might otherwise be occluded or entrapped in the metal during solidification;

degassing – (1) a chemical reaction resulting from a compound added to molten metal to remove gases from the metal; inert gases are often used in this operation; (2) a fluxing procedure used for aluminum alloys in which nitrogen, chlorine, chlorine, nitrogen, chlorine and argon are bubbled up through the metal to remove dissolved hydrogen gases and oxides from the alloy;

dendrite – a crystal that has a treelike branching pattern, being most evident in cast metals slowly cooled through the solidification range;

deoxidation – removal of excess oxygen from the molten metal; usually accomplished by adding materials with a high affinity for oxygen;

deoxidizer – a substance that can be added to molten metal to remove either free or combined oxygen;

deoxidizing – (1) the removal of oxygen from molten metals through the use of a suitable deoxidizer; (2) sometimes refers to the removal of undesirable elements other than oxygen through the introduction of elements or compounds that readily react with them; (3) in metal finishing, the removal of oxide films from metal surfaces by chemical or electrochemical reaction;

dephosphorization – the elimination of phosphorus from molten steel;

descaling – a chemical or mechanical process for removing scale or investment material from castings;

desulfurizing – the removal of sulfur from molten metal by reaction with a suitable slag or by the addition of suitable compounds;

dewaxing – the process of removing the expendable wax pattern from an investment mold or shell mold; usually accomplished by melting out the application of heat or dissolving the wax with an appropriate solvent;

die casting – (1) a casting made in a die; (2) a casting process in which molten metal is forced under high pressure into the cavity of a metal mold;

die pull – the direction in which the solidified casting must move when it is removed from the die; the die pull direction must be selected such that all points on the surface of the casting move away from the die cavity surfaces;

die separation – the space between the two halves of a die casting die at the parting surface when the dies are closed. The separation may be the result of the internal cavity pressure exceeding the locking force of the machine or warpage of the die due to thermal gradients in the die steel;

dip coat – (1) in the solid mold technique of investment casting, an extremely fine ceramic precoat applied as a slurry directly to the surface of the pattern to reproduce maximum surface smoothness. This coating is surrounded by coarser, less expensive and more permeable investment to form the mold; (2) in the shell mold technique of investment casting, an extremely fine ceramic coating called the first coat, applied as a slurry directly to the surface of the pattern to reproduce maximum surface smoothness. The first coat is followed by other dip coats of different viscosity and usually containing different grading of ceramic particles; after each dip, coarser stucco material is applied to the still-wet coating;

directional solidification – solidification of molten metal in such a manner that feed metal is always available for that portion that is just solidifying;

discontinuity – any interruption in the normal physical structure or configuration of a part, such as cracks, laps, seams, inclusions or porosity; a discontinuity may or may not affect the utility of the part;

distortion – any deviation from the desired shape or contour;

dolomite brick – a calcium magnesium carbonate ($CaMg(CO_3)_2$) used as a refractory brick that is manufactured substantially or entirely of dead-burned dolomite;

dowel – (1) a wooden or metal pin of various types used in the parting surface of parted patterns and core boxes; (2) in die casting dies, metal pins to ensure correct registry of cover and ejector halves;

downgate – same as sprue;

draft – (1) an angle or taper on the surface of a pattern, core box, punch or die (or of the parts made with them) that facilitates removal of the parts from a mold or die cavity or a core from a casting; (2) the change in cross section that occurs during rolling or cold drawing;

drag – the bottom section of a flask, mold or pattern;

draw – a term used to denote the shrinkage that appears on the surface of a casting; formerly used to describe tempering;

drawing (pattern) – removing a pattern from a mold or a mold from a pattern in production work;

draw plate – a plate attached to a pattern to facilitate drawing of a pattern from the mold;

drop – a casting imperfection due to a portion of the sand dropping from the cope or other overhanging section of the mold;

dross – the scum that forms on the surface of molten metal largely because of oxidation but sometimes because of the rising of impurities to the surface;

dry and baked compression test – an American Foundrymen's Society test for determining the maximum compressive stress that a baked sand mixture is capable of developing;

dry permeability – the property of a molded mass of sand, bonded or unbonded, dried at ~100 to 110 °C (~220 to 230 °F) and cooled to room temperature, that allows the transfer of gases resulting during the pouring of molten metal into a mold;

dry sand casting – the process in which the sand molds are dried at above 100 °C (212 °F) before use;

dry sand mold – a casting mold made of sand and then dried at ~100°C (~220°F) or above before being used;

dry strength – the maximum strength of a molded sand specimen that has been thoroughly dried at ~100 to 100°C (~220 to 230°F) and cooled to room temperature; also known as dry bond strength;

dual-metal centrifugal casting – centrifugal castings produced by pouring a different metal into the rotating mold after the first metal poured has solidified; also referred to as bimetal casting;

ductile iron – a cast iron that has been treated while molten with an element such as magnesium or cerium to induce the formation of free graphite as nodules or spherulites, which imparts a measurable degree of ductility to the cast metal; also known as nodular cast iron, spherulitic graphite cast iron and SG iron.

E

ejector – a pin (rod) or mechanism that pushes the solidified die casting out of the die;

ejector pin – see ejector;

electric arc furnace – see arc furnace;

electric furnace – a metal melting or holding furnace that produces heat from electricity; It may operate on the resistance or induction principle;

electrode – compressed graphite or carbon cylinder or rod used to conduct electric current in electric arc furnaces, arc lamps, carbon arc welding and so forth;

electroslag remelting – a consumable-electrode remelting process in which heat is generated by the passage of electric current through a conductive slag; the droplets of metal are refined by contact with the slag;

endothermic reaction – designating or pertaining to a reaction that involves the absorption of heat;

erosion – abrasion of metal or other material by liquid or gas, it gets accelerated by pressure of solid matter particles in suspension;

equiaxed grain structure – a structure in which the grains have approximately the same dimensions in all directions;

ethyl silicate – a strong bonding agent for sand and refractories used in preparing molds in the investment casting process;

eutectic – (1) an isothermal reversible reaction in which a liquid solution is converted into two or more intimately mixed solids upon cooling, the number of solids formed being the same as the number of components in the system, (2) an alloy having the composition indicated by the eutectic point on an equilibrium diagram; (3) an alloy structure of intermixed solid constituents formed by a eutectic reaction;

exothermic reaction – chemical reactions involving the liberation of heat, such as the burning of fuel or the deoxidizing of iron with aluminum;

expendable pattern – a pattern that is destroyed in making a casting; it is usually made of wax (investment casting) or expanded polystyrene (lost foam casting);

expanded metal – a rigid, metal sheet or plate made of carbon or stainless steel, aluminum, and a variety of alloys. It is slit and expanded (drawn) into an open mesh pattern . That makes it stronger, lighter and more rigid than the original material.

F

facing – any material applied in a wet or dry condition to the face of a mold or core to improve the surface of the casting;

feeder (feeder head, feedhead) – a riser;

feeding – (1) in casting, providing molten metal to a region undergoing solidification, usually at a rate sufficient to fill the mold cavity ahead of the solidification front and to compensate for any shrinkage accompanying solidification, (2) conveying metal stock or workpieces to a location for use or processing, such as wire to a consumable electrode, strip to a die or workpieces to an assembler;

ferrite – an essentially carbon-free solid solution in which alpha iron is the solvent and which is characterized by a body-centered cubic crystal structure;

ferroalloy – an alloy of iron that contains a sufficient amount of one or more other chemical elements to be useful as an agent for introducing these elements into molten metal, especially into steel or cast iron;

ferrous – metallic materials in which the principal component is iron;

fillet – concave corner piece usually used at the intersection of casting sections; also the radius of metal at such junctions as opposed to an abrupt angular junction;

fillet radius – blend radius between two abutting walls;

fin – metal on a casting caused by an imperfect joint in the mold or die;

finish allowance – amount of stock left on the surface of a casting for machining;

firebrick – a refractory brick, often made from fireclay , that is able to withstand high temperature (1500 to 1600 °C or 2700 to 2900 °F) and is used to line furnaces, ladles or other molten metal containment components;

fireclay – a mineral aggregate that has as its essential constituent the hydrous silicates of aluminum with or without free silica; it is used in commercial refractory products;

fired mold – a shell mold or solid mold that has been heated to a high temperature and is ready for casting;

flake graphite – graphitic carbon, in the form of platelets, occurring in the microstructure of gray iron;

flash – a thin section or fin of metal formed at the mold, core or die joint or parting in a casting due to the cope and drag not matching completely or where core and core print do not match;

flask – a metal or wood frame used for making and holding a sand mold; The upper part is called the cope ; the lower, the drag;

flaw – a nonspecific term often used to imply a crack like discontinuity;

floor molding – making sand molds from loose or production patterns of such size that they cannot be satisfactorily handled on a bench or molding machine, the equipment being located on the floor during the entire operation of making the mold;

flowability – a characteristic of a foundry sand mixture that enables it to move under pressure or vibration so that it makes intimate contact with all surfaces of the pattern or core box;

fluidity – the ability of liquid metal to run into and fill a mold or die cavity;

flux – (1) in metal refining, a material used to remove undesirable substances, such as sand, ash or dirt, as a molten mixture; it is also used as a protective covering for certain molten metal baths; lime or limestone is generally used to remove sand, as in iron smelting; sand, to remove iron oxide in copper refining; (2) in brazing, cutting, soldering or welding, material used to prevent the formation of or to dissolve and facilitate the removal of oxides and other undesirable substances;

foundry returns – metal in the form of gates, sprues, runners, risers and scrapped castings of known composition returned to the furnace for remelting;

free carbon – the part of the total carbon in steel or cast iron that is present in elemental form as graphite or temper carbon;

free ferrite – ferrite formed into separate grains and not intimately associated with carbides as in pearlite;

freezing range – that temperature range between liquidus and solidus temperatures in which molten and solid constituents coexist;

full mold – a trade name for an expendable pattern casting process in which the polystyrene pattern is vaporized by the molten metal as the mold is poured.

G

gassing – **(**1) absorption of gas by a metal; (2) evolution of gas from a metal during melting operations or upon solidification; (3) evolution of gas from an electrode during electrolysis;

gas holes – holes in castings or welds that are formed by gas escaping from molten metal as it solidifies; gas holes may occur individually, in clusters or throughout the solidified metal;

gas pocket – a cavity caused by entrapped gas;

gas porosity – fine holes or pores within a metal that are caused by entrapped gas or by the evolution of dissolved gas during solidification;

gate – the portion of the runner in a mold through which molten metal enters the mold cavity; the generic term is sometimes applied to the entire network of connecting channels that conduct metal into the mold cavity;

gated pattern – a pattern that includes not only the contours of the part to be cast but also the gates;

gating system – the complete assembly of sprues, runners and gates in a mold through which metal flows to enter the casting cavity; the term is also applied to equivalent portions of the pattern;

glove mold – a mold that is brushed on to the original part, creating a thinner, floppy mold that can easily be pulled of the part;

gooseneck – in die casting, a spout connecting a molten metal holding pot or chamber, with a nozzle or sprue hole in the die and containing a passage through which molten metal is forced on its way to the die; it is the metal injection mechanism in a hot chamber machine;

grain – an individual crystal in a polycrystalline metal or alloy; it may or may not contain twinned regions and subgrains;

grain fineness number – a system developed by the American Foundrymen's Society for rapidly expressing the average grain size of a given sand; it approximates the number of meshes per inch of that sieve that would just pass the sample;

grain refinement – the manipulation of the solidification process to cause more (and therefore smaller) grains to be formed and/or to cause the grains to form in specific shapes; the term refinement is usually used to denote a chemical addition to the metal, but can refer to control of the cooling rate;

grain refiner – any material added to a liquid metal for producing a finer grain size in the subsequent casting;

grain size – for metals, a measure of the areas or volumes of grains in a polycrystalline material, usually expressed as an average when the individual sizes are fairly uniform. In metals containing two or more phases, grain size refers to that of the matrix unless otherwise specified; grain size is reported in terms of number of grains per unit area or volume, in terms of average diameter or as a grain size number derived from area measurements;

graphite – one of the crystal forms of carbon; also the uncombined carbon in cast irons;

graphitic carbon – free carbon in steel or cast iron;

graphitization – the formation of graphite in iron or steel; where graphite is formed during solidification, the phenomenon is termed primary graphitization; where formed later by heat treatment, secondary graphitization;

gravity die casting – see permanent mold;

gray iron – cast iron that contains a relatively large percentage of the carbon present in the form of flake graphite;

green sand – a molding sand that has been tempered with water and is used for casting when still in the damp condition;

green sand core – (1) a core made of green sand and used as-rammed; (2) a sand core that is used in the unbaked condition;

green sand mold – a casting mold composed of moist prepared molding sand;

green strength – the strength of a tempered sand mixture at room temperature;

grit – crushed ferrous or synthetic abrasive material in various mesh sizes that is used in abrasive blasting equipment to clean castings;

gross porosity – in weld metal or in a casting, pores, gas holes or globular voids that are larger and in much greater numbers than those obtained in good practice;

growth (cast iron) – a permanent increase in the dimensions of cast iron resulting from repeated or prolonged heating at temperatures above 480°C (900 °F) due either to graphitizing of carbides or oxidation.

H

hardener – an alloy rich in one or more alloying elements that is added to a melt to permit closer control of composition than is possible by the addition of pure metals or to introduce refractory elements not readily alloyed with the base metal; sometimes called master alloy or rich alloy;

hearth – the bottom portions of certain furnaces, such as blast furnaces, air furnaces and other reverberatory furnaces, that support the charge and sometimes collect and hold molten metal;

heat – a stated tonnage of metal obtained from a period of continuous melting in a cupola or furnace or the melting period required to handle this tonnage;

heat-disposable pattern – a pattern formed from a wax or plastic-base material that is melted from the mold cavity by the application of heat;

holding furnace – a furnace into which molten metal can be transferred to be held at the proper temperature until it can be used to make castings;

hot box process – a furan resin-base process similar to shell coremaking; cores produced with it are solid unless mandrelled out;

hot chamber machine – a die casting machine in which the metal chamber under pressure is immersed in the molten metal in a furnace;

hot crack – a crack formed in a cast metal because of internal stress developed upon cooling following solidification; a hot crack is less open than a hot tear and usually exhibits less oxidation and decarburization along the fracture surface;

hot shortness – a tendency for some alloys to separate along grain boundaries when stressed or deformed at temperatures near the melting point; hot shortness is caused by a low-melting constituent, often present only in minute amounts, that is segregated at grain boundaries;

hot tear – a fracture formed in a metal during solidification because of hindered contraction;

hot top – (1) a reservoir, thermally insulated or heated, that holds molten metal on top of a mold for feeding of the ingot or casting as it contracts on solidifying, thus preventing the formation of pipe or voids; (2) a refractory-lined steel or iron casting that is inserted into the tip of the mold and is supported at various heights to feed the ingot as it solidifies.

I

impregnation – (1) treatment of porous castings with a sealing medium to stop pressure leaks; (2) the process of filling the pores of a sintered compact, usually with a liquid such as a lubricant; (3) the process of mixing particles of a nonmetallic substance in a matrix of metal powder, as in diamond- impregnated tools;

inclusions – particles of foreign material in a metallic matrix; the particles are usually compounds (such as oxides, sulfides or silicates), but may be of any substance that is foreign to (and essentially insoluble in) the matrix;

induction furnace – an alternating current electric furnace in which the primary conductor is coiled and generates, by electro-magnetic induction, a secondary current that develops heat within the metal charge;

induction heating or melting – heating or melting in an induction furnace;

inert gas – a gas that will not support combustion or sustain any chemical reaction, for example, argon or helium;

ingate – same as gate;

ingot – a casting of simple shape, suitable for hot working or remelting;

injection – the process of forcing molten metal into the die casting die;

injection molding – the injection of molten metal or other material under pressure into molds;

inoculant – materials that, when added to molten metal, modify the structure and thus change the physical and mechanical properties to a degree not explained on the basis of the change in composition resulting from their use;

inoculation – the addition of a material to molten metal to form nuclei for crystallization;

insert – (1) a part formed from a second material, usually a metal, that is placed in the molds and appears as an integral structural part of the final casting; (2) a removable portion of a die or mold;

insulating pads and sleeves – insulating material, such as gypsum, diatomaceous earth and so forth, used to lower the rate of solidification; as sleeves on open risers, they are used to keep the metal liquid, thus increasing the feeding efficiency;

internal shrinkage – a void or network of voids within a casting caused by inadequate feeding of that section during solidification;

internal stress – see residual stress;

inverse chill – the condition in a casting section in which the interior is mottled or white, while the other sections are gray iron; also known as reverse chill, internal chill and inverted chill;

inverse segregation – segregation in cast metal in which an excess of lower-melting constituents occurs in the earlier-freezing portions, apparently the result of liquid metal entering cavities developed in the earlier- solidified metal;

investing – the process of pouring the investment slurry into a flask surrounding the pattern to form the mold;

investment – a flowable mixture or slurry, of a graded refractory filler, a binder and a liquid vehicle that, when poured around the patterns, conforms to their shape and subsequently sets hard to form the investment mold;

investment casting – (1) casting metal into a mold produced by surrounding or investing. An expendable pattern with a refractory slurry that sets at room temperature, after which the wax or plastic pattern is removed through the use of heat prior to filling the mold with liquid metal; also called precision casting or lost wax process; (2) a part made by the investment casting process;

investment precoat – see dip coat;

investment precoat – an extremely fine investment coating applied as a thin slurry directly to the surface of the pattern to reproduce maximum surface smoothness; the coating is surrounded by a coarser, cheaper and more permeable investment to form the mold;

investment shell – ceramic mold obtained by alternately dipping a pattern set up in dip coat slurry and stuccoing with coarse ceramic particles until the shell of desired thickness is obtained.

J

jacket, mold – a wood or metal form slipped over a mold made in a snap or slip flask, to support the four sides of the mold during pouring; jackets and mold weights are shifted from one row of molds to another during the pouring period;

jolt ramming – packing sand in a mold by raising and dropping the sand, pattern and flask on a table; jolt squeezers, jarring machines and jolt rammers are machines using this principle; also called jar ramming;

jolt-squeezer machine – a combination machine that employs a jolt action followed by a squeezing action to compact the sand around the pattern.

K

keel block – a standard test casting, for steel and other high-shrinkage alloys, consisting of a rectangular bar that resembles the keel of a boat, attached to the bottom of a large riser or shrinkhead. Keel blocks that have only one bar are often called Y-blocks; keel blocks having two bars, double keel blocks; test specimens are machined from the rectangular bar and the shrinkhead is discarded;

kiln – an oven or furnace for burning, calcining or drying a substance;

knockout – (1) removal of sand cores from a casting; (2) jarring of an investment casting mold to remove the casting and investment from the flask; (3) a mechanism for freeing formed parts from a die used for stamping, blanking, drawing, forging or heading operations; (4) a partially pierced hole in a sheet metal part, where the slug remains in the hole and can be forced out by hand if a hole is needed.

L

ladle – metal receptacle frequently lined with refractories used for transporting and pouring molten metal; types include hand, bull, crane, bottom-pour, holding, teapot, shank and lip-pour;

ladle brick – refractory brick suitable for lining ladles used to hold molten metal;

ladle coating – the material used to coat metal ladles to prevent iron pickup in aluminum alloys; the material can only consist of sodium silicate, iron oxide and water, applied to the ladle when it is heated;

ladle preheating – the process of heating a ladle prior to the addition of molten metal; this procedure reduces metal heat loss and eliminates moisture-steam safety hazards;

launder – a channel for transporting molten metal;

lining – internal refractory layer of firebrick, clay, sand or other material in a furnace or ladle;

lip-pour ladle – ladle in which the molten metal is poured over a lip, much as water is poured out of a bucket;

liquation – partial melting of an alloy, usually as a result of coring or other compositional heterogeneities;

liquation temperature – the lowest temperature at which partial melting can occur in an alloy that exhibits the greatest possible degree of segregation;

liquidus – in a phase diagram, the locus of points representing the temperatures at which the various compositions in the system begin to freeze on cooling or finish melting on heating;

loam – a molding material consisting of sand, silt and clay, used over brickwork or other structural backup material for making massive castings, usually of iron or steel;

locating boss – a boss -shaped feature on a casting to help locate the casting in an assembly or to locate the casting during secondary tooling operations;

lost foam casting (process) – an expendable pattern process in which an expandable polystyrene pattern surrounded by the unbonded sand, is vaporized during pouring of the molten metal;

lost wax process – an investment casting process in which a wax pattern is used.

M

macroshrinkage – isolated, clustered or interconnected voids in a casting that are detectable macroscopically; such voids are usually associated with abrupt changes in section size and are caused by feeding that is insufficient to compensate for solidification shrinkage;

malleable iron – a cast iron made by prolonged annealing of white iron in which decarburization, graphitization or both take place to eliminate some or all of the cementite. The graphite is in the form of temper carbon; if decarburization is the predominant reaction, the product will exhibit a light fracture surface; hence whiteheart malleable. Otherwise, the fracture surface will be dark; hence blackheart malleable; ferritic malleable has a predominantly ferritic matrix; pearlitic malleable may contain pearlite, spheroidite or tempered martensite, depending on heat treatment and desired hardness;

malleablizing – annealing white iron in such a way that some or all of the combined carbon is transformed into graphite or, in some cases, so that part of the carbon is removed completely;

master alloy – an alloy, rich in one or more desired addition elements, that is added to a melt to raise the percentage of a desired constituent;

master pattern – a pattern embodying a double contraction allowance in its construction, used for making castings to be employed as patterns in production work;

match plate – a plate of metal or other material on which patterns for metal casting are mounted (or formed as an integral part) to facilitate molding; the pattern is divided along its parting plane by the plate;

melting point – the temperature at which a pure metal, compound or eutectic changes from solid to liquid; the temperature at which the liquid and the solid are in equilibrium;

melting range – the range of temperatures over which an alloy other than a compound or eutectic changes from solid to liquid; the range of temperatures from solidus to liquidus at any given composition on a phase diagram;

metal penetration – a surface condition in castings in which metal or metal oxides have filled voids between sand grains without displacing them;

microsegregation – segregation within a grain, crystal or small particle;

microshrinkage – a casting imperfection, not detectable microscopically, consisting of interdendritic voids. Microshrinkage results from contraction during solidification where the opportunity to supply filler material is inadequate to compensate for shrinkage; alloys with wide ranges in solidification temperature are particularly susceptible;

misrun – denotes an irregularity of the casting surface caused by incomplete filling of the mold due to low pouring temperatures, gas back pressure from inadequate venting of the mold and inadequate gating;

mold – the form, made of sand, metal or refractory material, that contains the cavity into which molten metal is poured to produce a casting of desired shape;

mold box – a container, not necessarily a square box shape, the holds an original for silicone or other molding material to be poured around it;

mold cavity – the space in a mold that is filled with liquid metal to form the casting upon solidification; the channels through which liquid metal enters the mold cavity (sprue, runner, gates) and reservoirs for liquid metal (risers) are not considered part of the mold cavity proper;

mold coating – (1) coating to prevent surface defects on permanent mold castings and die castings; (2) coating on sand molds to prevent metal penetration and to improve metal finish; also called mold facing or mold dressing;

molding machine – a machine for making sand molds by mechanically compacting sand around a pattern;

molding sands – sands containing over 5% natural clay, usually between 8 and 20%;

mold jacket – wood or metal form that is slipped over a sand mold for support during pouring;

mold shift – a casting defect that results when the parts of the mold do not match at the parting line;

mold wash – an aqueous or alcoholic emulsion or suspension of various materials used to coat the surface of a mold cavity;

mottled cast iron – iron that consists of a mixture of variable proportions of gray cast iron and white cast iron; such a material has a mottled fracture appearance;

mulling – the mixing and kneading of molding sand with moisture and clay to develop suitable properties for molding.

N

naturally bonded molding sand – a sand containing sufficient bonding material as mined to be suitable for molding purposes;

no-bake binder – a synthetic liquid resin sand binder that hardens completely at room temperature, generally not requiring baking; used in a cold-setting process;

nodular graphite – graphite in the nodular form as opposed to flake form (see flake graphite); nodular graphite is characteristic of malleable iron; the graphite of nodular or ductile iron is spherulitic in form, but called nodular;

nodular iron – see preferred term ductile iron;

nominal dimension – the size of the dimension to which the tolerance is applied; for example, if a dimension is 50 mm ± 0;5 mm (2;00 in; ± 0;02 in;), the 50 mm (2;00 in;) is the nominal dimension and the ±0;5 mm (±0;02 in;) is the tolerance;

normal segregation – a concentration of alloying constituents that have low melting points in those portions of a casting that solidify last;

nozzle – (1) pouring spout of a bottom-pour ladle; (2) on a hot chamber die casting machine, the thick- wall tube that carries the pressurized molten metal from the gooseneck to the die;

nucleation – the initiation of a phase transformation at discrete sites, with the new phase growing on the nuclei;

nucleus – (1) the first structurally stable particle capable of initiating recrystallization of a phase or the growth of a new phase and possessing an interface with the parent matrix; the term is also applied to a foreign particle that initiates such action; (2) the heavy central core of an atom, in which most of the mass and the total positive electric charge are concentrated.

O

olivine – a naturally occurring mineral of the composition $(Mg,Fe)_2SiO_4$ that is crushed and used as a molding sand;

open hearth furnace – a reverberatory melting furnace with a shallow hearth and a low roof; the flame passes over the charge on the hearth, causing the charge to be heated both by direct flame and by radiation from the roof and sidewalls of the furnace;

open-sand casting – any casting made in a mold that has no cope or other covering;

oxidation – a chemical reaction in which one substance is changed to another by oxygen combining with the substance; much of the dross from holding and melting furnaces is the result of oxidation of the alloy held in the furnace;

oxidation losses – reduction in the amount of metal or alloy through oxidation; such losses are usually the largest factor in melting loss;

oxygen lance – a length of pipe used to convey oxygen either beneath or on top of the melt in a steelmaking furnace or to the point of cutting in oxygen lance cutting.

P

padding – the process of adding metal to the cross section of a casting wall, usually extending from a riser, to ensure adequate feed metal to a localized area during solidification where a shrink would occur if the added metal were not present;

particle size – the controlling lineal dimension of an individual particle, such as of sand, as determined by analysis with screens or other suitable instruments;

particle size distribution – the percentage, by weight or by number, of each fraction into which a powder or sand sample has been classified with respect to sieve number or particle size;

parting – (1) the zone of separation between cope and drag portions of the mold or flask in sand casting; (2) in the recovery of precious metals, the separation of silver from gold; (3) cutting simultaneously along two parallel lines or along two lines that balance each other in side thrust; (4) a shearing operation used to produce two or more parts from a stamping;

parting compound – a material dusted or sprayed on patterns to prevent adherence of sand and to promote easy separation of cope and drag parting surfaces when the cope is lifted from the drag;

parting line – (1) the intersection of the parting plane of a casting mold or the parting plane between forging dies with the mold or die cavity; (2) a raised line or projection on the surface of a casting or forging that corresponds to said intersection;

parting plane – (1) in casting, the dividing plane between mold halves; (2) in forging, the dividing plane between dies;

pattern – (1) a form of wood, metal or other material around which molding material is placed to make a mold for casting metals; (2) a form of wax- or plastic-base material around which refractory material is placed to make a mold for casting metals; (3) a full-scale reproduction of a part used as a guide in cutting;

pattern draft – taper allowed on the vertical faces of a pattern to permit easy withdrawal of the pattern from the mold or die;

pattern layout – a full-size drawing of a pattern showing its arrangement and structural features;

patternmaker's shrinkage – contraction allowance made on patterns to compensate for the decrease in dimensions as the solidified casting cools in the mold from the freezing temperature of the metal to room temperature; the pattern is made larger by the amount of contraction that is characteristic of the particular metal to be used;

penetration – see metal penetration;

permanent mold – a metal, graphite or ceramic mold (other than an ingot mold) that is repeatedly used for the production of many castings of the same form; liquid metal is poured in by gravity (gravity die casting);

permeability – (1) in founding, the characteristics of molding materials that permit gases to pass through them; (2) in powder metallurgy, a property measured as the rate of passage under specified conditions of a liquid or gas through a compact; (3) a general term used to express various relationships between magnetic induction and magnetizing force; these relationships are either absolute permeability, which is a change in magnetic induction divided by the corresponding change in magnetizing force or specific (relative) permeability, which is the ratio of the absolute permeability to the permeability of free space;

pinhole porosity – porosity consisting of numerous small gas holes distributed throughout the metal; found in weld metal, castings and clectrodeposited metal;

pilot casting or sample casting – a casting made from a pattern produced in a production die to check the accuracy of dimensions and quality of castings which will be made in quantity;

pipe – (1) the central cavity formed by contraction in metal, especially ingots, during solidification; (2) an imperfection in wrought or cast products resulting from such a cavity; (3) a tubular metal product, cast or wrought;

pit molding – molding method in which the drag is made in a pit or hole in the floor;

plaster molding – molding in which a gypsum-bonded aggregate flour in the form of a water slurry is poured over a pattern, permitted to harden and, after removal of the pattern, thoroughly dried; this technique is used to make smooth nonferrous castings of accurate size;

plunger – ram or piston that forces molten metal into a die in a die casting machine; plunger machines are those having a plunger in continuous contact with molten metal;

porosity – a characteristic of being porous, with voids or pores resulting from trapped air or shrinkage in a casting;

port – the opening through which molten metal enters the injection cylinder of a die casting plunger machine or is ladled into the injection cylinder of a cold chamber machine;

pot – (1) a vessel for holding molten metal; (2) the electrolytic reduction cell used to make such metals as aluminum from a fused electrolyte;

pouring – the transfer of molten metal from furnace to ladle, ladle to ladle or ladle into molds;

pouring basin – a basin on top of a mold that receives the molten metal before it enters the sprue or downgate;

precision casting – a metal casting of reproducible, accurate dimensions, regardless of how it is made; often used interchangeably with investment casting;

preformed ceramic core – a preformed refractory aggregate inserted in a wax or plastic pattern to shape the interior of that part of a casting which cannot be shaped by the pattern; the wax is sometimes injected around the preformed core;

pressure casting – (1) making castings with pressure on the molten or plastic metal, as in injection molding , die casting , centrifugal casting, cold chamber pressure casting and squeeze casting; (2) a casting made with pressure applied to the molten or plastic metal;

primary alloy – any alloy whose major constituent has been refined directly from core, not recycled scrap metal;

projected area – the area of a cavity or portion of a cavity, in a mold or die casting die measured from the projection on a plane that is normal to the direction of the mold or die opening.

R

ramming – (1) packing sand, refractory or other material into a compact mass; (2) the compacting of molding sand in forming a mold;

rattail – a surface imperfection on a casting, occurring as one or more irregular lines, caused by the expansion of sand in the mold;

recrystallization – a process in which the distorted grain structure of cold-worked metals is replaced by a new, strain-free grain structure during heating above a specific minimum temperature;

recrystallization temperature – the lowest temperature at which the distorted grain structure of a cold-worked metal is replaced by a new, strain-free grain structure during prolonged heating; time, purity of the metal and prior deformation are important factors;

refractory – (1) a material of very high melting point with properties that make it suitable for such uses as furnace linings and kiln construction; (2) the quality of resisting heat;

residual stress – stress present in a body that is free of external forces or thermal gradients;

reverberatory furnace – a furnace in which the flame used for melting the metal does not impinge on the metal surface itself, but is reflected off the walls of the roof of the furnace; the metal is actually melted by the generation of heat from the walls and the roof of the furnace;

rheocasting – casting of a continuously stirred semisolid metal slurry;

rigging – the engineering design, layout and fabrication of pattern equipment for producing castings; including a study of the casting solidification program, feeding and gating, risering, skimmers and fitting flasks;

riser – a reservoir of molten metal connected to a casting to provide additional metal to the casting, required as the result of shrinkage before and during solidification;

runner – (1) a channel through which molten metal flows from one receptacle to another; (2) the portion of the gate assembly of a casting that connects the sprue with the gate(s); (3) parts of patterns and finished castings corresponding to the portion of the gate assembly described in (2);

runner box – a distribution box that divides molten metal into several streams before it enters the mold cavity;

runout – (1) the unintentional escape of molten metal from a mold, crucible or furnace; (2) the defect in a casting caused by the escape of metal from the mold.

S

sag – an increase or decrease in the section thickness of a casting caused by insufficient strength of the mold sand of the cope or of the core;

sand – a granular material naturally or artificially produced by the disintegration or crushing of rocks or mineral deposits. In casting, the term denotes an aggregate, with an individual particle (grain) size of 0,06 to 2 mm (0,002 to 0,08 in;) in diameter, that is largely free of finer constituents such as silt and clay, which are often present in natural sand deposits. The most commonly used foundry sand is silica; however, zircon, olivine, alumina and other crushed ceramics are used for special applications;

sandblasting – abrasive blasting with sand;

sand casting – metal castings produced in sand molds;

sand grain distribution – variation or uniformity in particle size of a sand aggregate when properly screened by standard screen sizes;

sand reclamation – processing of used foundry sand by thermal, air or hydraulic methods so that it can be used in place of new sand without substantially changing the foundry sand practice;

sand tempering – adding sufficient moisture to molding sand to make it workable;

scab – a defect on the surface of a casting that appears as a rough, slightly raised surface blemish, crusted over by a thin porous layer of metal, under which is a honeycomb or cavity that usually contains a layer of sand; defect common to thin-wall portions of the casting or around hot areas of the mold;

scaling (scale) – surface oxidation, consisting of partially adherent layers of corrosion products, left on metals by heating or casting in air or in other oxidizing atmospheres;

screen – one of a set of sieves designated by the size of the openings, used to classify granular aggregates such as sand, ore or coke by particle size;

screen analysis – see sieve analysis;

seam – (1) a surface defect on a casting related to but of lesser degree than a cold shut ; (2) a ridge on the surface of a casting caused by a crack in the mold face;

secondary alloy – any alloy whose major constituent is obtained from recycled scrap metal;

segregation – a casting defect involving a concentration of alloying elements at specific regions, usually as a result of the primary crystallization of one phase with the subsequent concentration of other elements in the remaining liquid. Microsegregation refers to normal segregation on a microscopic scale in which material richer in an alloying element freezes in successive layers on the dendrites (coring) and in constituent network. Macrosegregation refers to gross differences in concentration (for example, from one area of a casting to another);

semipermanent mold – a permanent mold in which sand cores are used;

shakeout – removal of castings from a sand mold;

shell molding – forming a mold from thermo-setting resin-bonded sand mixtures brought in contact with preheated (150 to 260 °C or 300 to 500 °F) metal patterns, resulting in a firm shell with a cavity corresponding to the outline of the pattern; also called Croning process;

shift – a casting imperfection caused by the mismatch of cope and drag or of cores and mold;

shot – (1) small, spherical particles of metal; (2) the injection of molten metal into a die casting die; the metal is injected so quickly that it can be compared to the shooting of a gun;

shotblasting – blasting with metal shot; usually used to remove deposits or mill scale more rapidly or more effectively than can be done by sandblasting;

shrinkage – see casting shrinkage;

shrinkage cavity – a void left in cast metal as a result of solidification shrinkage;

shrinkage cracks – cracks that form in metal as a result of the pulling apart of grains by contraction before complete solidification;

sieve analysis – particle size distribution; usually expressed as the weight percentage retained on each of a series of standard sieves of decreasing size and the percentage passed by the sieve of finest size; synonymous with sieve classification;

silica – silicon dioxide (SiO_2); the primary ingredient of sand and acid refractories;

silica flour – a sand additive, containing about 99;5% silica, commonly produced by pulverizing quartz sand in large ball mills to a mesh size of 80 to 325;

skim gate – a gating arrangement designed to prevent the passage of slag and other undesirable materials into a casting;

skimming – removing or holding back dirt or slag from the surface of the molten metal before or during pouring;

skin drying – drying the surface of the mold by direct application of heat;

slag – a nonmetallic product resulting from the mutual dissolution of flux and nonmetallic impurities in smelting, refining, and certain welding operations. In steelmaking operations, the slag serves to protect the molten metal from the air and to extract certain impurities;

slag inclusion – slag or dross entrapped in a metal;

slip flask – a tapered flask that depends on a movable strip of metal to hold the sand in position. After closing the mold, the strip is retracted and the flask can be removed and reused; molds made in this manner are usually supported by a mold jacket during pouring;

slush casting – a hollow casting usually made of an alloy with a low but wide melting temperature range; after the desired thickness of metal has solidified in the mold, the remaining liquid is poured out;

snap flask – a foundry flask hinged on one corner so that it can be opened and removed from the mold for reuse before the metal is poured;

solid shrinkage – see casting shrinkage;

solidification – the change in state from liquid to solid upon cooling through the melting temperature or melting range;

solidification shrinkage – see casting shrinkage;

solidus – in a phase diagram, the locus of points representing the temperatures at which various compositions stop freezing upon cooling or begin to melt upon heating;

solute – a metal or substance dissolved in a major constituent; the component that is dissolved in the solvent;

solvent – the base metal or major constituent in a solution; the component that dissolves the solvent;

sprue – (1) the mold channel that connects the pouring basin with the runner or, in the absence of a pouring basin, directly into which molten metal is poured; sometimes referred to as downsprue or downgate; (2) sometimes used to mean all gates, risers, runners, and similar scrap that are removed from castings after shakeout;

squeeze casting – a hybrid liquid-metal forging process in which liquid metal is forced into a permanent mold by a hydraulic press;

stack molding – a molding method that makes use of both faces of a mold section, with one face acting as the drag and the other as the cope. Sections, when assembled to other similar sections, form several tiers of mold cavities and all castings are poured together through a common sprue;

stopper rod – a device in a bottom-pour ladle for controlling the flow of metal through the nozzle into a mold; the stopper rod consists of a steel rod, protective refractory sleeves and a graphite stopper head;

stopping off – filling in a portion of a mold cavity to keep out molten metal;

strainer core – a perforated core in the gating system for preventing slag and other extraneous material from entering the casting cavity;

stripping – removing the pattern from the mold or the core box from the core;

styrofoam pattern – an expendable pattern of foamed plastic, especially expanded polystyrene, used in manufacturing castings by the lost foam process;

supercooling – lowering the temperature of a molten metal below its liquidus during cooling;

superheat – any increment of temperature above the melting point of a metal; sometimes construed to be any increment of temperature above normal casting temperatures introduced for the purpose of refining, alloying or improving fluidity;

superheating – raising the temperature of molten metal above the normal melting temperature for more complete refining and greater fluidity;

supersaturated – a metastable solution in which the dissolved material exceeds the amount the solvent can hold in normal equilibrium at the temperature and other conditions that prevail;

surface area – the actual area of the surface of a casting or cavity; the surface area is always greater than the projected area;

sweep – a type of pattern that is a template cut to the profile of the desired mold shape that, when revolved around a stake or spindle, produces that shape in the mold.

T

teapot ladle – a ladle in which, by means of an external spout, metal is removed from the bottom rather than the top of the ladle;

temper – **(**1) to moisten green sand for casting molds with water; (2) in heat treatment, to reheat hardened steel or hardened cast iron to some temperature below the eutectoid temperature for the purpose of decreasing hardness and increasing toughness; the process is also sometimes applied to normalized steel; (3) in nonferrous alloys and in some ferrous alloys (steels that cannot be hardened by heat treatment), the hardness and strength produced by mechanical or thermal treatment or both and characterized by a certain structure, mechanical properties or reduction in area during cold working;

thermal expansion – the increase in linear dimensions of a material accompanying an increase in temperature;

thin-wall casting – a term used to define a casting that has the minimum wall thickness to satisfy its service function**;**

tie bar – a bar-shaped connection added to a casting to prevent distortion caused by uneven contraction between two separated members of the casting;

tolerance – the specified permissible deviation from a specified nominal dimension or the permissible variation in size or other quality characteristic of a part;

tramp element – contaminant in the components of a furnace charge or in the molten metal or castings, whose presence is thought to be either unimportant or undesirable to the quality of the casting; also called trace element;

transfer ladle – a ladle that can be supported on a monorail or carried in a shank and used to transfer metal from the melting furnace to the holding furnace or from the furnace to the pouring ladles;

tumbling – rotating workpieces, usually castings or forgings, in a barrel partially filled with metal slugs or abrasives, to remove sand, scale or fins; it may be done dry or with an aqueous solution added to the contents of the barrel; sometimes called rumbling or rattling;

tuyere – an opening in a cupola, blast furnace or converter for the introduction of air or inert gas.

U

undercooling – same as supercooling**;**

undercut – a recess having an opening smaller than the internal configuration, thus preventing the mechanical removal of a one-piece core.

V

vacuum arc remelting – a consumable-electrode remelting process in which heat is generated by an electric arc between the electrode and the ingot. The process is performed inside a vacuum chamber; exposure of the droplets of molten metal to the reduced pressure reduces the amount of dissolved gas in the metal; sometimes abbreviated VAR;

vacuum casting – a casting process in which metal is melted and poured under very low atmospheric pressure; a form of permanent mold casting in which the mold is inserted into liquid metal, vacuum is applied and metal is drawn up into the cavity;

vacuum degassing – the use of vacuum techniques to remove dissolved gases from molten alloys;

vacuum induction melting – a process for remelting and refining metals in which the metal is melted inside a vacuum chamber by induction heating; the metal can be melted in a crucible and then poured into a mold; sometimes abbreviated VIM;

vacuum melting – melting in a vacuum to prevent contamination from air and to remove gases already dissolved in the metal; the solidification can also be carried out in a vacuum or at low pressure;

vacuum molding – see V process;

vacuum refining – melting in a vacuum to remove gaseous contaminants from the metal;

vent – a small opening or passage in a mold or core to facilitate the escape of gases when the mold is poured;

vermicular iron – same as compacted graphite iron;

viscosity – the measure of an uncured materials resistance to flow, measured in centipoise;

void – a shrinkage cavity produced in castings during solidification;

V process – a molding process in which the sand is held in place in the mold by vacuum; the mold halves are covered with a thin sheet of plastic to retain the vacuum.

W

warpage – deformation other than contraction that develops in a casting between solidification and room temperature; also the distortion that occurs during annealing, stress relieving and high- temperature service;

wash – (1) a coating applied to the face of a mold prior to casting; (2) an imperfection at a cast surface similar to a cut (3);

wax pattern – a precise duplicate, allowing for shrinkage, of the casting and required gates, usually formed by pouring or injecting molten wax into a die or mold;

white iron – cast iron that shows a white fracture because the carbon is in combined form.

Y

yield – comparison of casting weight to the total weight of metal poured into the mold.

Z

zircon – the mineral zircon silicate ($ZrSiO_4$), a very high melting point acid refractory material used as a molding sand;

zone melting – highly localized melting, usually by induction heating, of a small volume of an otherwise solid piece, usually a rod. By moving the induction coil along the rod, the melted zone can be transferred from one end to the other; in a binary mixture where there is a large difference in composition on the liquidus and solidus lines, high purity can be attained by concentrating one of the constituents in the liquid as it moves along the rod.

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ТЕХНОЛОГІЇ ВИРОБНИЦТВА ЗАГОТОВОК ЛИТТЯМ

Навчальний посібник

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галузі знань 13 «Механічна інженерія»

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