Ministry of Education and Science of Ukraine
Ternopil Ivan Puluj National Technical University

Department of building mechanics

Study guide on

"Building Material Science"

Part 1"Material Science"

for students of "Civil Engineering" *field of study 6.060101*

Student ____

Faculty ____

Course _______________________ Group ___________________________

Ternopil
2017

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The notes and laboratory reports have been approved by the Mechanical Engineering Faculty methodological committee (minutes № 4 from 10 February 2017)

Contents

INTRODUCTION

"Building Material Science" for students of "Civil Engineering" consists of two parts – Part 1 "Material science" and Part 2 " Modern building materials" and studing sn 1 semesters. Part 1 "Material science" include_16 hours of lectures, 16 hours of labs and 54 hours of individual work. Part 2 " Modern building materials" has 18 hours of lectures, 18 hours of labs and 54 hours of individual work.

"Building Material Science" is one of the basic technical disciplines in the curriculum for "Civil Engineering" field of study.

The study of materials that are used in construction, alloy's properties dependence on the chemical composition, structure, methods of treatment and external environments is of great importance for the Civil Engineering bachelors training. The study of the theory and practice of different methods of materials strengthening is to provide a high reliability and longevity of the building construction, machine's details, devices, tools etc.

Selecting the most appropriate material of construction for an application involves the making of numerous important decisions. This is true whether it be for the construction of a bridge, a household appliance, a piece of chemical processing equipment, or the decorative facing of a building. Factors such as physical and mechanical properties, corrosion resistance, workability, and cost must all be taken into consideration.

With the introduction of new metallic alloys and advances in the production of the so-called exotic metals, what was the best choice several years ago may no longer be so. Over the years, improvements have been made to specific properties of various alloys. These improvements include methods to increase mechanical, physical, and corrosion resistance properties. Alternatives in composition have also been formulated to improve the workability of many alloys.

In order to conduct a meaningful evaluation of a design, all the data needed to select the most appropriate material must be available. It is the purpose of this book to supply as much of this information as possible for commercially available metallic materials.

Safety during lab activities

The laboratory classes for “Building Material Science. Part 1. Material science” will take place in the education-research laboratories of the department of building mechanics. The observation of the safety requirements is necessary during labs activities.

Students who are not taking part in the lab activities, must seat at their desks. **Students can’t:**

- store any unnecessary things, which are not used during the lab on the work place;
- whirl adjustment knob of microscope, machine for tensile strength and hardness testing and other devices, if it is not used during labs activities.
- turn on machine-tools, weld transformer, presses etc.

Students can do labs only when they are supervised by a teacher.

Labs equipment has high voltage (220 or 380 V).

To prevent danger by electrical current, **it is prohibited to:**

- turn on equipment that is not used during labs;
- open the doors of the electrical wardrobe and furnace;
- transfer equipment and devices.

Before turning on an equipment student must see that it is safe to do so. When a student observes that equipment has defects, it is prohibited to turn on voltage. The student must report such to the teacher immediately.

During some lab classes, students will use chemical substances. When chemical substance comes in contact with the student’s skin or eyes, it is necessary to wash with water immediately.

During the lab classes that require equipment with heating, beware of catching fire with your clothes and skin burn.

Violation of these safety rules may lead to unhappy accidents.

Follow these safety rules strictly!

Laboratory work 1.

MECHANICAL PROPERTIES: TENSILE TEST, HARDNESS TEST

Objectives:

1. To understand what stress-strain diagram is, and how it can be used to indicate some properties of materials.
2. To be able to calculate tensile strength, modulus of elasticity and ductility of different materials.
2. To conduct typical engineering hardness tests and and to be able to understand the correlation between hardness numbers and the properties of materials.
4. To learn the advantages and limitations of the common hardness test methods.

Fundamental concept

There are three main methods for mechanical properties testing of materials: tensile, compressive and bending testing (fig.1.1.).

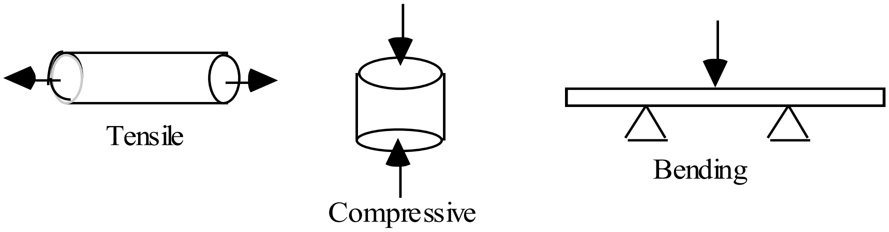


Fig.1.1. Tensile, compressive and bending testing for materials

Tensile Test

Tensile test determines the strength of the material when subjected to a simple stretching operation. Typically, standard dimension test samples are pulled slowly at a uniform rate in a testing machine while the ***strain*** is defined as :

$$\varepsilon = \Delta l / l_0 \qquad (1.1)$$

Stress is the internal forces produced by application of an external load, tending to displace component parts of the stressed material. The engineering stress is defined as:

$$\sigma = P / F_0 , \ \text{MPa} \qquad (1.2),$$

where $\mathbf{F_0 = (\pi\, d_0^2) / 4, mm^2}$ (1.3), $\mathbf{d_0}$ - original diameter of sample, mm (look at the fig.1.2.).

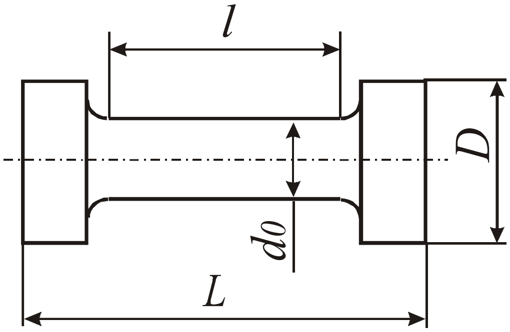


Fig.1.2 Test sample

Fig.1.3 and fig.1.4 show the stress-strain diagram of a ductile material where the linear portion of the graph indicates elastic deformation.

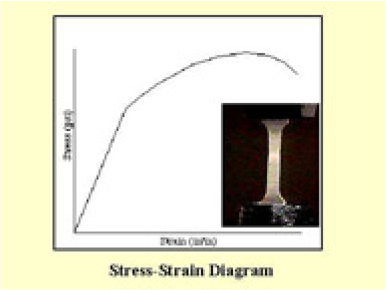


Fig. 1.3. Stress -Strain Diagram

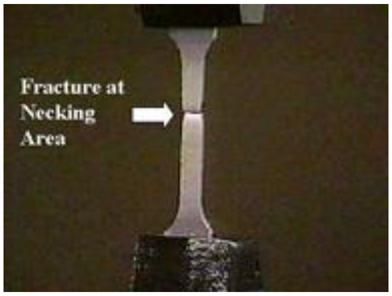


Fig. 1.4.Fracture of a Flat Tensile Test Specimen

Fig.1.5 shows the stress-strain diagram for typical (a) brittle and (b) ductile materials.

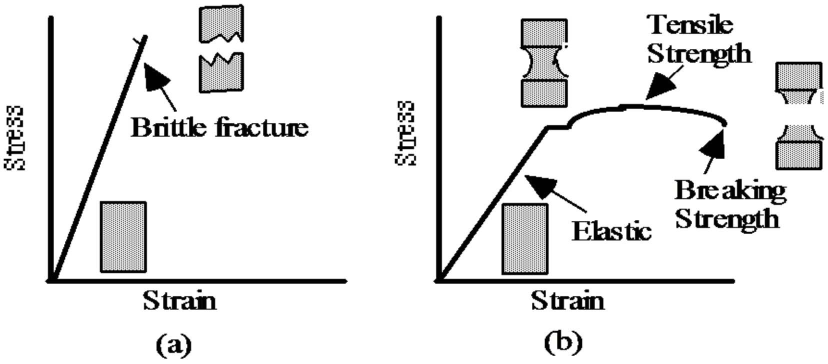


Fig. 1.5. Stress-Strain diagrams for typical (a) brittle and (b) ductile materials.

Modulus of Elasticity: The initial slope of the curve, related directly to the strength of the atomic bonds. This modulus indicates the stiffness of the material. (Modulus Elasticity is also known as Young's Modulus)

$$E = \sigma / \varepsilon \qquad (1.4)$$

Strength is a measure of the ability of a material to support a load.

Tensile Strength: The maximum stress applied to the specimen. Tensile strength is also known as Ultimate Strength. (The highest point on the stress-strain diagram).

$$\sigma_{ts} = P_{ts} / F_0,\ \text{MPa} \qquad (1.5)$$

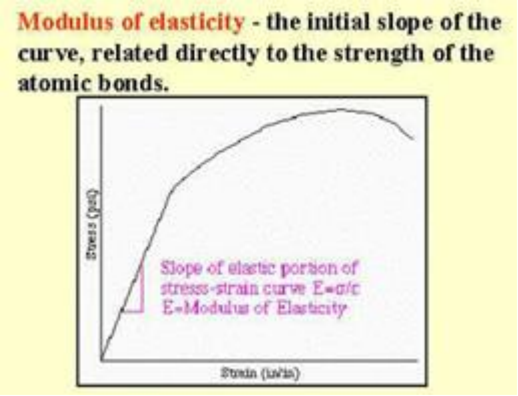


Fig.1.6. Modulus of Elasticity

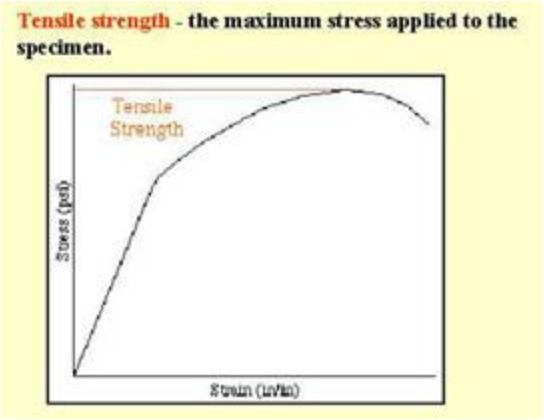


Fig 1.7.Tensile Strength

Ductility: The total elongation of the specimen due to plastic deformation, neglecting the elastic stretching. There are two indicators of ductility:

specific elongation $\delta = (l_f - l_o)\ 100\% / l_o$ (1.6)

specific contraction $\psi = (F_o - F_f)\ 100\% / F_o$.........(1.7)

Toughness is the ability to absorb energy of deformation without breaking. High toughness reguires both high strength and high ductility. Toughness is the total area under the curve, which indicates the energy absorbed by the specimen in the process of breaking.

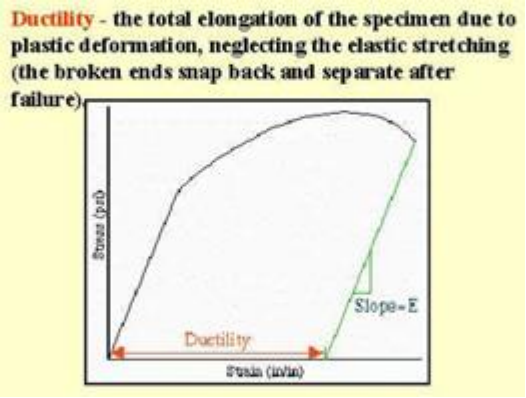


Fig.1.8. Ductility

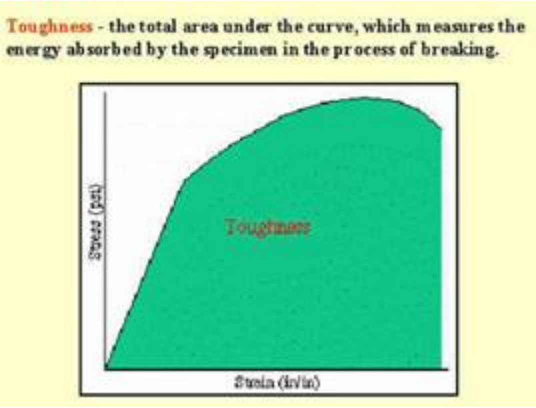


Fig.1.9. Toughness

Fig.1.10. Tensile Test Machine

Fig.1.11. Extensometer

Hardness is the resistance to indentation (ability of material to resist to introduction in him solid). Resistance to indentation is a function of the mechanical properties of the material, primarily its elasticity limit and to a lesser extent, its work-hardening tendency, and the modulus of elasticity. For a given composition it is possible to relate the elasticity limit, the tensile strength, ductility, and toughness. Hence, the hardness tests can provide information from which many important mechanical properties can be derived.

For example, dependence tensile strength and hardness is the following:

$$\boldsymbol{\sigma_{ts} = k \times BHN,} \tag{1.8}$$

where k – coefficient proportionality (k = 0.35 – for steel, k = 0.55 – for copper and copper alloys);

BHN - Brinell hardness number.

Since the hardness test can be conducted easily and quickly, they are very popular and are used to control processing.

The common hardness tests rely on the slow application of a fixed load to an indenter which is forced into the smooth surface of the specimen. Upon removal of the load either the area or the depth of penetration is measured as an indication of resistance to the load.

There are two types of hardness tests.

Rockwell Tests

The Rockwell tests depend on the measurement of the differential depth of a permanent deformation caused by the application and removal of differential loads. Various penetrator and load combinations are used to adapt different Rockwell tests to materials of varying hardness and thickness.

The ***penetrators*** include a cone-shaped diamond and hard steel balls 1.588 mm in diameter.

Standard Rockwell Test:

The Standard Rockwell tests use a light load of 100 N to seat the penetrator firmly in the surface of the specimen. This load is known as the ***minor load (P_0).*** After the application of the minor load, the depth gauge is zeroed and a larger load, known as ***major load (P_1)***, is applied and then removed. While the minor load still acts, the depth of permanent penetration is measured. The depth gauge which measures the penetration is calibrated to read in hardness numbers.

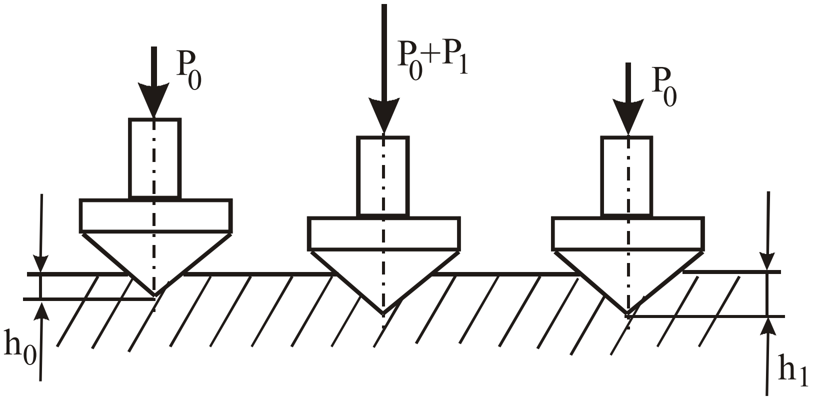


Fig. 1.12. Scheme of putting loads during Rockwell test

Major loads for Standard Rockwell tests are 450, 600, 1000 or 1500 N. The diamond penetrator is marked as "C-Brale".

The Rockwell hardness number, abbreviated as R_A, R_B, R_C. The Rockwell test is easier and more quickly performed than the Brinell test.

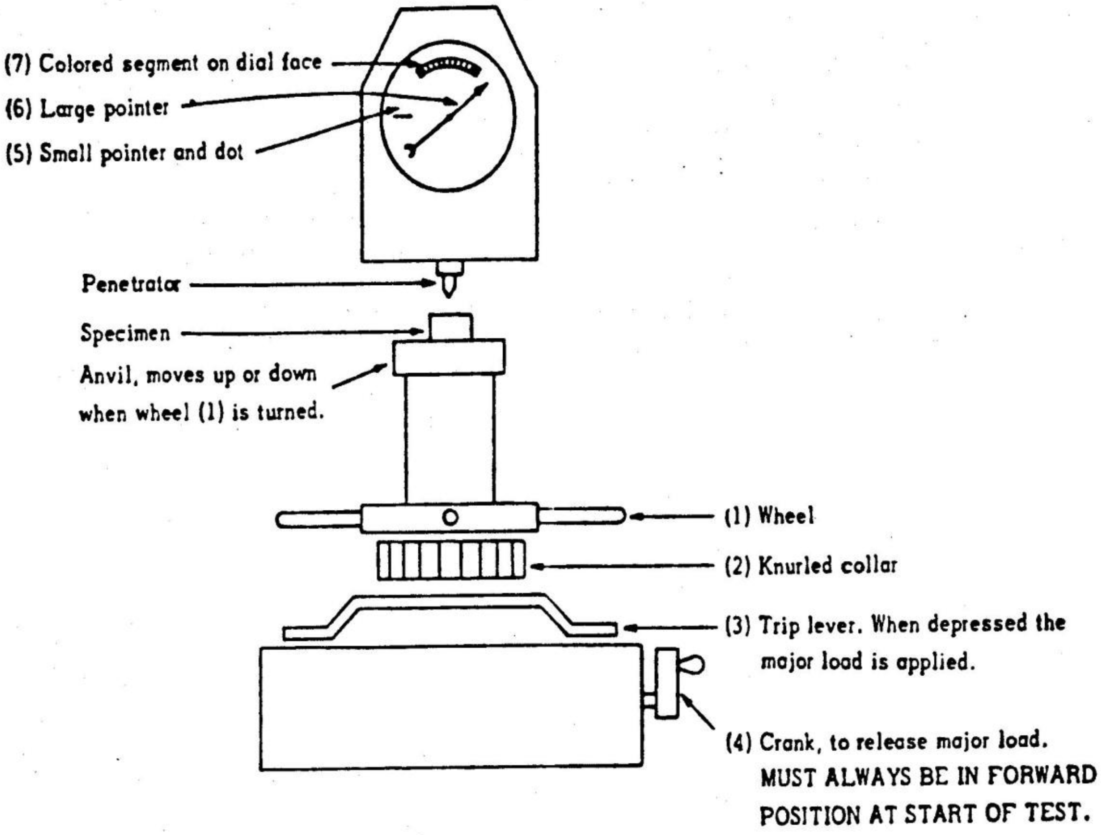


Fig.1.13 .Rockwell Testing Machine.

<u>Operation of Hardness Testing Equipment:</u>

(1) Select the correct combination of weights and penetrators (cone-shaped diamond or steel ball) for the hardness scale you wish to use. The numbers given in black represent the scales that use cone-shaped diamond and the numbers given in red represent the scales that use ball penetrators.

(2) Make sure that the crank (4) is in forward position (nearest to you).

(3) Place sample on the anvil.

(4) Slowly turn the wheel spokes (1) clockwise. This raises the anvil and sample toward the penetrator tip. After contact is gently made, continue raising sample until small pointer (5) is about in line with small black dot and large pointer(6) is within colored sector (7). The minor load has now been applied to the sample.

(5) After step 4, large pointer(6) on the dial is nearly “zero” line. Turn the knurled collar (2) until "zero" line on the dial scale is in line with large pointer (6).

(6) Depress trip lever (3). This triggers the mechanism that applies the major load. Crank (4) will automatically move away from you.

(7) After the crank (4) has come to rest (against a "stop" and away from you), gently pull the crank toward you as far as it will go. If this is done abruptly, a false reading will be obtained because of jarring.

(8) Now record the scale reading of large pointer (6). The black scale is read for the diamond penetrator (Example: Rockwell C), and the red scale is for ball penetrators (Example: Rockwell B).

(9) Remove the minor load, which remains on the specimen, by lowering the anvil (Turn the wheel (1) counter clock wise). Move the sample to position for next test and repeat the steps above.

Brinell Test

The Brinell test relies on mechanical or hydraulic loads as large as 30000 N. acting through a 2,5; 5 or 10 mm hard steel ball. In order to compensate for variations in the response of materials to the application of the load, the time for which the load is applied is specified. For hard materials such as steel, a 30-second loading period is adequate. Softer metals and alloys such as brass or aluminum require about 60 seconds.

After the load is removed, the diameter of the impression made by the ball is measured in millimeters (fig.1.14).

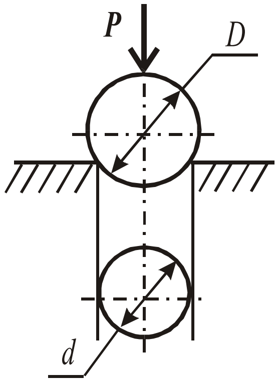


Fig.1.14. Scheme of putting load during Brinell test

The ***Brinell hardness number***, abbreviated as BHN, is the quotient of the load, P (N), divided by the area of the impression, F_i (mm^2):

$$\mathbf{HN} = \frac{\mathbf{2\,P}}{\pi\,(\mathbf{D} - (\mathbf{D}^2 - \mathbf{d}^2)^{1/2})\,\mathbf{D}} \quad \mathbf{MPa}, \qquad (1.9)$$

where **D** is the diameter of the ball penetrator (mm),
d is the diameter of the impression (mm).

In practice, the BHN is read directly from a table listing different values of d for various values of load, P.

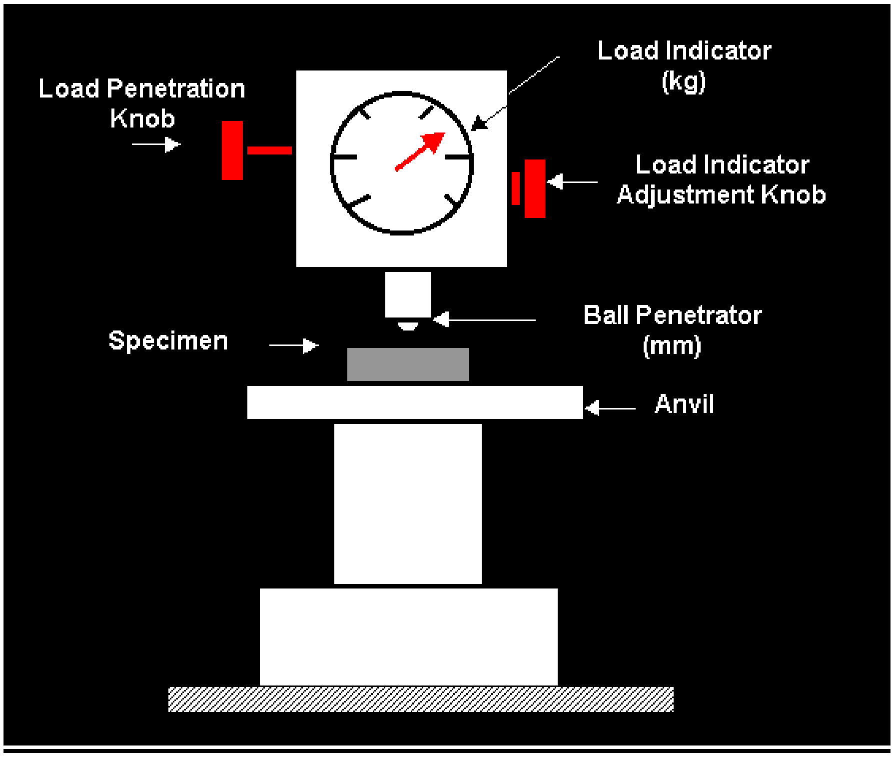


Fig.1.15 .Brinell Testing Machine

Operation of Brinell Testing Machine:

(1) Turn air on

(2) Set the required load on the dial.

Note: For steel and other hard materials the load is 29 400 N for 30 seconds. For non-ferrous materials a 4900 N load is used for 60 seconds. Thin specimens should not be tested by this method.

(3) Place the specimen on the anvil and apply a preload by bringing the specimen surface to contact with the ball penetrator.

(4) Pull the load knob and apply the appropriate timing at that load level.

(5) Release the load by pushing the load knob back into the initial position.

(6) Remove the specimen and measure the diameter of the indentation. The Brinell Microscope reads in millimeters. Take several readings and average them.

(7) Look up BHN from chart or calculate from the formula.

The following is a sample hardness data as presented in a laboratory report. Use the same format in your report.

Equipment:

1. Stress - strain diagram.
2. Rockwell Testing Machine.
3. Brinell Testing Machine.

4. Rockwell and Brinell Hardness Test Specimens of metal alloys.

Procedure:

1. For given original and final sizes of sample, gauge and stress-strain diagram:

measure and calculate $\boldsymbol{\varepsilon}$, $\boldsymbol{\sigma_{ts}}$, $\boldsymbol{\delta}$, $\boldsymbol{\psi}$ and write the results in the protocol 1.

2. Understand thoroughly the operation of each machine, and check its operation before proceeding.

3. Using the appropriate scale

(a) Check the hardness of test specimen on a Rockwell Test Machine.

(b) Write the results of every measuring in the protocol 2.

(c) Write to average of the three readings R_c values.

4. Using Brinell Machine

(a) Find the hardness of the cast aluminum alloy by converting the diameter of the impression to Brinell Hardness Number (BHN).

(b) Write the results of every measuring in the protocol 3.

(c) Write to average of the three readings BHN values.

Note: For each hardness number, select three locations on the sample. Read the hardness number at each location and take the average of the three readings.

Questions:

1. What is strain, stress and strength?
2. Plot a stress-strain diagram for brittle and ductile materials.
3. How is it possible to determine modulus of elasticity and tensile strength using a stress-strain diagram?
4. What are the indicators of ductility? Write formulas.
5. What is toughness and how can it be determined?
6. What is hardness?
7. What types of hardness tests do you now?
8. How tensile strength depends on hardness?
9. What penetrators are used in Rockwell and Brinell tests?
10. What loads are used in Rockwell and Brinell tests?
11. What scales and hardness numbers are used in Rockwell tests?
12. How to calculate Brinell hardness number?

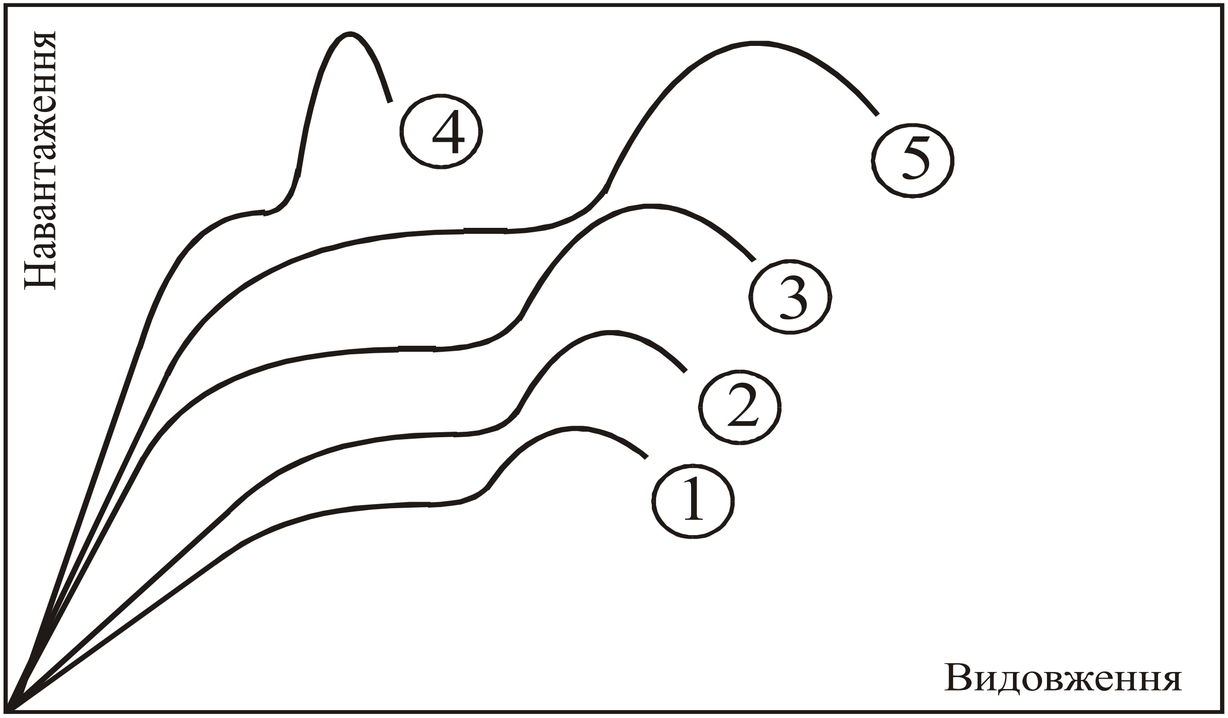
LABORATORY REPORT № 1

MECHANICAL PROPERTIES: TENSILE TEST, HARDNESS TEST

Protocol №1

1. *Tensile Test*

Type of sample	Cylinder
Material	Steel
Stress-strain diagram (on variant)	



NOTE! Variant - student's number according to the group list

Scale **σ**, MPa/mm	d_f mm	l_f, mm	Number of Stress- strain diagram				
			1	2	3	4	5
8.7	4.7	56	V1	V2	V3	V4	V5
10.2	4.6	57	V6	V7	V8	V9	V10
11.7	4.5	58	V11	V12	V13	V14	V15
13.3	4.4	59	V16	V17	V18	V19	V20
14.8	4.3	60	V21	V22	V23	V24	V25

Simple sizes	Original	Final, after fracture
Length (mm)	l_0 = 50	l_f =
Diameter (mm)	d_0 =5	d_f=
Area (mm^2)	F_0 =	F_f =

Indicators of strength, ductility	
Formula	Results of calculations
ε =	ε =
σ_{ts} =	Use the scale for calculations σ_{ts} =
δ =	δ =
Ψ =	Ψ =

Protocol №2

Hardness Rockvell test

Penetrator	
Material	
Type	
Minor load P_0, N	
Major load P_1, N	
Results of hardness Rockvell test	
Rc_1	
Rc_2	
Rc_3	
$Rc = (Rc_1 + Rc_1 + Rc_1)/ 3$	

Protocol №3

Hardness Brinelll test

Penetrator	
Material	
Type	
D, mm	
Load *P*, N	
Results of hardness Brinell test	
d_{i1}, mm	
d_{i2}, mm	
d_{i3}, mm	
$d_i = (d_{i1}+ d_{i2}+ d_{i3})/3$	
Formula BHN =	Results of calculations BHN =

_______________ Student's signature

"____"____________20___ y.

_______________ Teacher's signature

"____"_____________20___ y.

Laboratory work 2.

Macroscopic analysis of steel goods

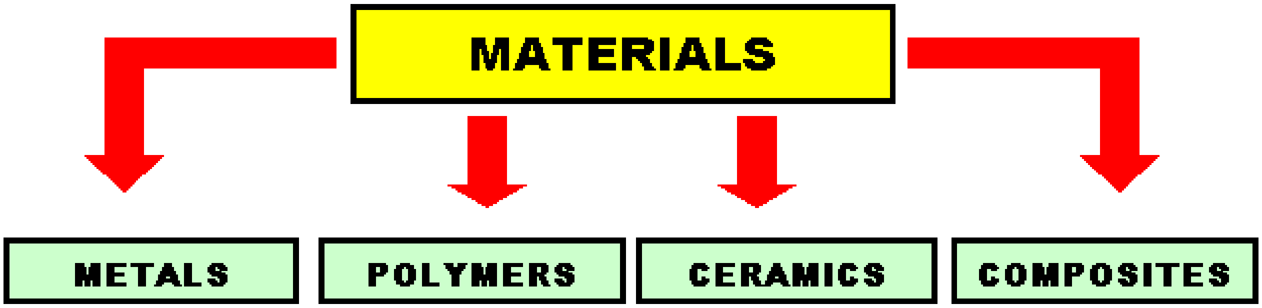
Objectives

Studying the nature of the distribution of impurities in metals and alloys, the influence of the mode of production (welding, forging, casting) on the structure of individual zones macro metal methods analysis. Research kinks steel products and alloys based on non-ferrous metals.

Scientific principles

Materials, that are used in the construction.

There are four types of materials that are used in the ***construction.***



Metals

Metals are metallically bonded compounds made from most of the elements on the periodic table. Metals can be monatomic such as copper, or an alloy such as steel. Metals can be easily bent, machined, cast or extruded into shape. The use of Metals is in large part due to this ease of manufacturing.

Metals are elements that generally have good electrical and thermal conductivity, ductile, malleable. Many metals have high strength, high stiffness, and have good ductility. Some metals, such as iron, cobalt and nickel are magnetic.

All of these properties come from the way metallic atoms bond together.

Pure metals:

Pure metals are elements of the periodic table. Examples of pure metals include copper in wire and water pipes, electrical wires; aluminum in cooking foil and beverage cans etc.

Metal Alloys:

Metal Alloys contain more than one metallic element. Their properties can be changed by changing the elements present in the alloy. Examples of metal alloys include stainless steel which is an alloy of iron, nickel, and chromium; gold jewelry which contains an alloy of gold and nickel.

The most important properties of metals include density, toughness, strength and plastic deformation. The atomic bonding of metals also affects their properties. In metals, the outer valence electrons are shared among all atoms, and are free to travel everywhere. Since electrons conduct heat and electricity, metals make good cooking pans and electrical wires.

Many metals and alloys have high densities and are used in applications which require a high mass-to-volume ratio.

Some metal alloys, such as those based on Aluminum, have low densities and are used in aerospace applications. Aluminium was available at a reasonable cost and in sufficient quantities until the beginning of XX century. He then gradually began to enter into the architecture, though initially only as a material for decorative items. The first loud In construction alloys based aluminum use on riveted bearing structures also are producing moldings, sheets, strip, wire, casing wall and roof panels, fittings.

Many metal alloys also have high toughness, which means they can withstand impact and are durable.

Some applications of metals.

Metals and metal alloys are used in:

Construction – rolling profiles, roofing sheets, fittings, columns, supporting pillows, pipes, arches, form of large span bridges, public and industrial buildings.

Transportation—cars, buses, trucks, trains, ships, and airplanes.

Aerospace— rockets and the space shuttle.

Computers and other electronic devices that require conductors (TV, radio, stereo, calculators, security devices, etc.)

Communications including satellites that depend on a tough but light metal shell.

Food processing —Microwave and conventional ovens and refrigerators and freezers.

Biomedical applications—As artificial limb.

Electrical power production — Boilers, turbines, generators, transformers, power lines, nuclear reactors and pipelines.

Farming—Tractors, combines etc.

Mode goods —Ovens, dish and clothes washers, vacuum cleaners, blenders, pumps, etc.

Polymers

Polymer have one type of repeating unit of many different types of repeating units.

Polymers are light-weight, ductile, usually non-conductive and melt at low temperatures. A polymer has a repeating structure, usually based on a carbon. The repeating structure results in large molecules.

Polymers are useful because they are lightweight, are corrosion resistant, are easy to process at low temperatures, and are generally inexpensive.

Some important characteristics of polymers include their size (or molecular weight), softening and melting points, crystallinity, and structure. The mechanical properties of polymers generally include low strength and high toughness.

One of the distinct properties of polymers is that they are poor conductors of electricity and heat, which makes them good insulators.

Disadvantages and limitations:

- Properties are very sensitive to mixing and proportioning procedures;
- Strong Allergenic, toxical;
- non bio-degradable;
- easily breakable;
- flame retardancy is low;
- a long time to decompose etc.

Polymers are used for a large kinds of goods: bags, wire insulation, computer chips, packing materials etc.

In construction polymers are used for manufacturing of pipe, window and door profiles PVC, mouldings, production of finishing materials, production of various products needed in engineering and technical areas of operation (plumbing etc.), production of protective, paint, etc.

Polymers can be made into goods by injection molding, extrusion, pressing, stamping or machining.

Ceramics

Ceramics are defined as inorganic non-metallic materials. Ceramics are covalently or ionically bonded (or a mixture of the two).

Examples of such materials can be NaCl (salt), clay (a complex silicate).

Ceramics are brittle, strong and non-conducting materials. Ceramics are compounds consisting of metals covalently bonded to oxygen, nitrogen or carbon. Ceramics are used for high temperature applications, abrasives, transparent windows and pottery. Ceramic goods are generally made through extrusion, slip casting, or compression molding.

Some of the useful properties of ceramics and glasses include high melting temperature, low density, high strength, stiffness, hardness, wear resistance, and corrosion resistance. Many ceramics are good electrical and thermal insulators.

Some ceramics have special properties: some ceramics are magnetic materials; some are piezoelectric materials; and a few special ceramics are superconductors at very low temperatures.

A glass is an inorganic nonmetallic material that does not have a crystalline structure. Such materials are amorphous.

Ceramics and glasses have one major disadvantage: they are brittle. Slow to process. Temperature to melt for repairs is very high in some cases. This could cause serious problems for *in-situ* repairs to primary or secondary structures, especially if being done near fuel tanks or hydraulic systems. Can be health hazards. Slow to repair.

Composites

A ***composite material*** is made up of a matrix and a reinforcement phase. Composites take advantage of directional properties of the reinforcement phase and gluing properties of the matrix. The reinforcement phase may be any material in fiber, platelet, or aggregate form. The matrix phase must be able to flow around the reinforcement and later hardened. Metals, ceramics, cement, and polymers are all regularly used for composites. Composites are very difficult to manufacture. New techniques has made it easier to make sporting equipment, space shuttle parts, and car parts out of composites.

Composites are formed from two or more types of materials. Examples include polymer/ceramic and metal/ceramic composites.

Composites are used because their properties are better to those of the individual components. For example: polymer/ceramic composites have a greater modulus than the polymer component, but aren't as brittle as ceramics.

Composite construction is a generic term to describe any building construction involving multiple dissimilar materials. Composite construction is often used in building aircraft, watercraft, and building construction. There are several reasons to use composite materials including increased strength, aesthetics, and environmental sustainability.

Future Trends

In the future, we will continue to depend heavily on metals. Lightweight aluminum alloys will be utilized more in automobiles to increase fuel efficiency. New, heat resistant superalloys will be developed so that engines can operate at higher, more efficient temperatures. Similarly, ceramic coatings will be used more to protect metals from high temperatures, and to increase the lifetime of tools. New, radiation-resistant alloys will allow nuclear power plants to operate longer, and thus lower the cost of nuclear energy.

Steel will continue to be the most commonly used metal for many years to come, due to its very low cost (approximately 20 cents/pound) and the ability to customize its properties by adding different alloying elements.

As easily-mined, high grade ores are depleted, recycling will become more important. Already, half of all aluminum, copper, and steels are being recycled.

Macroscopic analysis is to examine the structure of metals and alloys without the use of any device and (or) through a magnifying glass at low magnification (30 times).

Macroscopic analysis allows to conclude that the structure of the metal or the sample as a whole. The structure of metals, which studied using macro analysis, called ***macrostructure.***

Methods of studying the macrostructure are divided into three main groups: ***deep and surface etching and prints.*** Etching methods give information about material defects associated with its receipt and processing.

Deep etching reveals cracks, without carbon layers, saturated carbon layers and nitrided layers segregation of harmful impurities, dendritic structure. After deep etching macro grinding has a textured surface on which presents visible elements of the macrostructure and defects.

Surface etching reveals some details of the structure and conduct further microscopic study. It requires a thorough preparation surface grinding (fine grinding), especially for the evaluation of grain size and shape, determination variety of grain, grain growth direction.

Print method means that the image does not appear on the macrostructure but on photographic paper. Density contact of metal surface with photo paper must be complete; there shall be no air bubbles. Reagents react with certain structural elements, forming a characteristic color patterns. The most widely used method of print to identify the distribution of sulfur method (Bauman).

The main objectives of macro study **are:**

1. Identify hidden defects metal – cracks, porosity, films and zonal heterogeneity.
2. Identify the nature of the crystal structure of the metal.
3. Detection of impurities in the metal and the nature of their distribution.
4. Detection of metal structure after thermo mechanical processing.
5. Identify the structure of heat-treated or weld products (zone hardening, carburizing, thermal effects).

Identifying hidden defects of metal.

This problem is often solved by deep etching. Defects such as cracks (after hardening), separation of the metal are not visible on the surface even with a magnifying glass. Subjecting the products of such defects acids, we "uncover" them and as a result of vigorous erosion surface.

For this purpose a mixture of hydrochloric acid, sulfuric acid and distilled water use. To speed up the action reagent used it heated to 50^0C. Etching time is depending on the composition of steel (from 20 minutes to 2 hours). The same reagent is used to identify dendritic structure. In this case, the duration is much shorter.

Also use a 20% solution of sulfuric acid heated to 60°C condition (time of up to 2 hours.).

Identifying the nature of the crystal structure.

In the metal can be formed as granular and dendritic structure. Dendritic structure is the initial stage of crystallization of the metal, further development of which leads to the formation of homogeneous microstructure or granular structure.

Under certain etching methods can simultaneously detect both structures, showing their relationship. Fair active reagents such as reagent Heine (10% solution of aqueous solution of perchloric double salt of copper and ammonia), exhibit primarily grain boundaries. With more vigorous reagents (acid solution) can be found dendritic structure. To identify dendritic structure in carbon steels used reagents:

- 10% solution of ammonium persulfate $(NH_4)_2S_2O_8$, heated at 80-90°C for 5-10 minutes;
- Reagent Keshiyena a mixture of concentrated hydrochloric and sulfuric acid and distilled water for 20 - 25 minutes at room temperature.

Macro grinding of steel, pre-wipe with alcohol, immerses the ground surface in one of the reagents. After holding simples were washed with water and analyzed.

Identification of impurities and the nature of their distribution.

Chemical analysis gives the average content of metal elements in the sample, but not gives an idea of their distribution. Heterogeneity of chemical composition by volume castings, parts, grain, which occurs during the crystallization of metal, is called ***liquation (phase separation).*** Most prone to liquation is sulfur, phosphorus, to a lesser extent – silicon, manganese, carbon occupies an intermediate position. Method of detection heterogeneity distribution of impurities is based on different locations with different color of their content.

Sulfur in steels is harmful element and its accumulation in certain areas of the structure causes increased fragility. To detect liquation of sulfur in steel specimen ***the method Bauman*** is using**.** Doing the following:

- Specimen wipe with cotton wool moistened with alcohol, and put on the table the ground surface up;
- Leaf glossy bromide silver photographic paper at light soak for 3 ... 5 min in 5 % aqueous solution of sulfuric acid, to dry between two sheets of filter paper to remove excess solution;
- Impose a photographic emulsion side on the work surface macro grinding, remove air bubbles;
- To withstand photographic macro grinding for 2 to 3 minutes, squeezing them together and carefully remove the photo paper;
- The resulting washes water mark, fixed in 25% aqueous solution of hyposulfite, rinse again with water and dried.

Getting on photo paper brown areas indicate the places enriched sulfur (sulfide clusters). If the photo paper has a uniform color, the sulfur is placed evenly.

In the boundary layers of metal, where are impurities of sulfur (as FeS, MnS) the interactions happen:

$$FeS + H_2SO_4 \rightarrow FeS0_4 + H_2S \qquad (2.1)$$

$$MnS + H_2SO_4 \rightarrow MnSO_4 + H_2S \qquad (2.2)$$

$$H_2S + 2AgBr \rightarrow Ag_2S + 2HBr \qquad (2.3)$$

Gaseous hydrogen sulfide, which is released in areas where there is sulfur, acting on photo paper with the formation of Ag_2S. After this fix photo paper 10-15% hypo solution of sulfite. Sensitive layer of paper appear dark blotches that match the sulfur impurities in the metal. In addition, the relative density of inclusions can conclude the pollution with sulfur. Phosphorus in this way does not define.

Method Heine reveals liquation of phosphorus. Grinding sample, wipe with alcohol, immersed in a 10-12% solution of aqueous chloric double salt of copper and ammonium ground surface for 1-2 minutes. After washing grinding sample dried at filter paper. Places enriched with phosphorus, painted a dark color.

Study of breaks, their classification and characteristic features.

At the macro analysis widely used method fractography. ***Fractography*** exploring structure breaks. Fracture is a kind of photo destruction process, structural condition and material properties in the local volume.

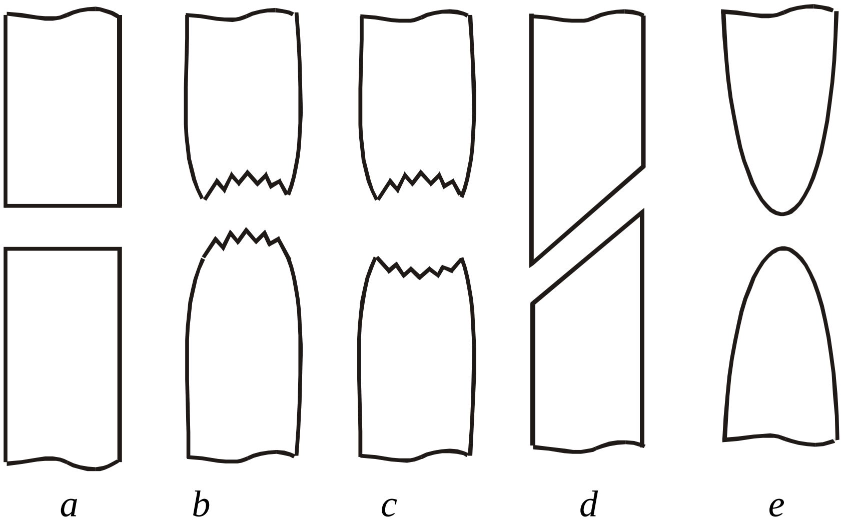
For the analysis using the newly formed fracture surfaces without mechanical damage, traces of oxidation, dirt etc. The presence of oxides, traces of oil paints may provide additional information on the conditions of formation of cracks. Macro analysis begin to break the surface destruction due to the naked eye or with a magnifying glass (increase 5 ... 10 times) and slowly moving to an increase of 20 ... 120 times.

When carrying out the macro analysis evaluated fracture and classified in the following ***main features:*** orientation fracture surfaces, macro geometry, the degree of plastic deformation, roughness, color.

Orientation of fracture associated with the nature of load and stress state, normal and tangential stresses, which determine the fracture.

For orientation fracture surfaces breaks are classified as straight, slanting and straight with slanting (cup).

Direct (Fig. 2.1) is called fracture which surface is oriented normal to the axis of the sample or product that is perpendicular to the direction of greatest tension efforts. This fracture orientation is a characteristic feature of brittle fracture.



a *b* *c* *d* *e*

Fig.2.1. Specific types of fractures in tension
a) straight, b) straight and bevel type "cup - Cone"
c) straight from the bevel type "double cup", d) slanting, e) cone.

*Oblique (*slanting*)* fracture surface is inclined at an angle to the axis of the sample is formed by a cut in the plane of greatest stress. This fracture occurs in the destruction of anisotropic materials with limited ductility.

Straight fracture with a slant (cup) is formed of smooth cylindrical tensile specimens (usually alloyed steels).

Formation of the "cup" is associated with the formation of a neck in a deformed sample, leading to significant lateral and axial stresses in the center of the sample.

The presence of the side edges of cuts fracture is a sign macro viscous destruction. For maximum realization of plasticity of the material in the zone of fracture in tension may be formed entirely *conical* fractures, characteristic only for very ductile materials (plumbum, pure aluminum, electrolytic copper).

Type of fracture is the criterion of evaluation of quality material. There conditional division of breaks on ***brittle*** and ***plastic.***

For macrogeometry breaks divided into homogeneous and heterogeneous.

For ***homogeneous*** breaks characterized morphologically identical surface, this is rare, such as a fracture of brittle materials, carbon steel at low temperatures.

Most fractures ***are heterogeneous.*** This may be due to two reasons:

- Heterogeneity of the studied material chemical composition, structure, properties (anisotropy of material);

- Features of the destruction process associated with the original heterogeneity of the stress and strain state.

Heterogeneity of fracture surface visually visible with the change of roughness on different parts of fracture. At fatigue destruction roughness by the surface can be divided into areas: nucleation of cracks 2, development of fatigue destruction 3 (small roughness) and static fracture 4 (high roughness) (see Fig. 2.2). In addition, the sample shows a cut (stress concentrators).

For section 3 fatigue destruction characteristic by fine-grained structure, smooth matte surface.

Areas of fracture formed at the final stage of destruction as a result of fatigue fracture cross-sectional size decreases to a critical value and cyclic tension reaches the boundary strength. In the area of brittle materials fracture has large crystalline structure and for viscous materials are characteristic fibrous structure and plastic braces along the periphery of the sample (Fig. 2.2 b, pos. 4).

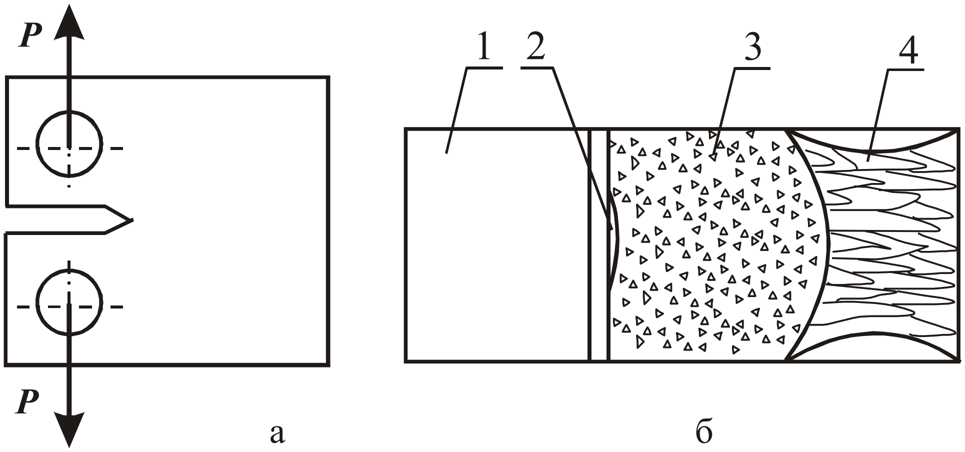


Figure. 2.2. The standard model for testing the strength of materials under cyclic loading (a) and scheme of fatigue destruction (b)

In real structures stress concentrators, which can begin fatigue, are:

- Design (grooves, ledges, etc.);
- Technological (low quality machining, cracks after forming by pressure and heat treatment);
- Metallurgical defects (structural heterogeneity of the material, liquation of sulfur and phosphorus in steel, etc.).

Fractography researches are mandatory peer review in surface damage in real structures. These results make it possible to identify the causes of destruction for them in the future.

Classification of fractures ***with help of surface roughness.***

The presence of crystalline fracture is one of the characteristic features of brittle fracture, and the presence of fiber - viscous. Among the defects that cannot be eliminated and are caused by violation of the technology of heat and hot machining, shall break, that has large crystalline structure and forms on surface smooth, shiny areas of nonmetallic look like.

For ***degree of plastic deformation*** fracture divided into ***brittle, quasi brittle and viscous.***

The difference ***by color*** is one of the characteristic signs of fractures related to structure, test conditions and the presence of alloying elements in steel. Carbon steel have silver color of breakdown, nickel - light gray. Manganese steel provides a breakdown characteristic dull gray color.

Materials and Equipment:

1. Set of samples.
2. Sandpaper.
3. 5% solution of sulfuric acid.
4. Hypo solution sulfate.
5. Sheets of photo paper.
6. Filter paper.

7. Reactive Keshiyena.

8. Cups for reagent.

9. Foot 9 x 12, 11 x 19.

10. Magnifier.

Procedure:

1. Get samples for macro research.

2 Draw and analyze defects, found in samples obtained by casting production or after rolling.

3. Clean up by sandpaper the surface of macro samples, clean with gasoline wool.

4 In the case of large sample set them horizontally on the stand.

5 Perform test by Bauman.

6 Rinse the surface with cotton wool and dry filter paper.

7 The print paste in the protocol.

8 Examine the collection of breaks, describe them and sketch the resulting structure.

9 Remove the workplace.

10. Fill report.

Questions:

1. Define macroanalysis.
2. Explain the purpose (objectives) of macroanalysis.
3. Define macrostructure.
4. Explain macroanalysis methods.
5. Which of metal defects are called ”hidden”?
6. Explain possible impurities in metals.
7. Explain types of crystal structure of the metal.
8. Explain types of metal fracture.
9. List the criteria for classifying metal fracture.
10. Explain effect of phosphorus and sulfur on the properties of steel.
11. Explain how impurities in the metal are located.
12. Define liquation.
13. Define anisotropy.
14. Define polymorphism.
15. Explain Bauman method.
16. Explain effect of alloyed metals on the color of fracture.

Laboratory work № 2

Macroscopic analysis of steel products

PURPOSE OF WORK:____-
____
____

DEVICES AND MATERIALS:
____
____
____

PROTOCOL № 1 (SAMPLE № 1)

Name of sample ____

Material ____________________________

Description of macrostructure and identified defects:____________________________
____
____

____

Method of manufacturing sample __________
____
____

Figure

PROTOCOL № 2 (Bauman method)

Name of sample ____

Material _______________________________

Description of macrostructure and identified defects:_____________________________
____
____

____
____

Conclusion:
____

(conclude the existence of sulphur liquation)

____

PROTOCOL № 3

Name of sample ____

Material ______________________________

Description of fracture by characteristic features:_____________________________________

____

____

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____

____

Mechanism of destruction _________________

____

Figure

PROTOCOL № 4

Name of sample ____

Material ______________________________

Description of fracture by characteristic features:_____________________________________

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____

____

____

Mechanism of destruction _________________

____

Figure

Conclusions:____

(analyze the macrostructure of various metals and alloys, the reasons that led to the destruction)

____

____

_________________________ _________________________

Student’s signature

Teacher’s signature

“____”_______ ____20___ y.

“____”____________20___ y.

LABORATORY WORK № 3

CRYSTALLIZATION PROCESS

Objectives

1. To understand what the metallic bonding is and its effect on metal properties.
2. To learn about crystallization process of the water solution drop of various salts, which is a model of metal.

Scientific principles

Metallic bond and lattice structure of metals

There are three aggregate states of metals: crystalline, liquid and gaseous. In the gaseous state they do not differ from non-metals, and in liquid and crystalline the states are specific characteristics. Properties of the metals give ***the metallic bonding*** – bond between the metallic ions and the negative electron "cloud". This is illustrated schematically in Fig. 3.1.

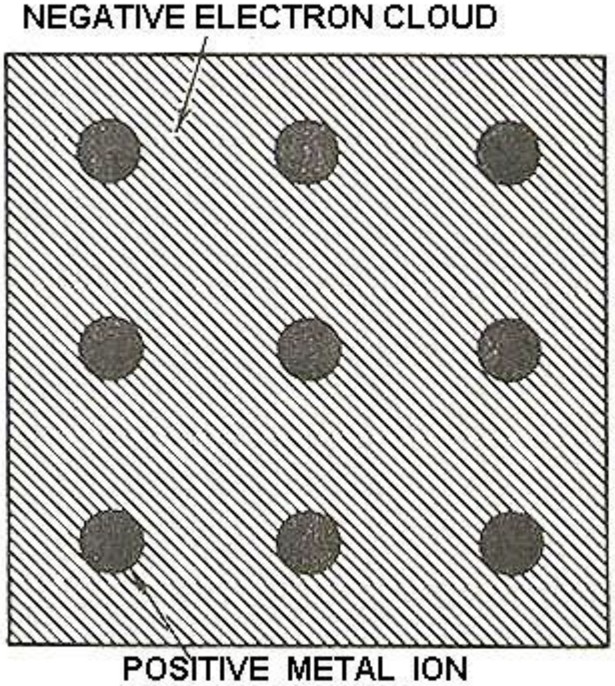


Fig.3.1. Metallic bond and electron cloud

Metals are widely used because they have high properties: strength, ductility, high melting point, thermal and electrical conductivity, toughness that depend on the structure of metals. Metals are composed of atoms, which are held together by strong bonds.

Above their melting point, metals are liquids, and their atoms are randomly arranged and relatively free to move. However, when cooled below their melting point, metals rearrange to form ordered, crystalline structures.

liquid solid

Fig.3.2. Arrangement of atoms in a liquid and a solid states

Atoms are the building blocks of all materials. In a liquid state the atoms of metal having short-range order. However, this is a probability event. Since the forces are weak and there is much activity taking place, they soon separate and re-form again. This phenomenon of random grouping, scattering, and regrouping for short periods of time is characteristic of the liquid state. Above their melting point, metals are liquids, and their atoms are randomly arranged and relatively free to move. However, when cooled below their melting point, metals rearrange to form ordered, crystalline structures.

The random movement of the unlike atoms becomes less frequent, the bonding becomes stronger, and ordered arrays of atoms form lattices.

A crystal is a repeating array. In describing this structure we must distinguish between the pattern of repetition (the lattice type) and what is repeated (the unit cell). The most fundamental property of a crystal lattice is its symmetry. In three-dimensions, unit cells stack like boxes, filling the space, making the crystal. The different colors are just to show the separate boxes - each unit cell is identical.

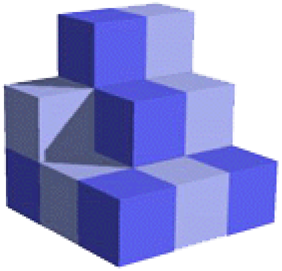


Fig.3.3. Cubic Lattice Structure

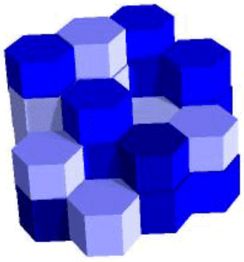


Fig.3.4. Hexagonal Lattice Structure

If we take a unit cell and stack it, we produce a lattice. Once the orientation of a unit cell is determined, all unit cells within that lattice have the same orientation.

<u>Unit Cell</u>: When a solid has a crystalline structure, the atoms are arranged in repeating structures called unit cells, which are the smallest units that show the full symmetry of a crystal. The smallest repeating array of atoms in a crystal is called a ***unit cell***.

Lattice: The three dimensional array formed by the unit cells of a crystal is called **lattice.**

The majority of metals have one of ***three well-packed crystal structures***:

- Face-centered cubic (F.C.C.): Aluminum, γ-Iron, Nickel, Copper, Lead, Gold, Platinum
- Body-centered cubic (B.C.C.) Chromium, α-Iron, Niobium, Vanadium, Silver
- Hexagonal-close-packed (H.C.P.): Cadmium, Cobalt, Titanium, Zinc, Zirconium, Magnesium.

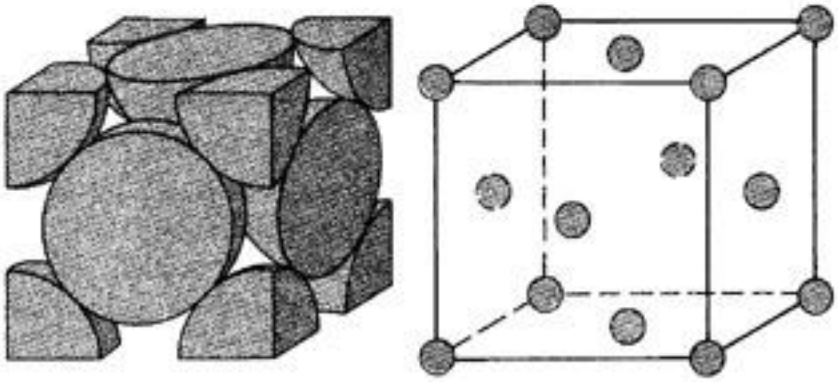


Fig.3.5. Face Centered Cubic (F.C.C) Lattice Structure

In the FCC arrangement, again there are eight atoms at corners of the unit cell and one atom centered in each of the faces. FCC unit cells consist of four atoms, eight eighths at the corners and six halves in the faces.

Tthe body-centered cubic (BCC) unit cell has atoms at each of the eight corners of a cube plus one atom in the center of the cube. The BCC unit cell consists of a net total of two atoms, the one in the center and eight eighths from the corners.

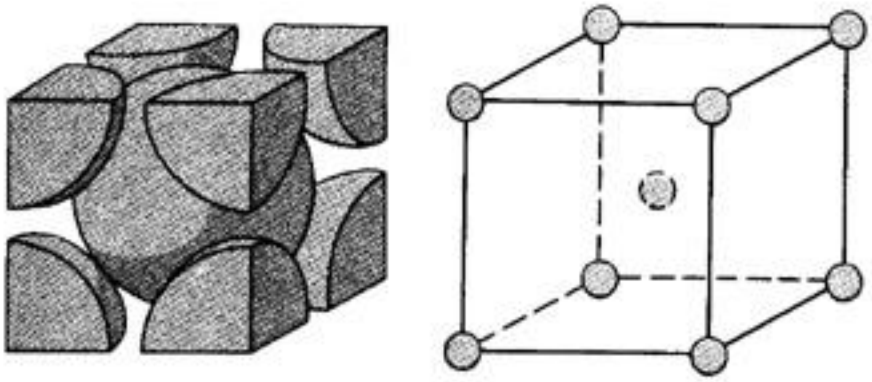


Fig.3.6. Body Centered Cubic (B.C.C) Lattice Structure

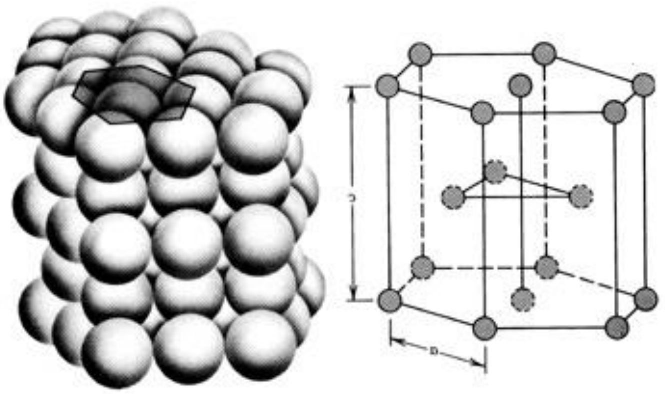


Fig.3.7. Closed Packed Hexagonal (C.P.H) Lattice Structure

Unit cell structures determine some of the properties of metals. For example, FCC structures are more likely to be ductile than BCC, (body centered cubic) or HCP (hexagonal close packed

Basic descriptions of unit cell are:

Lattice parameter, or period, – it is distance between neighbouring atoms;

closeness of packing – amount of atoms, that is on an elementary unit cell.

Crystal defects

The most important crystal defects are:

-Vacancies
- Interstitials
- Dislocations

Vacancies:

Vacancies are simply empty atom sites as shown in Fig.3.8. By successive jumps of atoms, it is possible for a vacancy to move in the lattice structure and therefore play an important part in diffusion of atoms through the lattice.

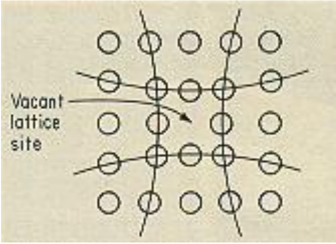


Fig.3.8. Vacancy crystal defect

Interstitials:

It is possible that some atoms may fall into interstitial positions or in the spaces of the lattice structure which may not be used by the atoms of a specific unit cell as shown in Fig.3.9. Interstitials tend to push the surrounding atoms farther apart and also produce distortion of the lattice planes.

Interstitial atoms may be produced by the severe local distortion during plastic deformation.

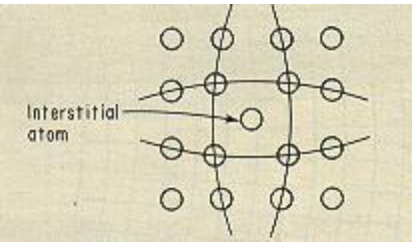


Fig.3.9. Interstitial crystal defect

<u>Dislocations:</u>

A ***dislocation may be defined*** as a disturbed region between two substantially perfect parts of a crystal. A dislocation is a linear defect around which some of the atoms are misaligned. Two simple types of dislocation are :

- Edge dislocation
- Screw dislocation

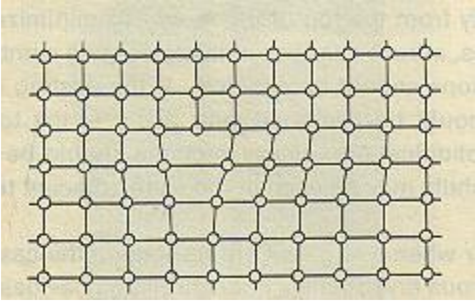


Fig.3.10. Edge dislocation

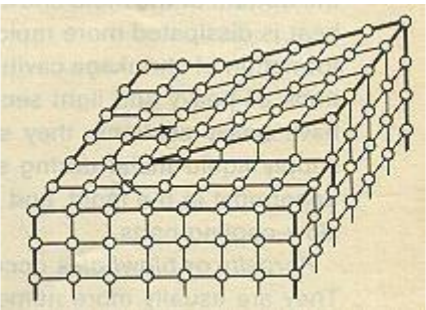


Fig. 3.11. Screw dislocation

Dislocations can be observed in crystalline materials using electron-microscopic techniques. Virtually all crystalline materials contain some dislocations that were introduced during solidification, during plastic deformation, and as consequence of thermal stresses that result from rapid cooling.

The importance of dislocations to the metal user is that dislocation interactions within a metal are a primary means by which metals are deformed and strengthened.

When metals deform by dislocation motion, the more barriers the dislocations meet, the stronger the metal.

Deformation by dislocation motion is one of the characteristics of metals that make them the most useful engineering materials. The metallic bond is such that strains to the crystal lattice are accommodated by dislocation motion. Many metals can tolerate significant plastic deformation before failing.

The crystallization process is a basic part of the technological process of obtaining goods by ***casting***.

A primary crystallization process is the transition from the liquid to the solid state with forming of crystalline lattice.

Crystallization begins after some overcooling of liquid metal below the equilibrium ***temperature of crystallization*** (or theoretical temperature of crystallization) T_s (fig.3.12). At a temperature the T_s both phases (liquid and solid) are found in equilibrium and the process of crystallization or process of melting does not take place.

Thus, the process of crystallization can pass only at overcooling of metal below than equilibrium temperature Ts. Difference between theoretical temperature Ts and real temperatures of crystallization Tr is called ***the overcooling degree:***

$$\Delta T=T_s-T_r \qquad (3.1)$$

The degree of overcooling is not a permanent size (fig.3.13). It depends on speed of cooling, nature and cleanness of metal.

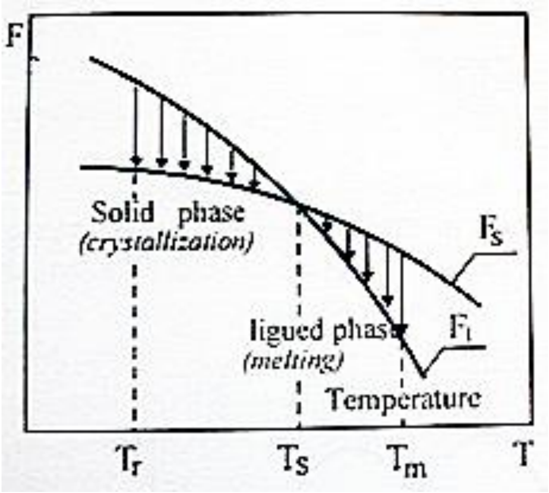


Fig.3.12. Change of free energy of the state liquid and crystalline depending on a temperature.

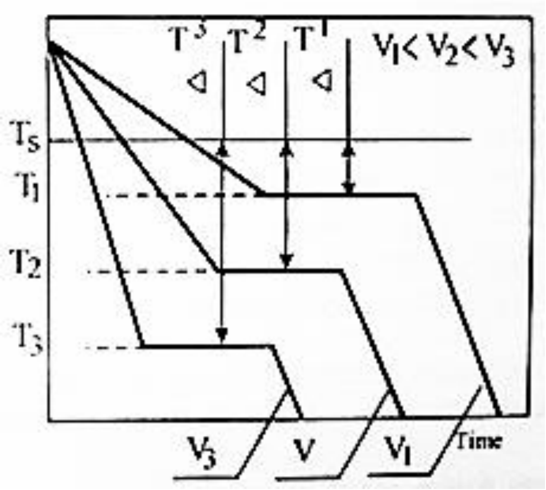


Fig. 3.13. Curve cooling during crystallization.

Stages of crystallization process

The crystallization process occurs in two stages:

1. Nucleus formation.
2. Crystal growth.

As the energy in the liquid system decreases, the movement of the atoms decreases and the probability increases for the arrangement of a number of atoms into a characteristic lattice for that material.

If crystal growth continues in three dimensions, the atoms attaching themselves in certain preferred directions, usually along the axes of a crystal. This gives rise to a characteristic treelike structure which is called ***dendrite*** .

As atoms of melted metal begin to pack together to form a crystal lattice, groups of these atoms form small crystals. These small crystals increase in size by the progressive addition of atoms. The resulting solid is not one crystal but actually many smaller crystals, called ***grains.*** The interface formed between them is called a ***grain boundary***

In a metal can show up both graininess and dendrite structure. The dendrite structure is the initial stage of consolidation of metal, further development of which results in formation of graininess structure.

Grains are sometimes large enough to be visible under an ordinary light microscope or even to the unaided eye. Fig.3.14 shows a typical view of a metal surface with many grains, or crystals.

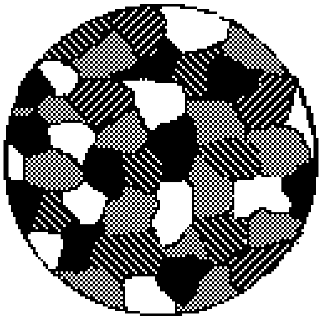


Fig.3.14. Grains and Grain Boundaries for a Metal.

The amount of nucleus (A.N.) formed in a metal, and speed of crystals growth (S.G.) depends on the degree of system's overcooling which in the turn depends on cooling speed (fig.3.15).

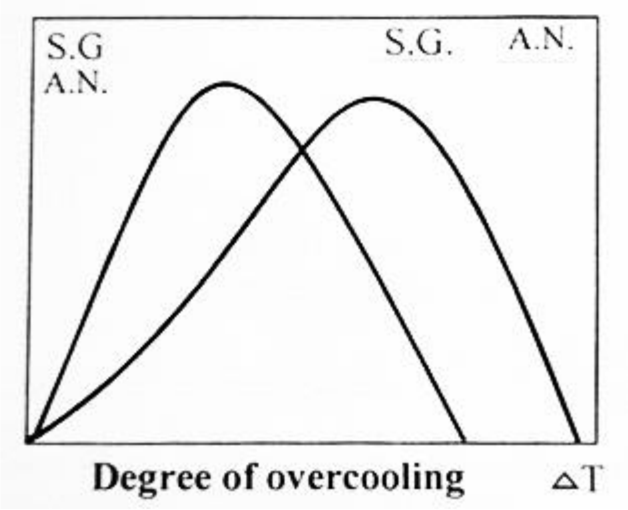


Fig.3.15. Speed of growth and amount of nucleus depending on the degree of overcooling.

For metals and alloys crooked AN and SG does not achieve a maximum, so as metals in the liquid state a small weakness is fed to overcooling.

Crystallization at the large degrees of overcooling is instrumental in formation of shallow grainy structure. Consequently, changing speed of cooling it is possible to get the grains of a different size.

The size of grains is found in such dependence on the amount of nucleus and speed of growth:

$$d = 1{,}1\sqrt[4]{(\frac{s.g.}{a.n.})^3} \qquad (3.2).$$

Phenomenon of anisotropy and polymorphism

Anisotropy is difference of crystalline bodies' properties in various directions. It is due to the different distances and, consequently, by different values of communication forces between ions in different directions in a crystal.

Polymorphism is a physical phenomenon where a material may have more than one unit cell. A material that shows polymorphism exists in more than one type of space lattice in the solid phase. If the change in structure is reversible, then the polymorphic change is known as ***allotropy***. Different crystalline structures of the same element are called its polymorphic ***modifications*** and marked by the initial letters of the Greek alphabet, beginning from low temperatures (Fe_α, Fe_γ; Co_α, Co_β; Mn_α, Mn_β, Mn_γ, Mn_δ and etc.)

There are two mechanisms of formation of centers of crystallization*:* ***spontaneous and heterogeneous.***

A spontaneous mechanism of formation passes in a pure liquid metal only. For a liquid there is a characteristic fellow creature order in disposing of atoms, that is only in separate micro volume the well-organized disposing of atoms is saved, that answered the hard state. As a result of thermal motion a fellow creature order is unsteady, and to that with the decline of temperature an amount and size of such micro volume is multiplied. At the temperatures of crystallization they grow into the nucleus of solid phase. Formation of nucleus causes reduction of free energy due to transition of some volume from the liquid state in solid one.

Heterogeneous formation of nucleus passes on prepared bases which are solid particles in an alloy, walls of form, impurities. In the real terms of formation of nucleus passes by a heterogeneous mechanism.

Materials and Equipment:

1. Kitchen-range.
2. Chemical cups for water solution of salts.
3. Water solution of salts ($K_2Cr_2O_7$ and $CuSO_4$)
4. Glass stick.
5. Glass plate.
6. Biological microscope.

Procedure:

1. Get equipment and water solution of salts.
2. Heat the water solution of salt to a temperature of 70-80 °C.

3. Set glass plate on a microscope, inflict a drop of $K_2Cr_2O_7$ and watch the process of crystallization (stages and structure).
4. Set glass plate on a microscope, inflict a drop of $CuSO_4$ and watch the process of crystallization (stages and structure).
5. In both cases, draw crystal structure on the first and second stage of crystallization.

Questions:

1. What is metallic bonding?
2. What are the structures of crystalline body?
3. What is a unit cell?
4. What are the types of lattice structure?
5. What is the different between F.C.C. and B.C.C.?
6. What are descriptions of a unit cell?
7. What are the defects of crystal structure?
8. What is a primary crystallization process?
9. What is the overcooling degree? Write formula.
10. Plot a graph showing the change of free energy of the liquid and crystalline phases on a temperature.
11. What are stages of crystallization process?
12 What kinds of crystalline structures do you now?
13. What are the mechanisms of crystallization process?
14. How do you determine grain size?
15. What is anisotropy?
16. What is polymorphism?
17. Which elements of Mendeleev’s Periodic Table have polymorphic modifications and give an example how it marked?

LABORATORY REPORT №3
CRYSTALLIZATION PROCESS

PROTOCOL №1

The name of the salt

The crystalline structure at the beginning of crystallization	The crystalline structure at the end of crystallization

<u>Conclusion:</u>

____

____

PROTOCOL №2

The name of the salt____

The crystalline structure at the beginning of crystallization	The crystalline structure at the end of crystallization

Conclusion: ____

____

General conclusion:____

____

____

______________________ Student's signature	________________________ Teacher's signature
"____"_______ ____20___ y.	"____"____________20___ y.

LABORATORY WORK № 4

PROCESS OF PLASTIC DEFORMATION

Objectives

1. To learn the influence of plastic deformation and temperature on aluminum grain's size after recrystallization.
2. To learn the influence of plastic deformation and recrystallization on aluminum properties.
3. To learn how to determine the critical degree of deformation and recrystallization temperature.

Scientific principles

When small loads (stresses) are applied to metals they deform, and they return to their original shape when the load is released. This is called ***elastic deformation*** and involves temporary stretching or bending of bonds between atoms.

When higher stresses are applied plastic deformation take place. The ***plastic deformation*** involves the breaking of bonds, often by the motion of dislocations. Dislocations move easily in metals, due to the delocalized bonding (fig.4.1). This largely explains why metals are ductile, while ceramics are brittle.

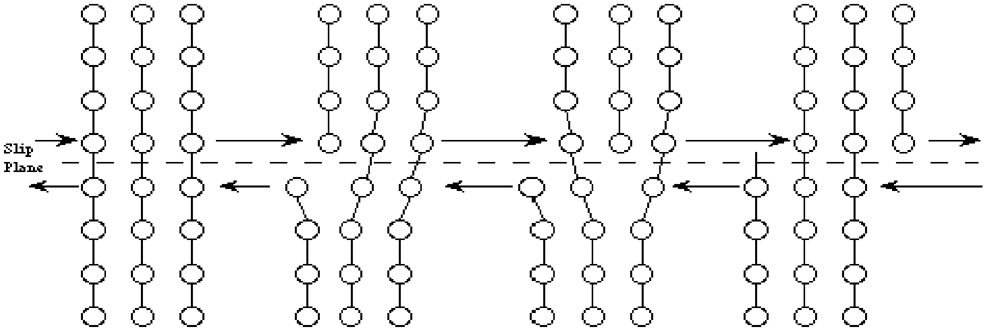


Fig.4.1. Dislocation movement in a crystal

If placed under large of a stress, metals will mechanically fracture. This can also result over time from many small stresses. The most common reason (about 80%) for metal failure is fatigue. Through the application and release of small stresses as the metal is used, small cracks in the metal are formed and grow slowly. Then the metal is permanently deformed or it breaks (fractures).

When a material is stressed below its elastic limit, the resulting deformation or strain is temporary. When a material is stressed beyond its elastic limit, plastic or permanent deformation takes place, and it will not return to its original shape by the application of force alone. The ability of a metal to undergo plastic deformation is most important outstanding characteristic in comparison with other materials.

All shaping operations such as stamping, pressing, spinning, rolling, forging, drawing, and extruding involve plastic deformation of metals. Various machining operations such as milling, turning, sawing, and punching also involve plastic deformation.

Plastic deformation may take place by :

- Slip
- Twinning
- Combination of slip and twinning

Deformation by Slip:

If a single crystal of a metal is stressed in tension beyond its elastic limit, it elongates slightly, a step appears on the surface indicating relative displacement of one part of the crystal with respect to the rest, and the elongation stops. Increasing the load will cause another step. It is as if neighboring thin sections of the crystal had slipped past one another like a sliding cards on a deck. Each successive elongation requires a higher stress and results in the appearance of another step, which is actually the intersection of a slip plane with the surface of the crystal. Progressive increase of the load causes the material to fracture.

Deformation by Twinning:

When mechanical deformation is created by twinning, the lattice structure changes. The atoms move only a fraction of an interatomic space and this leads to a rearrangement of the lattice structure. Twinning is observed as wide bands under the microscope. These wide bands can not be removed by polishing.

Processes of cold working and annealing:

Because plastic deformation results from the movement of dislocations, metals can be strengthened by preventing this motion. When a metal is bent or shaped, dislocations are generated and move. As the number of dislocations in the crystal increases, they will get tangled or pinned and will not be able to move. This will strengthen the metal, making it harder to deform. This process is known as ***cold working.*** At higher temperatures the dislocations can rearrange, so little strengthening occurs.

Heating removes the effects of cold-working. When cold worked metals are heated, recrystallization occurs. New grains form and grow to consume the cold worked portion. The new grains have fewer dislocations and the original properties are restored.

Annealing is a process in which metals are heated and then allowed to cool slowly.

As a result of cold working, the hardness, tensile strength, and electrical resistance increase, while ductility decreases. There is also a large increase in the number of dislocations, and certain planes in the crystal structure are severely distorted. Most of the energy used to cold work the metal is dissipated in heat, and a finite amount of energy is stored in the crystal structure as internal energy associated with the lattice defects created by the deformation.

Full annealing is the process by which the distorted cold worked lattice structure is changed back to one which is strain free through the application of heat. This process is carried out entirely in the solid state and is usually followed by slow cooling in the furnace from the desired temperature.

The ***annealing process*** may be divided into three stages:

- Recovery
- Recrystallization
- Grain growth.

Recovery:

This is primarily a low temperature process, and the property changes produced do not cause appreciable change in microstructure or the properties, such as tensile strength, yield strength, hardness and ductility. The principal effect of recovery is the relief of internal stresses due to cold working.

When the load which causes plastic deformation is released, all the elastic deformation does not disappear. This is due to the different orientation of crystals, which will not allow some of them to move back when the load is released. As the temperature is increased, there is some spring back of these elastically displaced atoms which relieve most of the internal stresses. Electrical conductivity is also increased appreciably during the recovery stage.

Since the mechanical properties of the metal are essentially unchanged, the main purpose of heating in the recovery range is stress relieving cold worked alloys to prevent stress corrosion cracking or to minimize the distortion produced by residual stresses.

Recrystallization:

As the temperature of the recovery range is reached, minute new crystals appear in the microstructure. These new crystals have the same composition and lattice structure as the original undeformed grains and are not elongated but are uniform in dimensions. The new crystals generally appear at the most drastically deformed portions of the grain, usually the grain boundaries and slip planes. The cluster of atoms from which the new grains are formed ***is called a nucleus***. Recrystallization takes place by a combination of nucleation of strain free grains and the growth of these nuclei to absorb the entire cold worked material.

The term recrystallization temperature does not refer to a definite temperature below which recrystallization will not occur, but refers to the approximate temperature at which a highly cold worked material completely recrystallizes in one hour.

Recrystallization temperature is determined by the Bochvar’s rule:

$$T_{recryst..} = a \times T_{melt.}, \text{K} \qquad (4.1)$$

where a – coefficient of material purity (it is equal to 0.1 – for pure metal; 0.4 - for technical pure metal; 0.8 – for alloy),

T_{melt} – melting point.

Cold working takes place at the temperature below recrystallization temperature. ***Hot working*** takes place at the temperature that is higher than recrystallization temperature.

Pure metals have low recrystallization temperatures as compared with alloys. Zinc, tin and lead have recrystallization temperatures below room temperature. This means that these metals cannot be cold worked at room temperature since they crystallize spontaneously, reforming a strain free structure.

The greater the prior deformation, the lower the temperature for the start of recrystallization. Increasing the annealing time decreases the recrystallization temperature for the start of recrystallization.

Small degree of deformation (8-15%) is a reason for sharp grain growth after recrystallization (grain’s size is maximum). It is called the ***critical degree of deformation***. The appearance of large grains makes material to be brittle. During the cold work the critical degree of deformation must be avoided.

During the recrystallization stage, there is a significant drop in tensile strength, hardness and a large increase in the ductility of the material (Fig.4.2).

Grain Growth:

In this stage the tensile strength and hardness continue to decrease but at a much less rate than the recrystallization stage. The major change observed during this stage is the growth of the grain boundaries and reaching the original grain size (Fig.4.2).

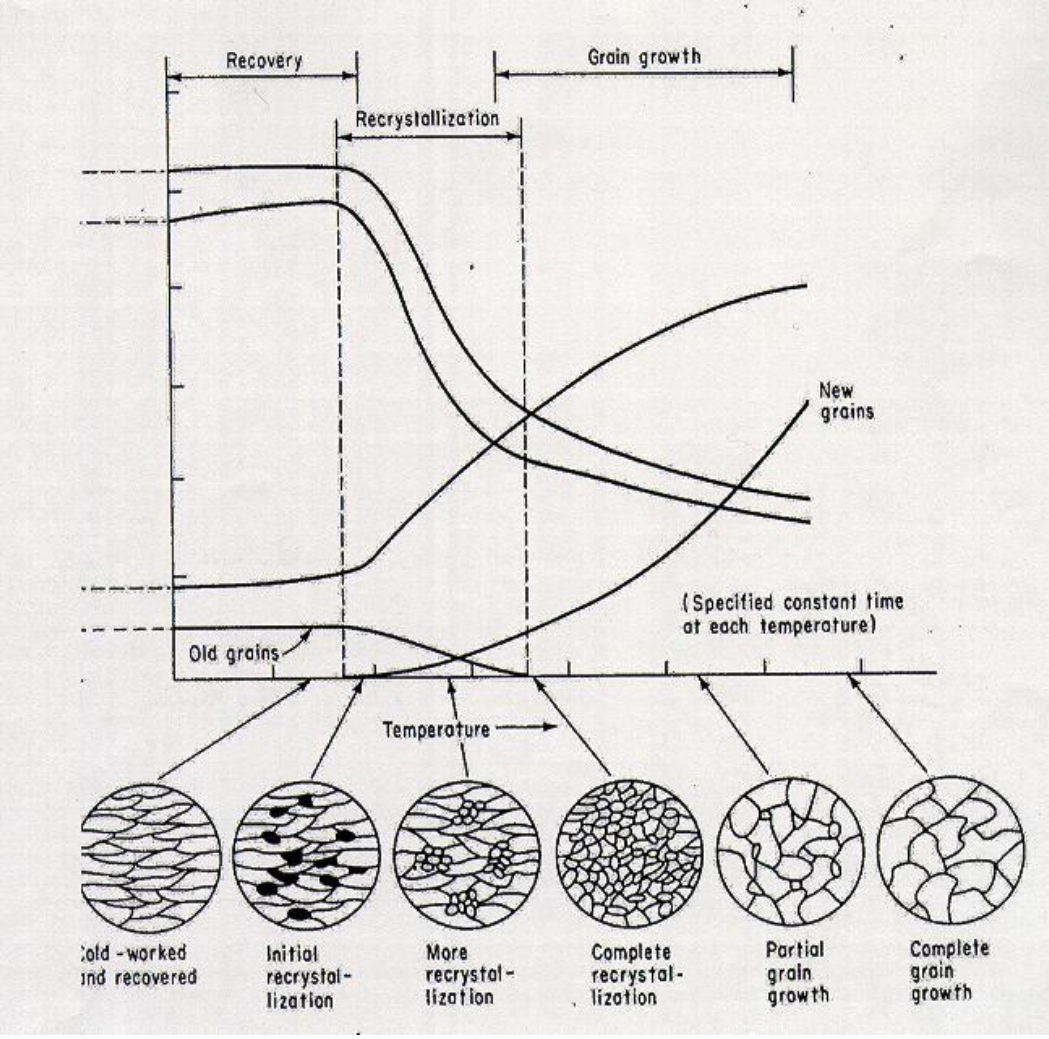


Fig.4.2. Effect of annealing on tensile strength, hardness, ductility and grain size

Materials and Equipment:

1. 6 specimen of aluminum plate after recrystallization (without plastic deformation and with 3, 6, 9, 12, 15% degree of deformation).
2. Magnifying glass.

Procedure:

1. To get equipment and specimens of aluminum plate after recrystallization.
2. To determine the critical degree of deformation.
3. To draw the microstructure of aluminum after recrystallization (without plastic deformation and with 3, 6, 9, 12, 15% degree of deformation).
4. To calculate the recrystallization temperature for tungsten, iron, aluminum, zinc, tin, cooper and titanium of different purity.
5. To determine at what temperatures the cold working of pure tungsten is possible.

Questions:

1. What is elastic deformation?
2. What is plastic deformation?
3. What is the difference between elastic and plastic deformation?
4. Why do dislocations occur easily in metal?
5. What shaping operations do you now?
6. In what ways may plastic deformation take place?
7. Describe plastic deformation by slip.
7. Describe plastic deformation by twinning.
6. What is cold working?
7. What is annealing process?
8. How do the mechanical properties change after cold working?
9. What are the stages of annealing process?
10. Describe the recovery process.
11. Describe the recrystallization process.
12. How do the mechanical properties change during the stage of grain growth?
13. Show how to determine the recrystallization temperature? Write the formula.
14. What is the critical degree of deformation?
15. Why must critical degree of deformation be avoided?
16. At what temperatures does cold and hot working take place?
17. Why can zinc not be cold worked at room temperature?
18. Graph the effect of annealing on tensile strength, hardness and ductility.

LABORATORY REPORT №4

PROCESS OF PLASTIC DEFORMATION

PROTOCOL №1

Material____________________________________

The influence of plastic deformation on the grain's size and determination the critical degree of deformation

0% **3%** **6%** **9%** **12%** **15%**

Conclusion:

PROTOCOL №2

Determination of the recrystallization temperature

Metal	Purity of the metal	Coefficient of metal purity, a	T_{melt} , ^{o}C	T_{melt} , К	$T_{recryst.}$, К	$T_{recryst..}$, ^{o}C
Fe	Technical pure metal		1539			
Al	-//-		658			
Cu	-//-		1083			
Zn	-//-		419			
W	-//-		3410			
Sn	Pure metal		232			
Ti	-//-		1672			
W	-//-		3410			

Conclusion:

Student's signature

"____"____________20___ y.

Teacher's signature

"____"____________20___ y.

LABORATORY WORK 5

THERMAL ANALYSIS

Objectives

1. To learn the method of cooling curves construction.
2. Determination of critical points by the method of thermal analysis for alloy Pb-Sn.
3. To learn to determine the chemical composition and the percentage of each phase that is present at various temperatures by the inverse lever rule.

Scientific principles

The properties of a material depend on the type, number, amount, and form of the phases present, and can be changed by altering these quantities. In order to make these changes, it is essential to know the conditions under which these quantities exist and the conditions under which a change in phase will occur.

The best method to record the data of phase changes in many alloy systems is in the form of ***phase diagrams***, also known as equilibrium diagrams.

In order to specify completely the state of a system in equilibrium, it is necessary to specify three independent variables: temperature, pressure and composition. When pressure is constant and equal at atmospheric value, the equilibrium diagram indicates the structural changes due to variation of temperature and composition.

Phase diagrams show the phase relationships under equilibrium conditions, that is, under conditions in which there will be no change with time. Equilibrium conditions may be approached by extremely slow heating and cooling, so that if a phase change is to occur, sufficient time is allowed.

Phase diagrams are usually plotted with temperature as the ordinate, and the alloy composition as the abscissa.

Experimental Methods:

The data for the construction of equilibrium diagrams are determined experimentally by a variety of methods, the most common methods are:

- Metallographic Methods
- X-ray Diffraction Technique
- Thermal Analysis

Thermal Analysis:

This is the most widely used experimental method. ***It relies*** on the information obtained from the cooling diagrams. In this method, alloys mixed at different compositions are melted and then the temperature of the mixture is measured at a certain time interval while cooling back to room temperature.

A cooling diagram for each mixture is constructed and the initial and final phase change temperatures are determined. Then these temperatures are used for the construction of the phase diagrams.

Every point of the diagram answers the certain state of the system at a certain temperature in the conditions of equilibrium. On fig.4.1 the chart of experimental plant for determination of metal's and alloy's critical points is shown. It includes heater 1, which melts the explored alloy 2 in crucible 3, covered by plate 4. For the control of the temperature changes, a thermo-electric pyrometer is used. It consists of the thermocouple 5, wires 6 and term voltmeter 7.

Thermocouple represents by itself two wires from different metals with the soldered ends from one side and which connects with term voltmeter from another side. This connection in thermocouple is named hot solder and intended for placing in the area of temperature determination.

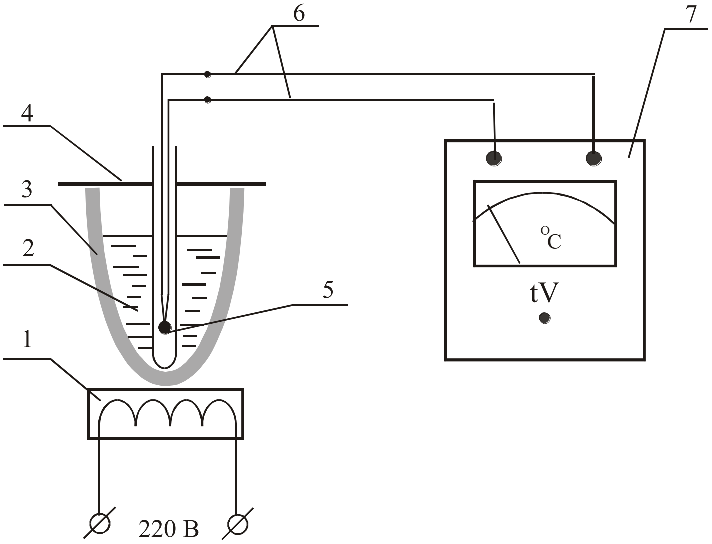


Fig.5.1. Chart of experimental plant for determination of metal's and alloy's critical points by the method of thermal analysis.

In a technique the widest application was found following thermocouple (on material of wires):

platinum - platinumrhodium, PP-1-1 (0...1300ºC);

chromel - alyomel, ChA (0...100ºC);

cooper-constantan, CC (0...400ºC).

For measuring of Pb - Sn alloys temperature use cooper-constantan thermocouple (constantan - alloy 58.4% Cu, 1.6% Mn, 40% Ni).

Cooling Curve of a Pure Metal:

Under equilibrium conditions, all metals exhibit a definite melting or crystallization point. If a cooling curve is plotted for a pure metal. It will show a horizontal line at the melting or crystallization temperature.

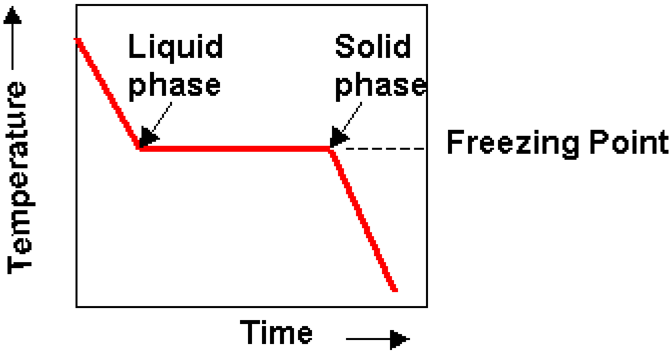


Fig.5.1. Cooling curve for the solidification of a pure metal.

There are three kinds of initial elements (or components) interaction:

1. Solid solution (complete and limited). It marked as α => A(B), β =>B(A).
2. Mechanically mixture. It marked as A+ B.
3. Chemical composition. It marked as A_nB_m.

Cooling Curve of a Solid Solution:

A solid solution consists of two kinds of atoms combined in one type of space lattice. A solution is composed of two parts: a solute and a solvent. The solute is the minor part of the solution or the material which is dissolved, while the solvent constitutes the major portion of the solution. When solidification of the solution starts, the temperature may be higher or lower than the crystallization point of the pure solvent. Most solid solutions solidify over a range in temperature.

Eutectic System:

Eutectic system is a phase transformation that takes place when a single-phase liquid transforms directly to a two-phase solid.

L ---> S1 + S2

Liquid ---> Solid 1 + Solid 2

(This is a reversible phase transformation).

Phase diagram of real alloys Pb-Sn (soft solders for soldering process) is shown in the fig. 5.2. This is typical phase diagram with eutectic transformation, which takes place at temperature equal 183 °C. There are two limited solid solutions at room temperature: α => Pb(Sn) and β =>Sn(Pb).

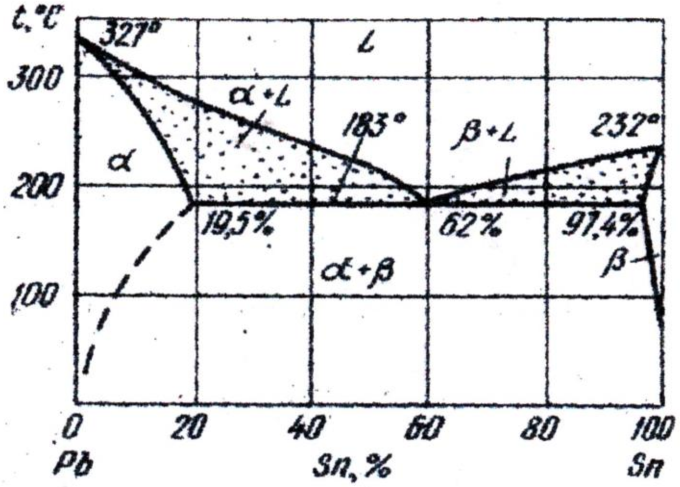


Fig.5.2. Phase Diagram of the alloys Pb-Sn.

Inverse Lever Rule:

Inverse lever rule is used to determine the percentage of each phase that is present at various temperatures.

The length of line XY represents the sum of the two phases as 100 percent. The inverse lever rule states that liquid phase can be calculated by taking the length of the line XZ and dividing this by XY.

The solid phase can be calculated by taking the length of the line ZY and dividing it by XY. To get the percentages, the values are multiplied by 100.

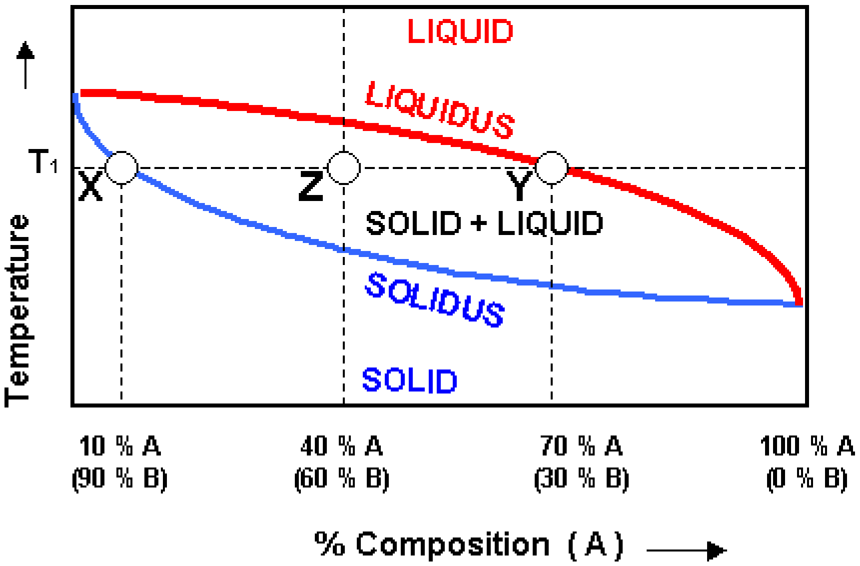


Fig.5.3. Phase diagram of a mixture with complete solubility in liquid and solid states

Sample Calculation :

Alloy with 40 % A and 60 %B at room temperature is heated to a temperature T1 . Calculate the liquid and solid phase and indicate the composition of each phase.

Liquid Phase =(XZ / XY) x 100 = [(40-10) / (70-10)] x100 = 50%

Solid Phase = (ZY / XY) x 100 = [(70-40) / (70-10)] x100 = 50%

At temperature T1, the solid composition is found by the intersection (point X) of isothermal line T1 and the solidus curve.

Solid composition: 10 % A and 90 % B

The liquid composition at temperature T1 is found by the intersection (point Y) of isothermal line T1 and the liquidus curve.

Liquid composition: 70% A and 30 % B

Materials and Equipment:

1. Experimental plant for determination of metal’s and alloy’s critical points.
2. Pb-Sn alloy.
3. Watch with second hand.

Procedure:

1. Put 100-150g Pb-Sn alloy of certain composition at the bottom of a crucible.
2. Set hot solder of thermocouple in crucible and put cold ends of thermocouple with the termvoltmeter together.
3. Cover crucible by plate.
4. Turn on the heater.
5. Turn off the heater, when the temperature is 250 ºC.
5. Record the indicators of termvoltmeter every 30 second.
6. Stop recording the indicators of termvoltmeter when the temperature is 140ºC.
7. Add 15 ºC (room temperature) to each temperature.
8. From the data obtained, graph the cooling curve of alloy in coordinates “temperature – time”.
9. Define the temperature of beginning and end of crystallization for explored alloy.
10. Plot a phase diagram of Pb-Sn alloys.
11. Through the cross point of the line of liquidus curve for hypoeutectic alloys and temperature of the explored alloy beginning of the crystallization take the vertical line.
12. Apply inverse lever rule at the temperature equal 200 ºC for explored alloy.
13. Determine chemical composition of the explored alloy.

Questions:

1. What does the phase diagram show?
2. Which experimental methods of phase diagram construction do you know?
3. Describe the thermal analysis process.
4. What does the experimental plant for determination of metal’s and alloy’s critical points by the method of thermal analysis consist of?
5. What is a thermocouple?
6. What types of thermocouple do you know?
7. Graph cooling curves for pure metal and alloys.
8. What kinds of initial elements interaction do you know?
9. Plot phase diagram with complete solubility in liquid and solid state forming.
10. Plot phase diagram with mechanical mixture of initial elements in solid state forming.
11. Plot phase diagram with eutectic transformation.
12. Plot phase diagram with eutectoid transformation.
13. Apply inverse lever rule for some alloy of phase diagram with complete solubility in liquid and solid state forming. Temperature must be chosen independently.

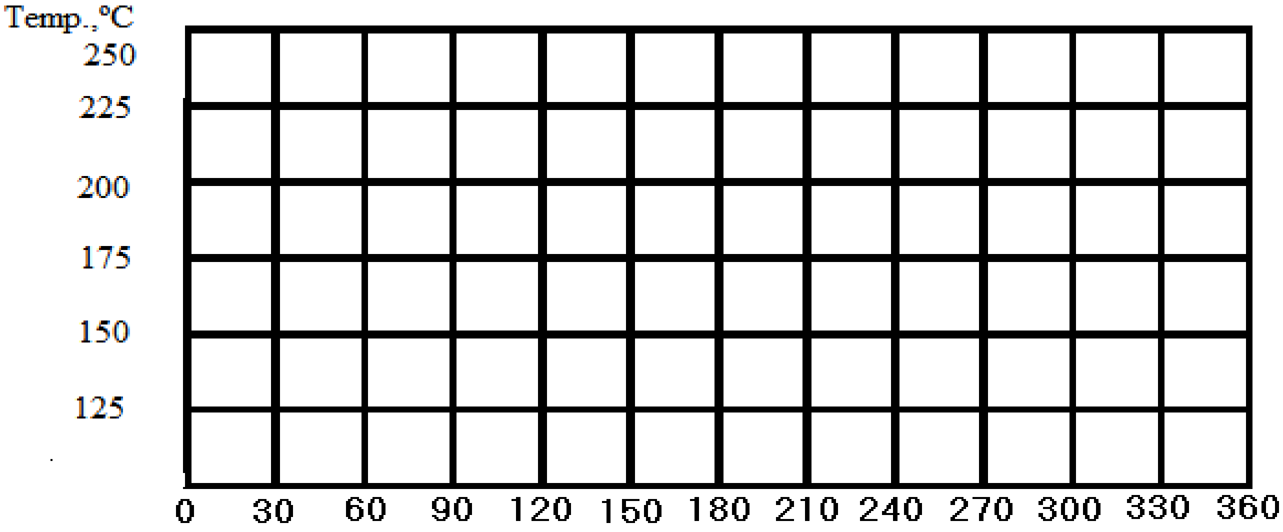
Laboratory work № 5
THERMAL ANALYSIS

PROTOCOL №1
Determination of critical points at cooling of alloy
Results of thermal analysis

Time, s	0	30	60	90	120	150	180	210	240	270	300	330	360
Temperature of the cooling, °C	250												
Temperature of the cooling +20°C	270												

Time, s	390	420	450	480	510	540	570	600	630	660	690	720	750
Temperature of the cooling, °C													
Temperature of the cooling +20°C													

Cooling curve of the alloy

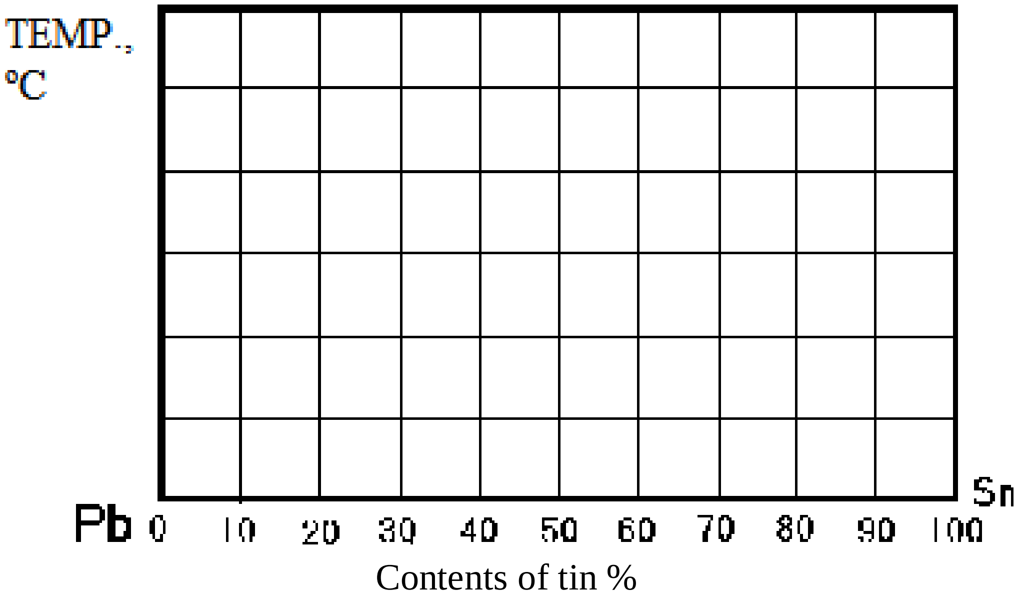


Time of cooling, s

Temperature of critical points (^{0}C)

Begining of the crystallization- ____________End of the crystallization-____________

Phase Diagram of the alloys lead and tin



Application of the inverse lever rule for explored alloy at temperature 200 ^{0}C

Conclusions:

Student's signature
"____"____________20___ y.

Teacher's signature
"____"____________20___ y.

Practical 1. PHASE DIAGRAMS

Objectives

1. To learn the process of phase diagrams analysis.
2. To learn the construction of cooling curves.
3. To learn how to apply the phase rule and inverse level rule.

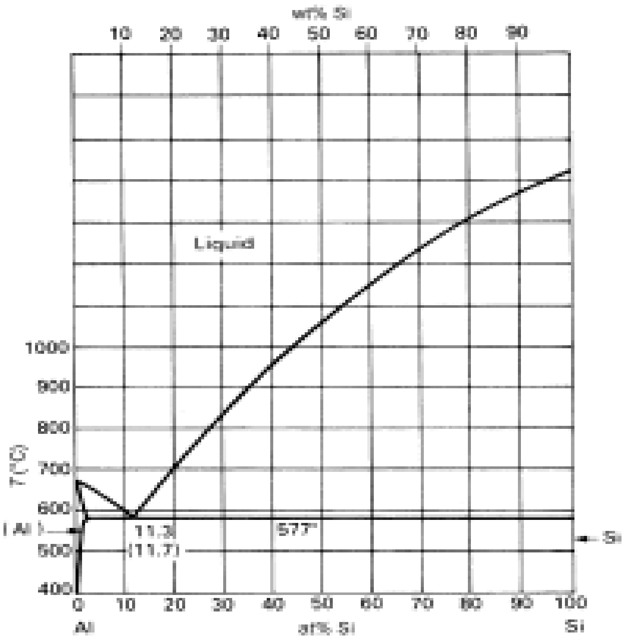
Activity

1. To analyse the phase diagram choose it from Table according to your variant and plot it.

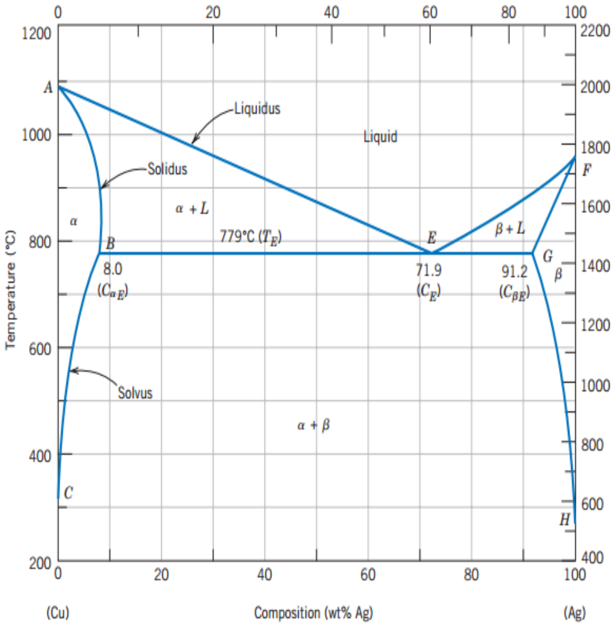
   Note! Your variant is your number in the group list or your number in the group list minus 10 (20).

2. Mark all critical points with letters.
3. Describe the lines of phase diagram (liquidus, solidus, phase transformation, lines of the solubility (if they are present)).
4. Identify the components of the alloys. Are there allotropic forms in the components? List them.
5. What kinds of initial elements interaction take place? Identify all phases which occur in the alloys.
6. Describe the phase reactions (if they are present) and write down their formula.
7. To analyse the alloy, choose its chemichal composition and temperature at any two-phase field. Draw alloy’s vertical, mark the point of chosen temperature and all points of where alloy’s vertical crosses the lines of phase diagram.
8. Construct the general shape of a cooling curve for chosen alloy.
9. Mark phases at every temperature period on the cooling curve.
10. Describe what happens if the alloy is cooled to room temperature. At which temperatures do changes in the number or type of phases occur?
11. Application of the phase rule. How many degrees of freedom are there at constant ***p*** in all fields.
12. How many phases can coexist in equilibrium at constant ***p***? Define them.
13. Describe what happens if the alloy is cooled to room temperature. At which temperatures do changes in the number or type of phases occur?
14. Application of the inverse level rule. Calculate the approximate composition and proportions by weight of each phase that is present at chosen temperature.

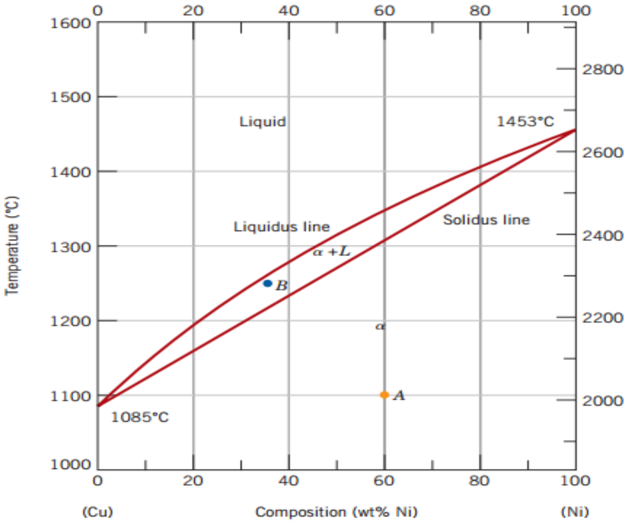
Table. Variants of the phase diagrams



V1



V2



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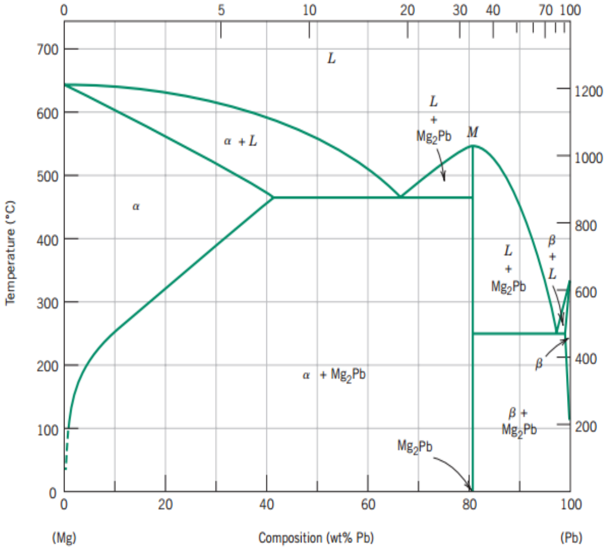
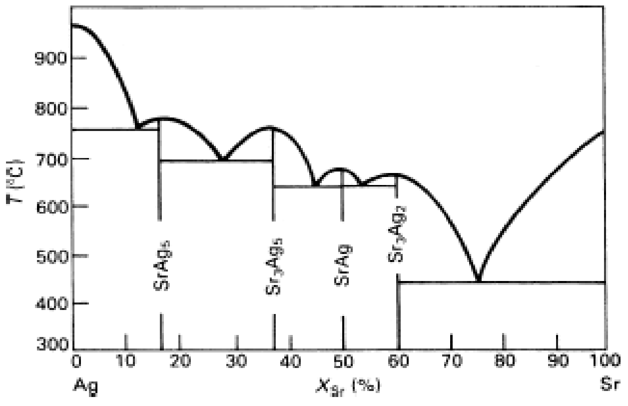
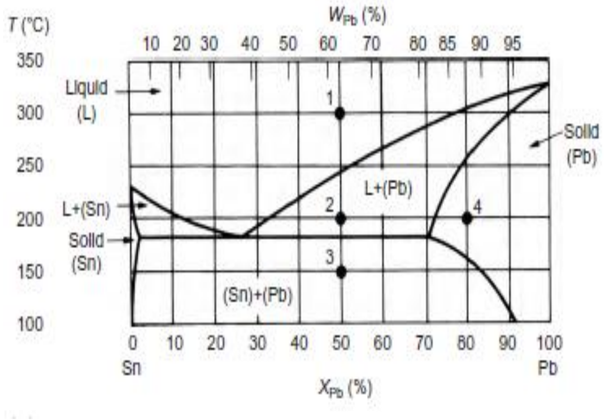


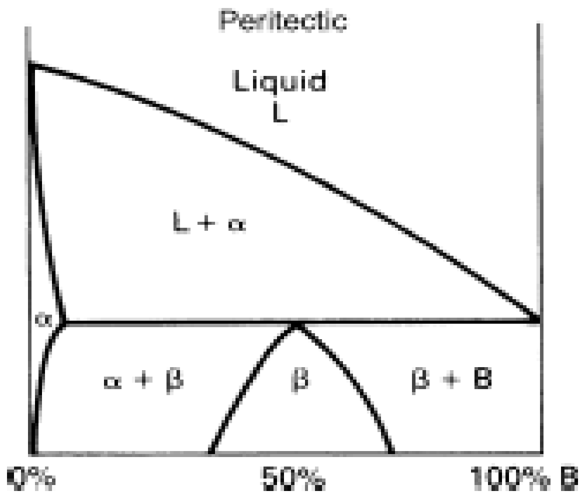
V4



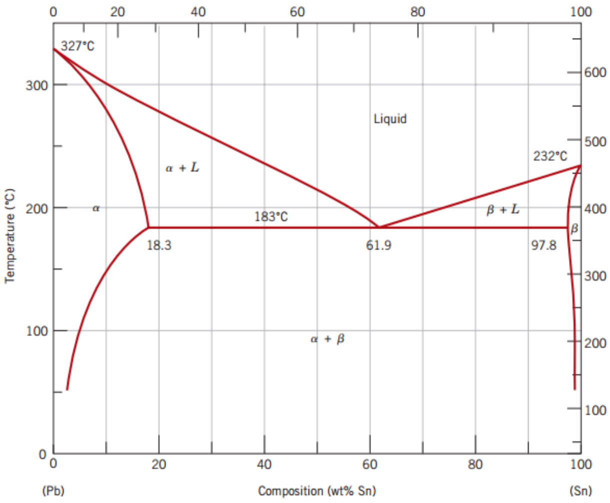
V5



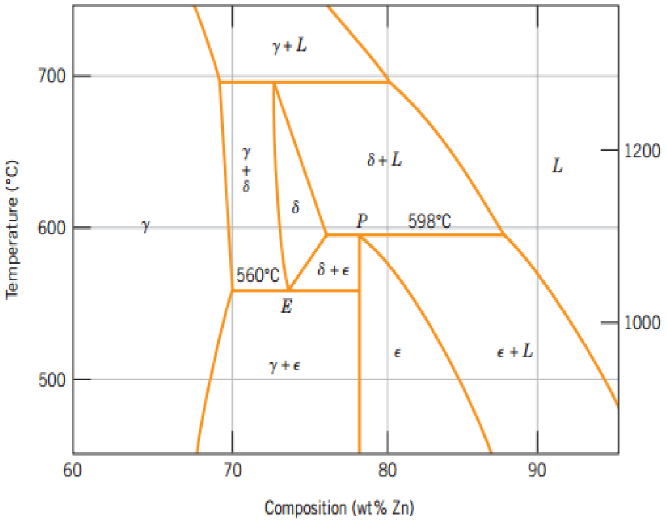
V6



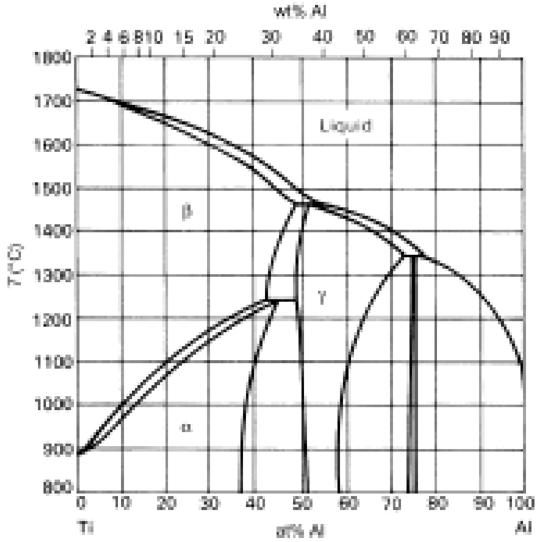
V7



V8



V9



V10

1.Phase diagram	2. Cooling curve

3. Lines of the phase diagram :

liquidus____________________________, solidus______________________________,

equilibrium phase transformation____,

lines of the solubility

____

____

4. Components of the alloys. _________.

Allotropic forms in the components ____.

5. Kinds of initial elements interaction___________________________________

6. Phases, which occur in the alloys

____

____

____.

7. Phase reactions and their formula

____

____

____

8. Chemical composition chosen alloy____________________________________

9. Application of the phase rule. Calculate the degrees of freedom in all fields at constant ***p***.

____

____

____

10. How many phases can coexist in equilibrium at constant ***p***? Define them.

____.

11. Describe what happens if the alloy is cooled to room temperature. At which temperatures do changes in the number or type of phases occur?

____

____

____

____

____.

12. Application of the inverse level rule. Calculate the approximate composition and the proportions by weight of each phase that is present at chosen temperature.

The composition of phase 1 is ____.

The composition of phase 2 is____

What (roughly) are the proportions by weight of each phase?

____

____

____

Conclusion____

____

____

______________________________ ______________________________

Student's signature Teacher's signature

"____"____________20___ y. "____"____________20___ y.

Practical 2. Fe – Fe_3C DIAGRAM

Objectives

1. To learn the process Fe – Fe_3C diagram analysis.
2.To learn how to apply the phase rule and inverse level rule.

Scientific principles

Fe and C are the main components of Fe – Fe_3C diagram. Fe has polymorphic modification; it’s marked by the initial letters of the Greek alphabet, beginning from low temperatures (Fe_{α}, Fe_{γ} Fe_{δ}).

When iron crystallizes at 1539 ºC it is B.C.C. (δ -iron), at 1392 ºC its structure changes to F.C.C. (γ -iron or austenite), and at 911 ºC it again becomes B.C.C. (α -iron or ferrite).

There are following phathes and structure of Fe – Fe_3C diagram:

CEMENTITE is an iron carbide that has the following chemical formula: Fe_3C. It contains 6.67 % carbon by weight. It is a typical hard and brittle interstitial compound of low tensile strength but high compressive strength. Its crystal structure is orthorhombic.

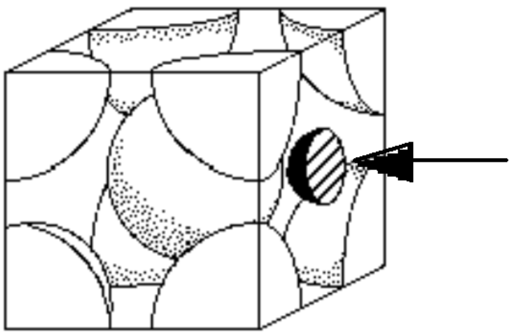
AUSTENITE (γ - iron):

It is also known as (γ -) gamma-iron, which is an interstitial solid solution of carbon dissolved in iron with a face centered cubic crystal (F.C.C) structure.

Austenite is normally unstable at room temperature. Under certain conditions it is possible to obtain austenite at room temperature.

FERRITE (α - iron):

It is (α -) alpha -iron, which is an interstitial solid solution of a small amount of carbon dissolved in iron with a Body Centered Cubic (B.C.C.) crystal structure. It is the softest structure on the iron-iron carbide diagram.



Interstitial Carbon in Iron
Since the interstitial sites are so small, the maximum solubility in BCC iron is only one carbon atom for 5000 iron atoms.

Fig. Pr 2.1. BCC iron showing the location of interstitial carbon atoms

PEARLITE (α - Fe + Fe_3C)

It is the eutectoid mixture containing 0.8 % carbon and is formed at 727°C on very slow cooling. It is very fine platelike or lamellar mixture of ferrite and cementite. The structure of pearlite includes a white matrix (ferritic background) which includes thin plates of cementite.

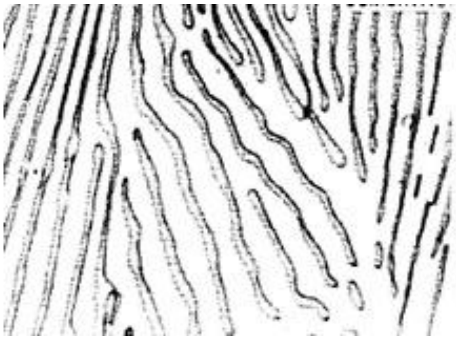


Fig.Pr 2.2. Pearlite microstructure (Light background is the ferrite matrix, dark lines are the cementite network)

LEDEBURITE (γ - Fe + Fe_3C)

It is the eutectic mixture of austenite and cementite. It contains 4.3% carbon and represents the eutectic of cast iron. Ledeburite exists when the carbon content is greater than 2.14%, which represents the dividing line on the equilibrium diagram between steel and cast iron.

There are **three phase reaction** at different constant temperature:

At the eutectic point, the phase reaction, on cooling, is ***eutectic***:

Liquid => austenite (_γ-iron) +cementite

or

Liquid => ledeburite.

But the diagram shows another feature which looks like a eutectic: it is the at the bottom of the austenite field. The transformation which occurs there is very like the eutectic transformation, but this time it is a solid, austenite, which transforms on cooling to two other solids. The point is called a eutectoid point. The compositions of the two new phases are given by the ends of the tie line through the eutectoid point.

At the eutectoid point, the phase reaction, on cooling, is ***eutectoid:***

Austenite => ferrite (_α-iron) + cementite

or

Austenite => pearlite.

At the peritectic point, the phase reaction, on cooling, is ***peritectic:***

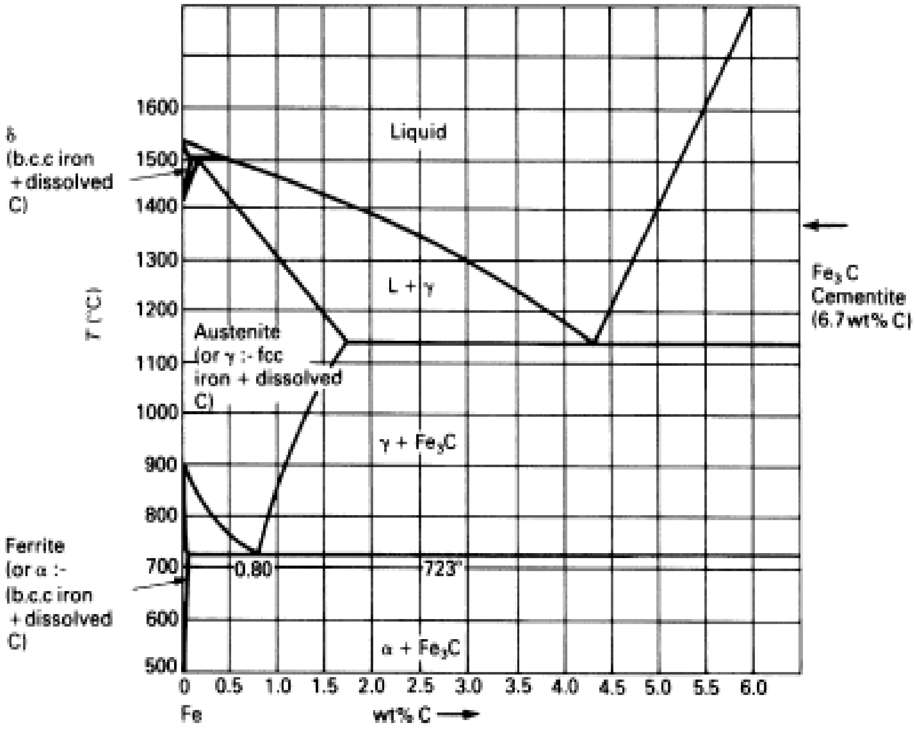
Liquid + ferrite (δ –iron) => austenite .

Activity

1. To analyse the Fe – Fe_3C diagram mark at all critical points of the Fe – Fe_3C diagram with letters.
2. Describe the lines of Fe – Fe_3C diagram (liquidus, solidus, phase reactions, lines of the solubility).
3. Identify components of alloys. List allotropic forms of the components.
4. What kinds of initial elements interaction take place there? Identify all phases and structure which occur in the chosen alloy.
5. Describe phase reactions and write down their formula.
6. To analyse the alloy, choose it carbon contant and temperature.
   Note! Your variant is your number in the group list or your number in the group list minus 10 (20).
7. Draw alloy's vertical, mark the point of chosen temperature and all points of where alloy's vertical crosses the lines of phase diagram.
8. Construct the general shape of cooling curve for chosen alloy.
9. Mark phases at every temperature period on the cooling curve.
10. Application of the phase rule. How many degrees of freedom are there at constant ***p*** in all fields.
11. How many phases can coexist in equilibrium at constant ***p***? Define them.
12. Describe what happens if alloy is cooled to room temperature. At which temperatures do changes in the number or type of phases occur?
13. Application of the inverse level rule. Calculate the approximate composition and proportions by weight of each phase that is present at chosen temperature.

Table. Carbon contant in the alloy and temperature to Fe – Fe_3C diagram analyse

	V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**V10**
Carbon contant % (wt.)	0.25	0.4	0.6	0.8	1.0	1.2	2.3	3.5	4.3	5.0
Temperature, ^{0}C	800	600	1450	1400	760	800	1000	1200	900	1200

1. Fe – Fe$_3$C diagram	2. Cooling curve
	

3. Lines of the Fe – Fe$_3$C diagram :

liquidus____________________________, solidus____________________________,

phase reactions ____,

lines of the solubility ____

____

4. Components of the alloys. _________.

Allotropic forms in the components ____.

5. Kinds of initial elements interaction____

6. Phases, which occur in the alloys

____

____.

7. Structure, which occur in the alloys

____

____.

8. Chemical composition of chosen alloy________________________________

9. Phase reactions in chosen alloy and their formulas

____

____

10. Application of the phase rule. Calculate degrees of freedom in all fields at constant ***p***.

____

____

11. How many phases can coexist in equilibrium at constant ***p***? Define them.

____

____.

12. Describe what happens if the alloy is cooled to room temperature. At which temperatures do changes in the number or type of phases occur?

____

____

____.

13. Application of the inverse level rule. Calculate the approximate composition and the proportions by weight of each phase that is present at chosen temperature.

The composition of phase 1 is ____.

The composition of phase 2 is____

What (roughly) are the proportions by weight of each phase?

____

____

____

Conclusion____

____

______________________________ ______________________________

Student's signature Teacher's signature

"____"___________20___ y. "____"_____________20___ y.

LABORATORY WORK 6

PLAIN CARBON STEELS

Objectives

1. To learn the microstructures of the steel.
2. To learn to determine of the steel chemical composition by its SAE-AISI number.

Scientific principles

There are two types of iron-carbon alloys- steel and cast iron.

Steel is an iron-carbon alloy, which contains less 2.14% carbon, alloying elements such as Mn, Si, Al and impurities S and P.

Cast irons are an iron-carbon alloys which contains more than 2.14% carbon (carbon may be presented as carbide (connected) and as graphite (free)) and impurities S, P, Mn, Si. The microstructure of steel and cast iron are described by Fe - Fe_3C diagram (Fig.5.1).

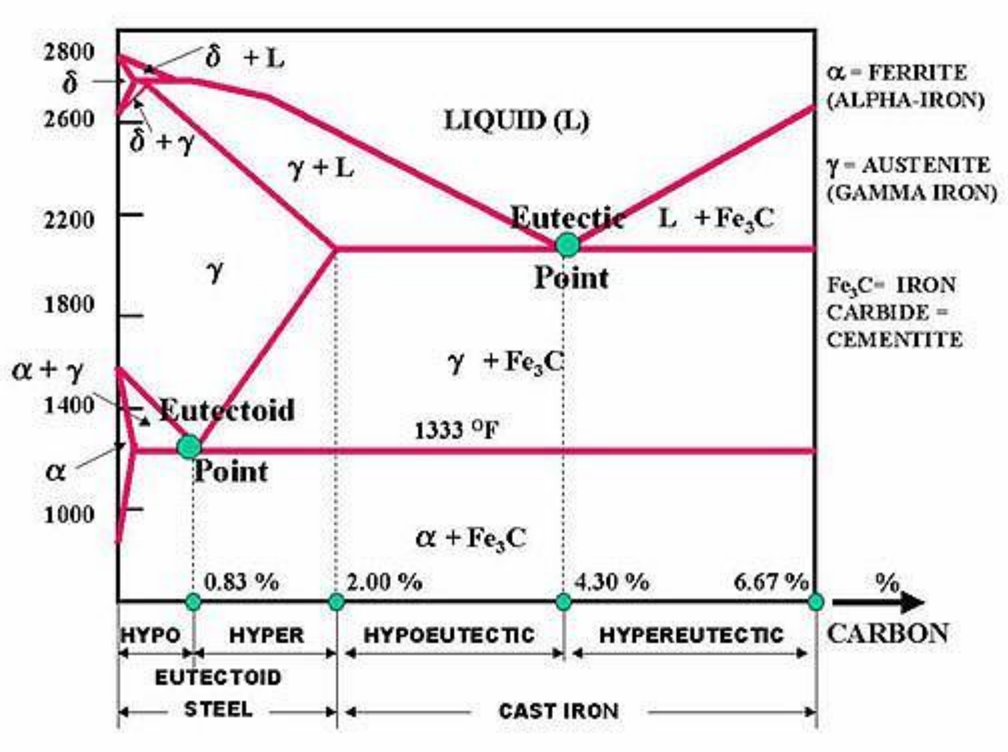


Fig.6.1. Iron-ironcarbide diagram.

The effect of Carbon on the Properties of Steel

In general, as the carbon content increases the hardness of the steel also increases. The tensile strength and the yield strength also increase to about 0.8% carbon. Thereafter, they level out. This is shown in Figure 6.2.

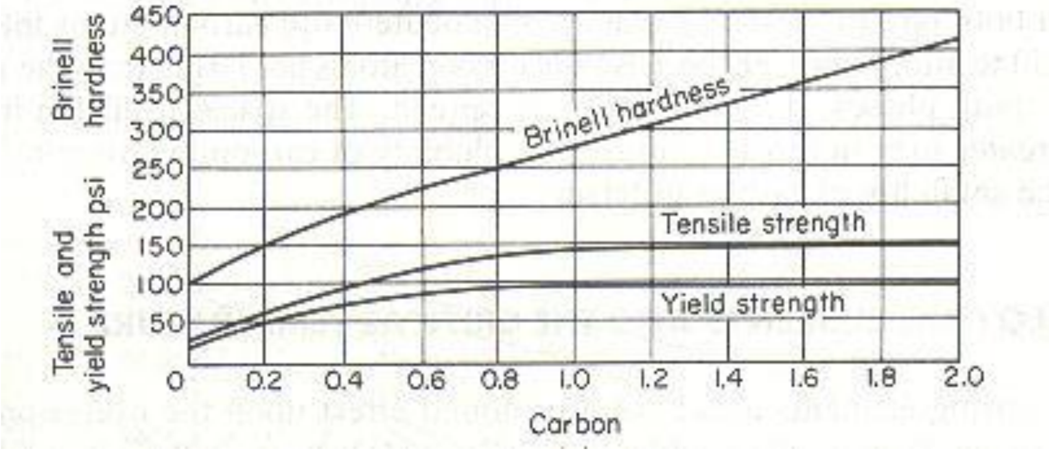


Fig 6.2. The effect of carbon on the hardness, tensile strength and yield strength

of steels.

The tensile strength and hardness are affected as the ratio of ferrite to cementite in the structure of steel changes. As the percentage of pearlite increases in the hypoeutectoid steels, the tensile strength increases. The hypereutectoid steels show only a slight increase in strength as the cementite-to-ferrite ratio increases.

The elongation and the reduction in area represent how ductile or brittle a material is. Fig.6.3 indicates the effect of carbon on the ductility and impact resistance (toughness) of steels. The elongation and the reduction in area drop sharply with increase in carbon content, going almost to zero at about 1.5 % carbon. This indicates that the carbon content of 1.5 % or more will cause high brittleness.

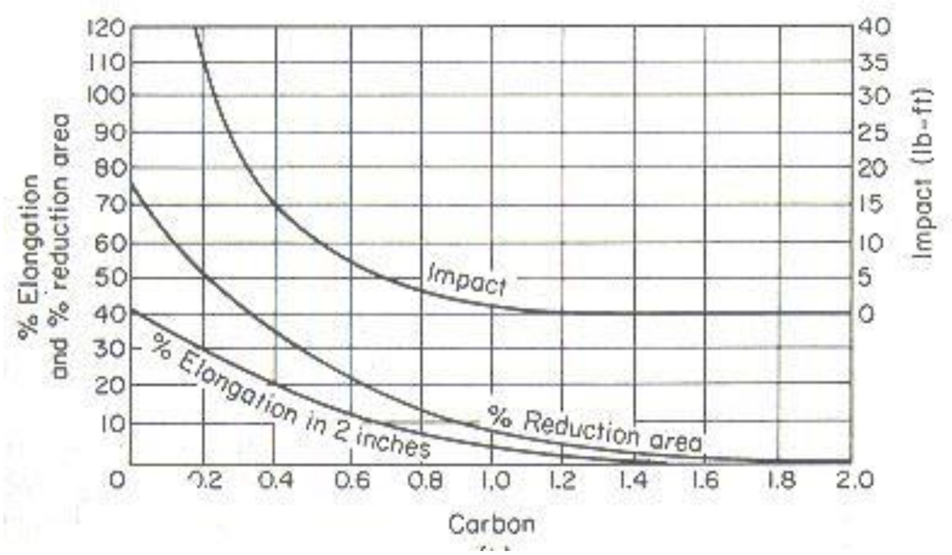
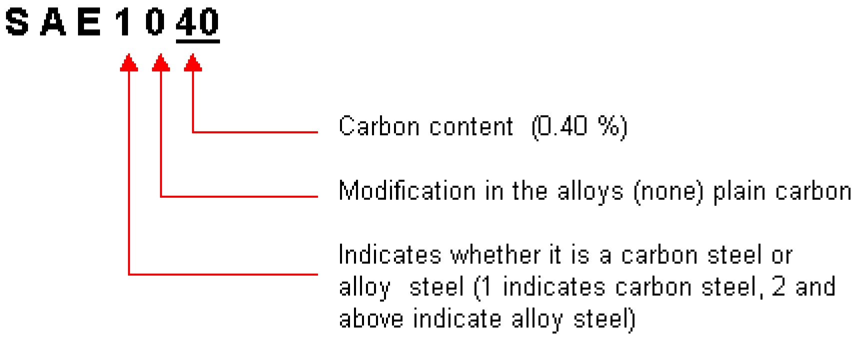


Fig. 6.3. The effect of carbon on the impact resistance and ductility of steels.

Classification of Steels

The Society of Automotive Engineers (SAE) has established standards for specific analysis of steels. In the 10XX series, the first digit indicates a plain carbon steel. The second digit indicates a modification in the alloys. 10XX means that it is a plain carbon steel where the second digit (zero) indicates that there is no modification in the alloys. The last two digits denote the carbon content in points. For example SAE 1040 is a carbon steel where 40 points represent 0.40 % Carbon content. Alloy steels are indicated by 2XXX, 3XXX, 4XXX, etc. The American Iron and Steel Institute (AISI) in cooperation with the Society of Automotive Engineers (SAE) revised the percentages of the alloys to be used in the making of steel, retained the numbering system.

General representation of steels:



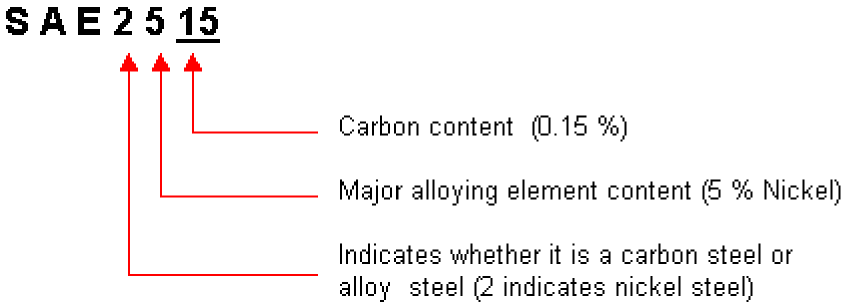


Table 6.1. Classification of steels

SAE - AISI Number	Classification
1XXX	Carbon steels Low carbon steels: 0 to 0.25 % C Medium carbon steels: 0.25 to 0.55 % C High carbon steels: Above 0.55 % Carbon

2XXX	Nickel steels 5 % Nickel increases the tensile strength without reducing ductility. 8 to 12 % Nickel increases the resistance to low temperature impact 15 to 25 % Nickel (along with Al, Cu and Co) develop high magnetic properties. (Alnicometals) 25 to 35 % Nickel create resistance to corrosion at elevated temperatures.
3XXX	Nickel-chromium steels These steels are tough and ductile and exhibit high wear resistance, hardenability and high resistance to corrosion.
4XXX	Molybdenum steels Molybdenum is a strong carbide former. It has a strong effect on hardenability and high temperature hardness. Molybdenum also increases the tensile strength of low carbon steels.
5XXX	Chromium steels Chromium is a ferrite strengthener in low carbon steels. It increases the core toughness and the wear resistnace of the case in carburized steels.
86XX 87XX 93XX 94XX 97XX 98XX	Triple Alloy steels which include Nickel (Ni), Chromium (Cr), and Molybdenum (Mo). These steels exhibit high strength and also high strength to weight ratio, good corrosion resistance.

Red Hardness: This property (also called hot-hardness) is related to the resistance of the steel to the softening effect of heat. It is reflected to some extent in the resistance of the material to tempering.

Hardenability: This property determines the depth and distribution of hardness induced by quenching.

Hot-shortness: Brittleness at high temperatures is called hot-shortness which is usually caused by sulfur. When sulfur is present, iron and sulfur form iron sulfide (FeS) that is usually concentrated at the grain boundaries and melts at temperatures below the melting point of steel. Due to the melting of iron sulfide, the cohesion between the grains is destroyed, allowing cracks to develop. This occurs when the steel is forged or rolled at elevated temperatures. In the presence of manganese, sulfur tends to form manganese sulfide (MnS) which prevents hot-shortness.

Cold-shortness: Large quantities of phosphorus (in excess of 0.12%P) reduces the ductility, thereby increasing the tendency of the steel to crack when cold worked. This brittle condition at temperatures below the recrystallization temperature is called cold-shortness.

Materials and Equipment:

1. Specimen of the hypoeutectoid and hypereutectoid steels.
2. Microscope MM – 4.

Procedure:

1. Set specimen of the hypoeutectoid and hypereutectoid steels on a microscope and look at their microstructure.
2. Draw the microstructure of the hypoeutectoid and hypereutectoid steels.
3. Determine the critical temperatures (UCT and LCT) for hypoeutectoid steel with 0.3 %C and hypereutectoid steel with 1.2%C.
4. Determine the chemical composition of the steels by its SAE-AISI number.

Questions:

1. What are the types of iron- carbon alloys?
2. What is steel?
3. What is cast iron?
4. Which polymorphic modifications does the iron have and at what temperatures interval is it stable?
5. List fathes and structure of the Fe-Fe_3C diagram.
6. What is cementite and what properties does it have?
7. What is austenite and what properties does it have?
8. What is ferrite and what properties does it have?
9. What is perlite and what properties does it have?
10. What is ledeburite?
11. What carbon content does the hypoeutectoid steel have?
12. What carbon content does hyperutectoid steel have?
13. What carbon content does hypoeutectic cast iron have?
14. What carbon content does hypereutectic cast iron have?
15. Discribe the effect of carbon on hardness and tensile strength of steels.
16. Discribe the effect of carbon on toughness (impact resistance) and ductility of steels.
17. What does number SAE 5230 and SAE 1020 mean?
18. What carbon content does medium carbon steels have?
19. What is the purpose of the steel alloying?
20. List the alloying elements.
21. What is red hardness?
22. What is hardenability?

Laboratory work № 6

PLAIN CARBON STEELS

PROTOCOL №1

Hypoeutectoid steel
Carbon content___________%

Hypereutectoid steel
Carbon contain___________%

Critical temperature ºC

Hypoeutectoid steel:
UCT = _________
LCT = ___________

Hypereutectoid steel:
UCT = _________
LCT = _________

PROTOCOL № 2

Steel	Chemical composition, %			
	C	Ni	Mo	Cr
SAE 1050				
SAE 2412				
SAE 4240				
SAE 5215				

Conclusions:

____
Student’s signature
“____”___________20___ y.

____
Teacher’s signature
“____”____________20___ y.

LABORATORY WORK 7

CAST IRONS

Objectives

1. To learn the microstructures of the cast iron.
2. To learn the advantages and disadvantages of the cast iron.

Scientific principles

Types of cast iron

Cast irons may often be used in place of steel at considerable cost savings. The design and production advantages of cast iron include:

Low tooling and production cost
Good machinability without burring
Ability to cast into complex shapes
Excellent wear resistance and high hardness (particularly white cats irons)
High inherent damping capabilities

The properties of the cast iron are affected by the following factors:

Chemical composition of the iron
Rate of cooling of the casting in the mold (which depends on the section thickness in the casting)
Type of graphite formed (if any)

Major types of cast iron are shown in Figure 7.1.

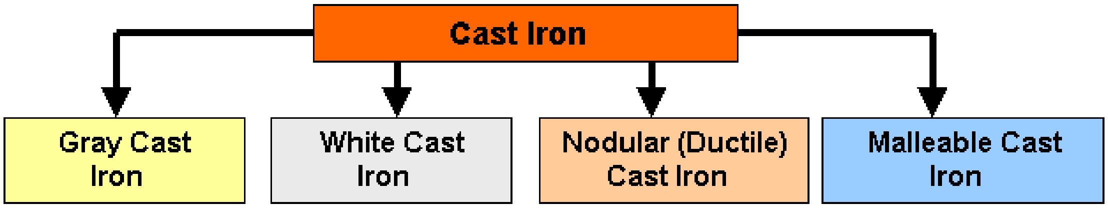


Fig.7.1. Types of Cast Iron

Gray cast iron

Gray iron, named so because of its fracture has a gray appearance. It contains carbon in the form of ***flake graphite*** in a matrix which consists of ferrite, pearlite or a mixture of the two. The fluidity of liquid gray iron, and its expansion during solidification due to the formation of graphite, has made this metal ideal for the economical production of shrinkage-free, intricate castings such as motor blocks.

The flake-like shape of graphite in Gray iron, see Fig.7.2 and 7.3, exerts a dominant influence on its mechanical properties. The graphite flakes act as stress raisers which may prematurely cause localized plastic flow at low stresses, and initiate fracture in the matrix at higher stresses. As a result, Gray iron exhibits no elastic behavior but excellent damping characteristics, and fails in tension without significant plastic deformation. The presence of graphite flakes also gives Gray Iron excellent machinability and self-lubricating properties.

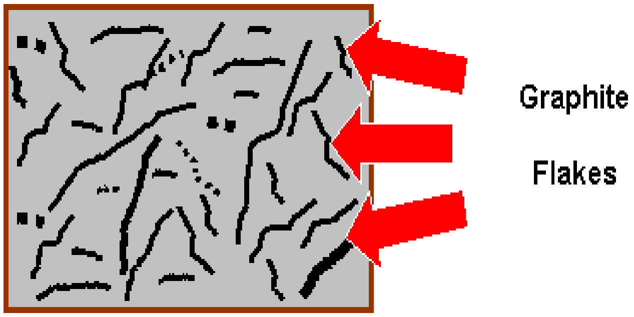


Fig.7.2. Graphite Flakes in Gray Cast iron

Fig.7.3. Photomicrograph of Gray Cast iron

Advantages of Gray Cast Iron:

- Graphite acts as a chip breaker and a tool lubricant.
- Very high damping capacity.
- Good dry bearing qualities due to graphite.
- After formation of protective scales, it resists corrosion in many common engineering environments.

Disadvantages:

- Brittle (low impact strength) which severely limits use for critical applications.
- Graphite acts as a void and reduces strength.
- Changes in section size will cause variations in machining characteristics due to variation in microstructure.
- Higher strength gray cast irons are more expensive to produce.

White cast iron

White cast iron is unique in that it is the only member of the cast iron family in which ***carbon is present only as carbide***. Due to the absence of graphite, it has a light appearance. The presence of different carbides, depending on the alloy content, makes white cast irons extremely hard and abrasion resistant but very brittle. An improved form of white cast iron is the chilled cast iron.

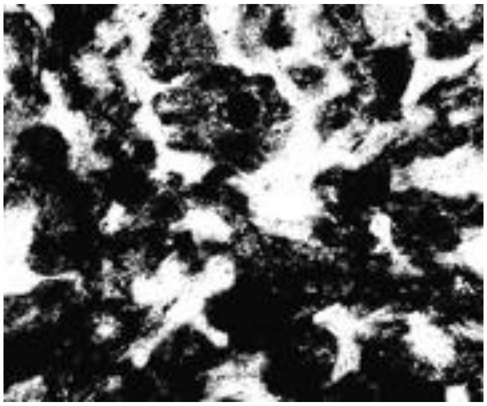


Fig.7.4. Photomicrograph of White Cast Iron

Ductile Cast iron (nodular cast)

This structure is developed from the melt. The carbon forms into ***spheres*** when cerium, magnesium, sodium, or other elements are added to a melt of iron with very low sulfur content that will inhibit carbon from forming. The control of the heat-treatment process can be pearlitic, ferritic, martensitic matrices into which the carbon spheres are embedded.

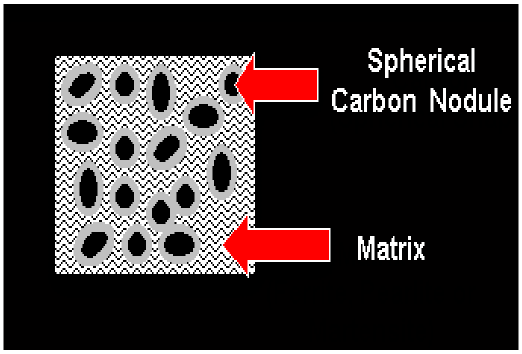


Fig.7.5. Nodular (Ductile) Cast Iron and the spherical carbon embedded into the matrix.

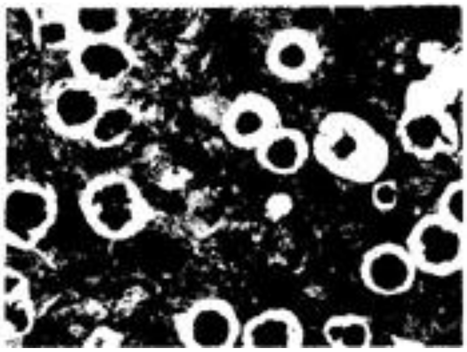


Fig.7.6. Photomicrograph of Nodular Cast iron

Ductile cast iron is used for many structural applications, particularly those requiring strength and toughness combined with good machinability and low cost. The automotive and agricultural industries are the major users of ductile iron castings. Because of economic advantage and high reliability, ductile iron is used for such critical automotive parts as crankshafts, engine connecting rods, idler arms, wheel hubs, truck axles, front wheel spindle supports, disk brake calipers, suspension system parts, power transmission yokes, high temperature applications for turbo housing and manifolds, and high security valves for many applications. The cast iron pipe industry is another major user of ductile iron.

Malleable Cast Iron

If cast iron is cooled rapidly, the graphite flakes needed for gray cast iron do not get a chance to form. Instead, white cast iron forms. This white cast iron is reheated to about 950°C for long periods of time and at the elevated temperatures cementite (Fe_3C) decomposes into ferrite and free carbon. Upon cooling, the combined carbon further decomposes to small compact particles of graphite (instead of flake -like graphite seen in gray cast iron). If the cooling is very slow, more free carbon is released. This free carbon is referred to as temper carbon, and the process is called ***malleableizing.***

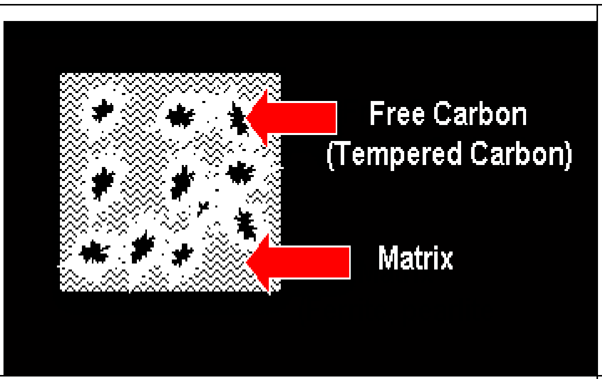


Fig.7.7. Malleable Cast Iron

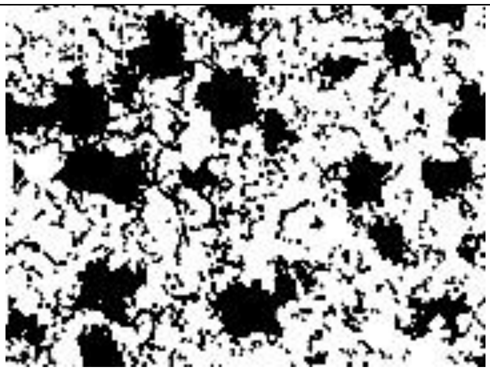


Fig.7.8. Ferritic Malleable Cast iron

Malleable cast iron is used for connecting rods and universal joint yokes, transmission gears, differential cases and certain gears, compressor crankshafts and hubs, flanges, pipe fittings and valve parts for railroad, marine and other heavy-duty applications.

Advantages:

- Excellent machinability
- Significant ductility
- Good shock resistance properties

Disadvantages:

The major disadvantage is shrinkage. Malleable cast iron decreases in volume during solidification, and as a result, requires attached reservoirs (feeders and risers) of liquid metal to offset the shrinkage and prevent the formation of internal or external shrinkage defect.

Materials and Equipment:

1. Specimens of the gray cast iron, nodular cast iron and malleable cast iron.
2. Microscope MM – 4.

Procedure:

1. Set specimen of the gray cast iron, nodular cast iron and malleable cast iron on a microscope and look at their microstructure.
2. Draw the microstructure of the gray cast iron, nodular cast iron and malleable cast iron.

Questions:

1. What are the advantages of cast iron?
2. What are the major types of cast iron?
3. List forms of the graphite and write what types of cast iron have those forms of graphite.
4. What form of graphite does the gray cast iron have?
5. What are the advantages of gray cast iron?
6. Write an example of used ductile cast iron.
7. Explain how to makes the malleable cast iron?
8. What are the advantages and disadvantages of malleable cast iron?

Laboratory work № 7

CAST IRONS

PROTOCOL №1

Gray cast iron nodular cast iron malleable cast iron

Graphite form

_______________ _______________ _______________

The type of the metallic matrix

_______________ _______________ _______________

Conclusions:

____

____

____

______________________ ________________________

Student’s signature Teacher’s signature

“____”___________20___ y. “____”____________20___ y.

LABORATORY WORK 8

PROCESSES OF HEAT TREATMENT OF STELL

Objectives

1. To learn how to choose temperature of different types of steel heat treatment.

Scientific principles

Types of heat treatment processes

Various types of heat treatment processes are used to change the following properties or conditions of the steel:

- Improve the toughness, the wear resistanceand the machinability
- Increase the hardness and the ductility
- Refine the grain structure
- Remove the residual stresses.

Figure 8.1 shows major types of heat treatment processes.

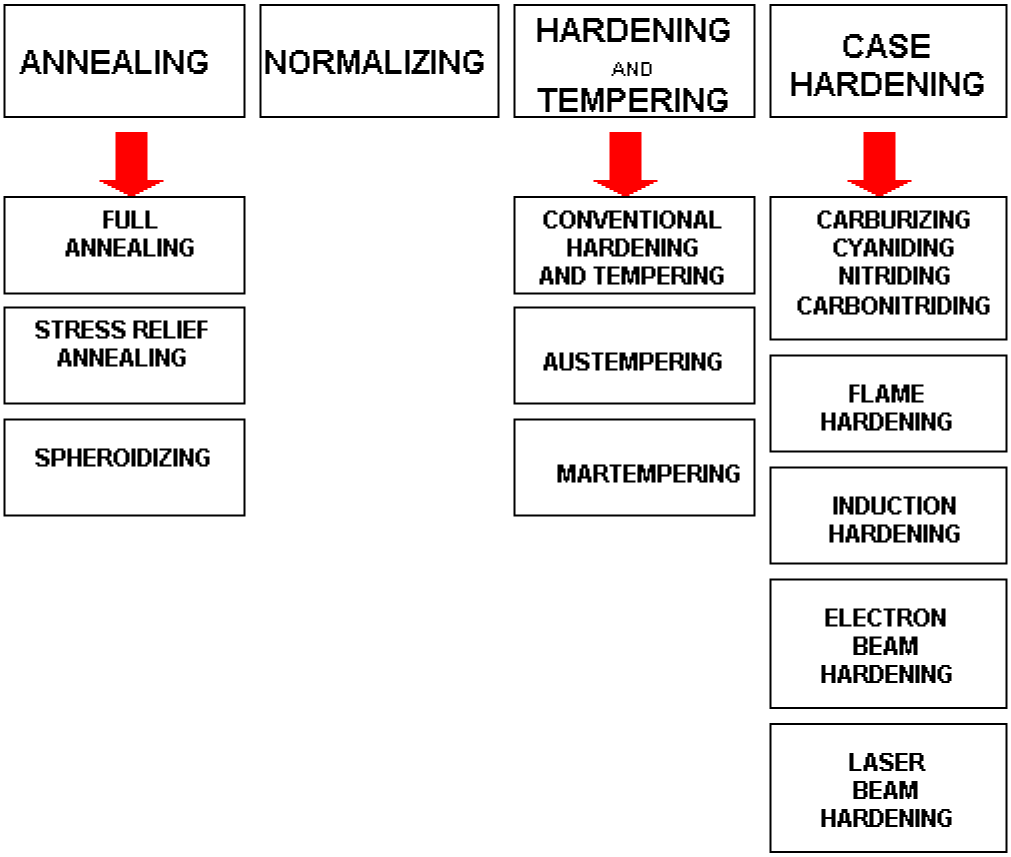


Fig.8.1. ***Types of Heat Treatment Processes.***

Time-Temperature-Transformation (TTT) Diagram

T(Time) T(Temperature) T(Transformation) diagram is a plot of temperature versus the logarithm of time for a steel alloy of definite composition. It is used to determine when transformations begin and end for an isothermal (constant temperature) heat treatment of a previously austenitized alloy. When austenite is cooled slowly to a temperature below ***LCT (Lower Critical Temperature)***, the structure that is formed is Pearlite. As the cooling rate increases, the pearlite transformation temperature gets lower. The microstructure of the material is significantly altered as the cooling rate increases. By heating and cooling a series of samples, the history of the austenite transformation may be recorded. ***TTT diagram indicates*** when a specific transformation starts and ends and it also shows what percentage of transformation of austenite at a particular temperature is achieved.

Cooling rates in the order of increasing severity are achieved by quenching from elevated temperatures as follows: furnace cooling, air cooling, oil quenching, liquid salts, water quenching, and brine. If these cooling curves are superimposed on the TTT diagram, the end product structure and the time required to complete the transformation may be found.

In Fig.8.2 the area on the left of the transformation curve represents the austenite region. Austenite is stable at temperatures above LCT but unstable below LCT. Left curve indicates the start of a transformation and right curve represents the finish of a transformation. The area between the two curves indicates the transformation of austenite to different types of crystal structures. (Austenite to pearlite, austenite to martensite, austenite to bainite transformation.)

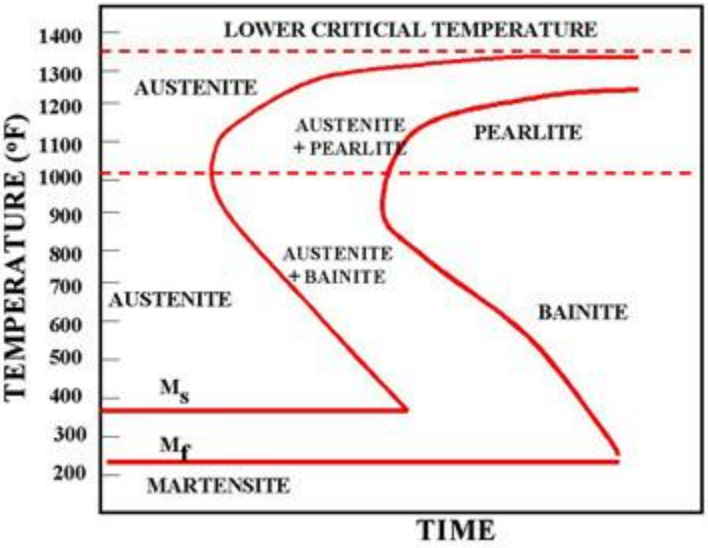


Fig.8.2. TTT Diagram

If the cooling rate is very slow such as annealing process, the cooling curve passes through the entire transformation area and the end product of this the cooling process becomes 100% Pearlite.

In Fig.8.3 the cooling rates A and B indicate two rapid cooling processes. In this case curve A will cause a higher distortion and a higher internal stresses than the cooling rate B. The end product of both cooling rates will be ***martensite.*** Cooling rate B is also known as the ***Critical Cooling Rate,*** which is represented by a cooling curve that is tangent to the nose of the TTT diagram. Critical Cooling Rate is defined as the lowest cooling rate which produces 100% Martensite while minimizing the internal stresses and distortions.

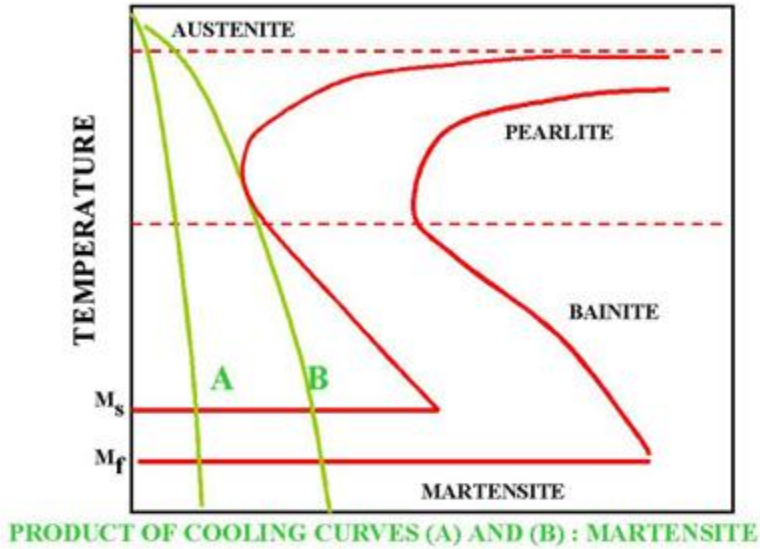


Fig.8.3. Rapid Quench

In Fig.8.4, a rapid quenching process is interrupted (horizontal line represents the interruption) by immersing the material in a molten salt bath and soaking at a constant temperature followed by another cooling process that passes through Bainite region of TTT diagram. The end product is Bainite, which is not as hard as Martensite. As a result of cooling rate D; more dimensional stability, less distortion and less internal stresses are created.

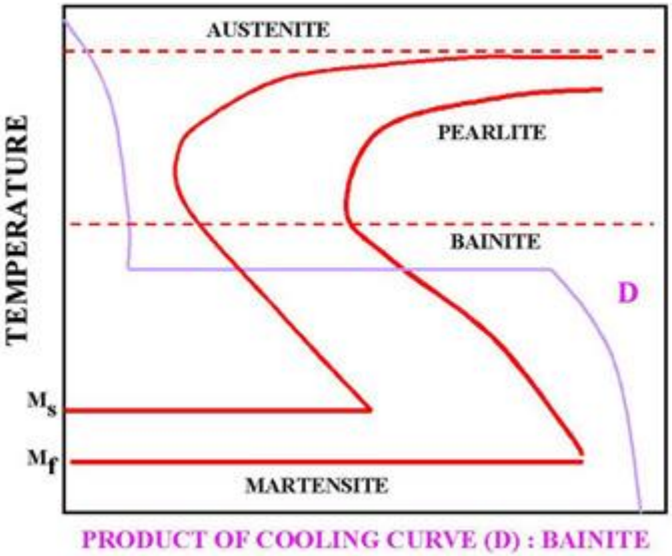


Fig. 8.4. Interrupted Quench

In Fig.8.5 cooling curve C represents a slow cooling process, such as furnace cooling. An example for this type of cooling is annealing process where all the Austenite is allowed to transform to Pearlite as a result of slow cooling.

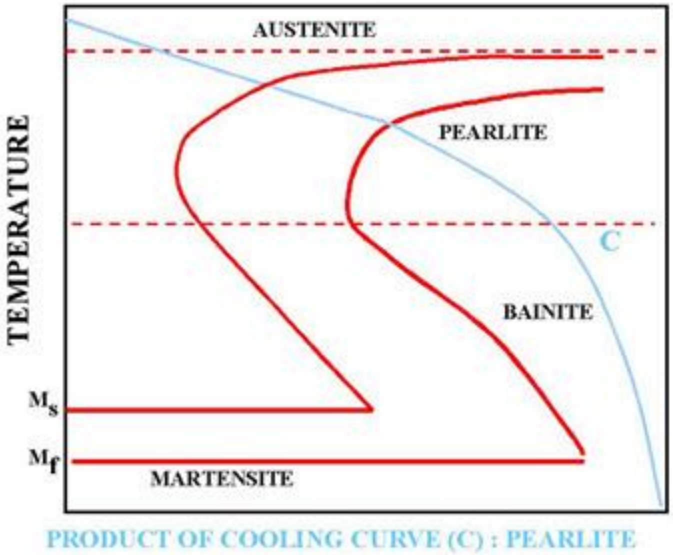


Fig.8.5. Slow cooling process (Annealing)

Processes of Annealing and Spheroidizing

There are two types of Critical Temperature according to the diagram iron-ironcarbide: ***LCT (Lower Critical Temperature) -*** line **PSK** (constant temperature 727 °C for all stell);

UCT (Upper Critical Temperature) **-** line **GSE** (temperature depends of carbon contain).

Full annealing is accomplished by heating a hypoeutectoid steel to a temperature ***above the UCT*** (Upper Critical Temperature). In practice, the steel is heated to about 30-50 °C above the UCT. It is then cooled in the furnace very slowly to room temperature. The formation of austenite destroys all structures that have existed before heating. Slow cooling yields the original phases of ferrite and pearlite.

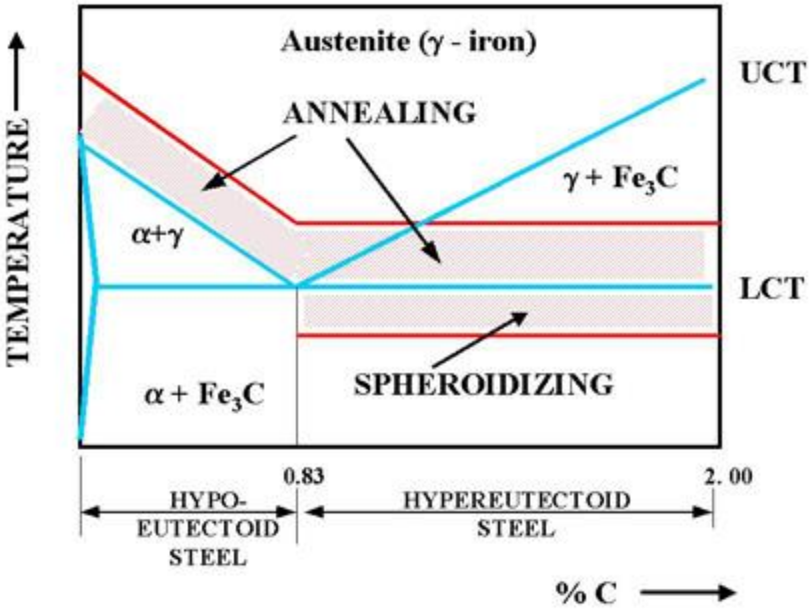


Fig. 8.6. Annealing and Spheroidizing Temperatures

Hypereutectoid steels consist of pearlite and cementite. The cementite forms a brittle network around the pearlite. This presents difficulty in machining the hypereutectoid steels. To improve the machinability of the annealed hypereutectoid steel spheroidize annealing is applied. This process will produce a spheroidal or globular form of a carbide in a ferritic matrix which makes the machining easy. Prolonged time at the elevated temperature will completely break up the pearlitic structure and cementite network. The structure is called spheroidite. This structure is desirable when minimum hardness, maximum ductility and maximum machinability are required.

Stress-Relief Annealing is sometimes called subcritical annealing, is useful in removing residual stresses due to heavy machining or other cold-working processes. It is usually carried out at temperatures below the LCT, which is usually selected around 600ºC.

Full annealing consists of (1) recovery (stress-relief), (2) recrystallization, (3) grain growth stages. Annealing reduces the hardness, yield strength and tensile strength of the steel.

Process of Normalizing

The ***normalizing*** of steel is carried out by heating approximately 30-50 ºC above the UCT (Upper Critical Temperature) followed by cooling in air to room temperature. Normalizing can be applied above the UCT for both hypoeutectoid and hypereutectoid steels. Fig.8.7 shows the normalizing temperatures.

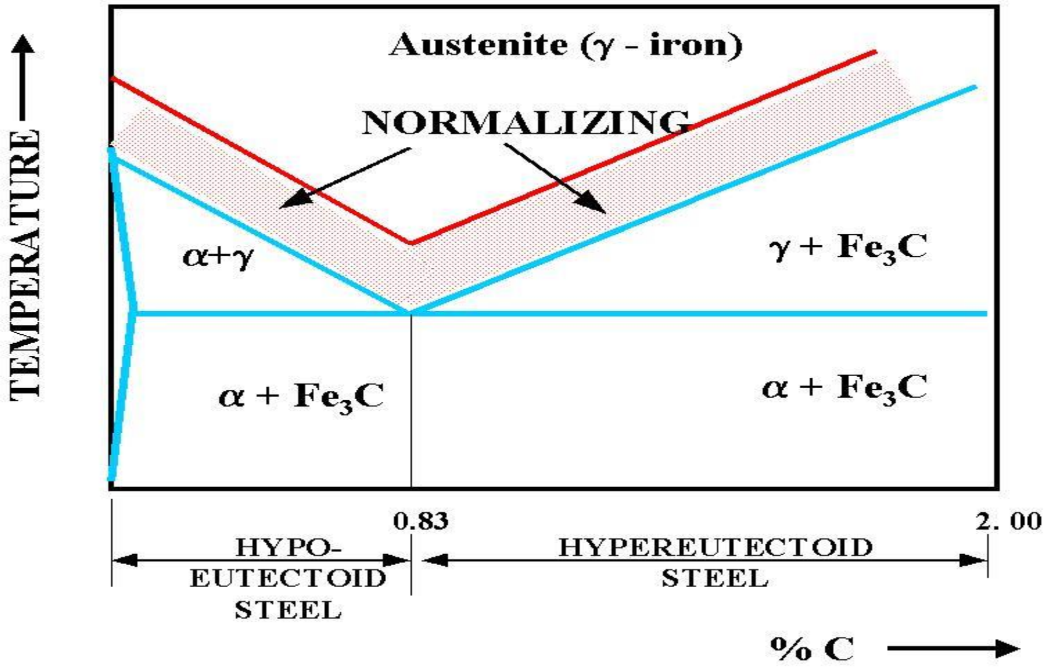


Fig.8.7. Normalizing temperatures for hypoeutectoid and hypereutectoid steels.

The following is the list of the reasons for normalizing the steel :

- To produce a harder and stronger steel than full annealing
- To improve the machinability
- To modify and refine the grain structure
- To obtain a relatively good ductility without reducing the hardness and strength

Annealing and normalizing do not present a significant difference on the ductility of low carbon steels. As the carbon content increases, annealing maintains the % elongation around 20%. On the other hand, the ductility of the normalized high carbon steels drop to 1 to 2 % level.

The tensile strength and the yield point of the normalized steels are higher than the annealed steels. Normalizing and annealing do not show a significant difference on the tensile strength and yield point of the low carbon steels. However, normalized high carbon steels present much higher tensile strength and yield point than those that are annealed.

The medium carbon steels can maintain similar hardness levels when normalized or annealed. However, when high carbon steels are normalized they maintain higher levels of hardness than those that are annealed.

Processes of Hardening and Tempering

Steels can be heat treated to high hardness and strength levels. Structural components subjected to high operating stress need the high strength of a hardened structure. Similarly, tools such as dies, knives, cutting devices, and forming devices need a hardened structure to resist wear and deformation.

Quenched hardened steels are so brittle that even slight impacts may cause fracture. ***Tempering*** is a heat treatment that reduces the brittleness of a steel without significantly lowering its hardness and strength. All hardened steels must be tempered before use.

QUENCH AND TEMPERING PROCESSES:

(1) Conventional Heat, Quench and Temper process
(2) Martempering
(3) Austempering

Conventional Heat, Quench and Temper Process:

Quench begins by conventional heating of a hypoeutectoid steel to a temperature to about 30-50ºC ***above the UCT*** (Upper Critical Temperature). Quench begins by heating of a hyperoeutectoid steel to a temperature ***above the LCT*** (Lower Critical Temperature). Then all steels are soaked and rapidly cooled. In this process, Austenite is transformed to Martensite as a result of rapid quench from furnace to room temperature. Then, martensite is heated to a temperature which gives the desired hardness. As the metal cools, it also contracts and its microstructure occupies less volume. Extreme variations in size of metal parts complicate the work of the heat treater and should be avoided in the designing of metal parts. This means there is a limit to the overall size of parts that can be subjected to such thermal processing. Figure 8.8 shows the conventional hardening, tempering process.

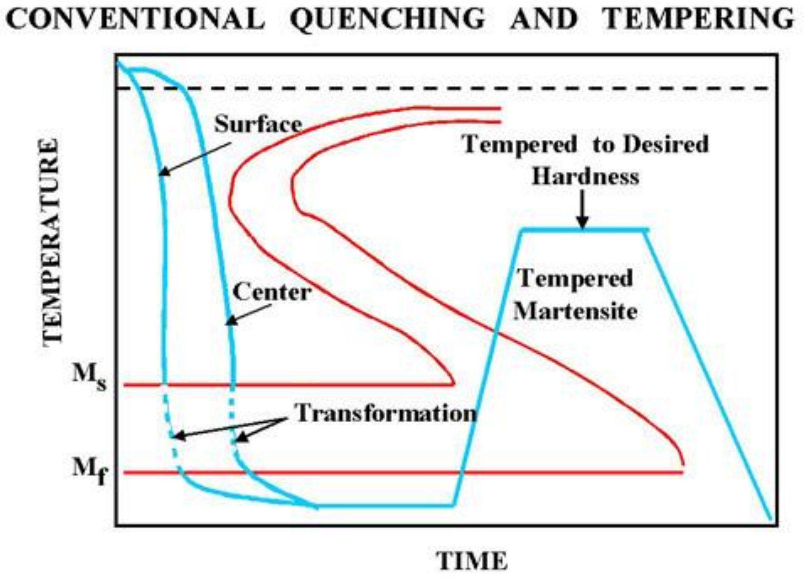


Fig.8.8. Conventional quenching and tempering process.

Martempering (Marquenching):

To overcome the restrictions of conventional quenching and tempering, Martempering process can be used. Martempering or marquenching permits the transformation of Austenite to Martensite to take place at the same time throughout the structure of the metal part. Then cooling is continued through the martensite region, followed by the usual tempering.

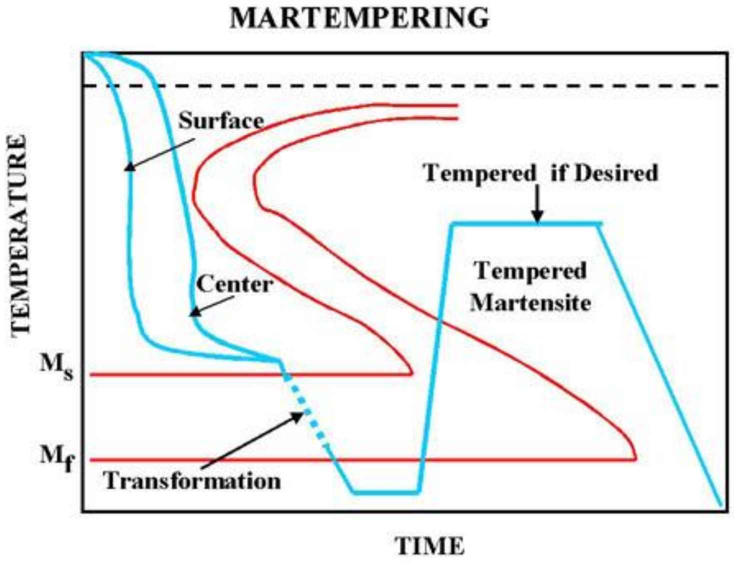


Fig.8.9. Martempering process

Austempering:

This is the second method that can be used to overcome the restrictions of conventional quench and tempering. The quench is interrupted at a higher temperature than for Martempering to allow the metal at the center of the part to reach the same temperature as the surface. By maintaining that temperature, both the center and the surface are allowed to transform to Bainite and are then cooled to room temperature.

Advantages of Austempering:

(1) Less distortion and cracking than martempering,

(2) No need for final tempering (less time consuming and more energy efficient)

(3) Improvement of toughness (impact resistance is higher than the conventional quench and tempering)

(4) Improved ductility

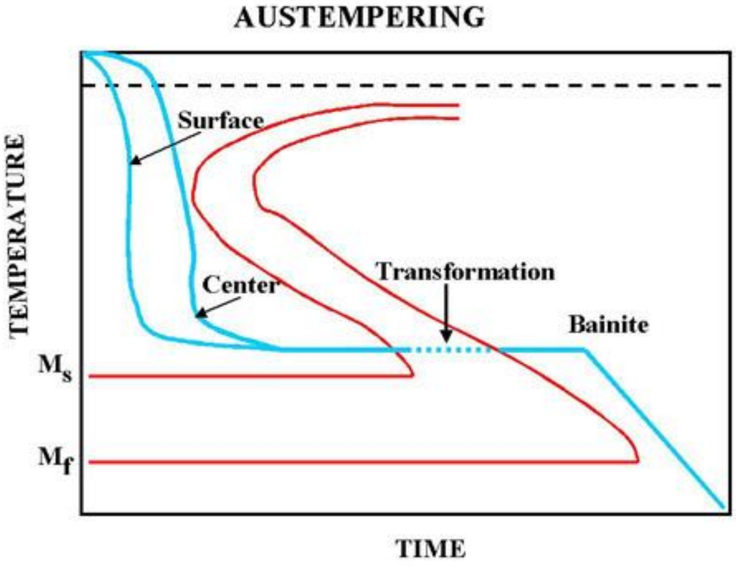


Fig.8.11. Austempering process.

In Austempering process, the end product is 100% bainite. It is accomplished by first heating the part to the properr austenitizing temperature followed by cooling rapidly in a slat bath which is maintained between 400 and 800 oF. The part is left in the bath until the transformation to bainite is complete. The steel is caused to go directly from austenite to bainite.

Materials and Equipment:

2. Specimen of the hypoeutectoid steel SAE 1040.
2. Microscope MM – 4.

Procedure:

1. Determine the carbon content of the steel SAE 1040.
2. Choose the temperature of the annealing, normalizing and quanch of this steel.
3. Define the major types of heat treatment processes.
4. Write conclusions about the difference between these processes.

Questions:

23. What properties or conditions of the steel change during the various types of heat treatment?
24. What are the major types of heat treatment processes?
25. Plot the TTT diagram.
26. What does the TTT diagram indicate?
27. What is the critical cooling rate?
28. What structure is formed during the slow cooling (annealing process)?
29. Show the upper and lower critical temperature on the $Fe\text{-}Fe_3C$ diagram.
30. What is the purpose of the spheroidizing process?
31. How to choose the normalizing temperature for hypo- and hypereutectoid steel?
32. What properties does the martensite have?
33. What transformation takes place during quench process?
34. What is the purpose of the tempering process?

Laboratory work № 8

HEAT TREATMENT OF STELL

PROTOCOL №1

<u>Define:</u>

Annealing____

____

____

Normalizing____

____

____

Quench____

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PROTOCOL №2

Steel	Carbon content, %	Critical temperature,ºC		Temperature of the processes, ºC		
SAE 1030		UCT		annealing	normalizing	quanch
		LCT				

Conclusions:

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Student’s signature Teacher’s signature

“____”____________20___ y. “____”_____________20___ y.

LABORATORY WORK № 9

CERAMICS

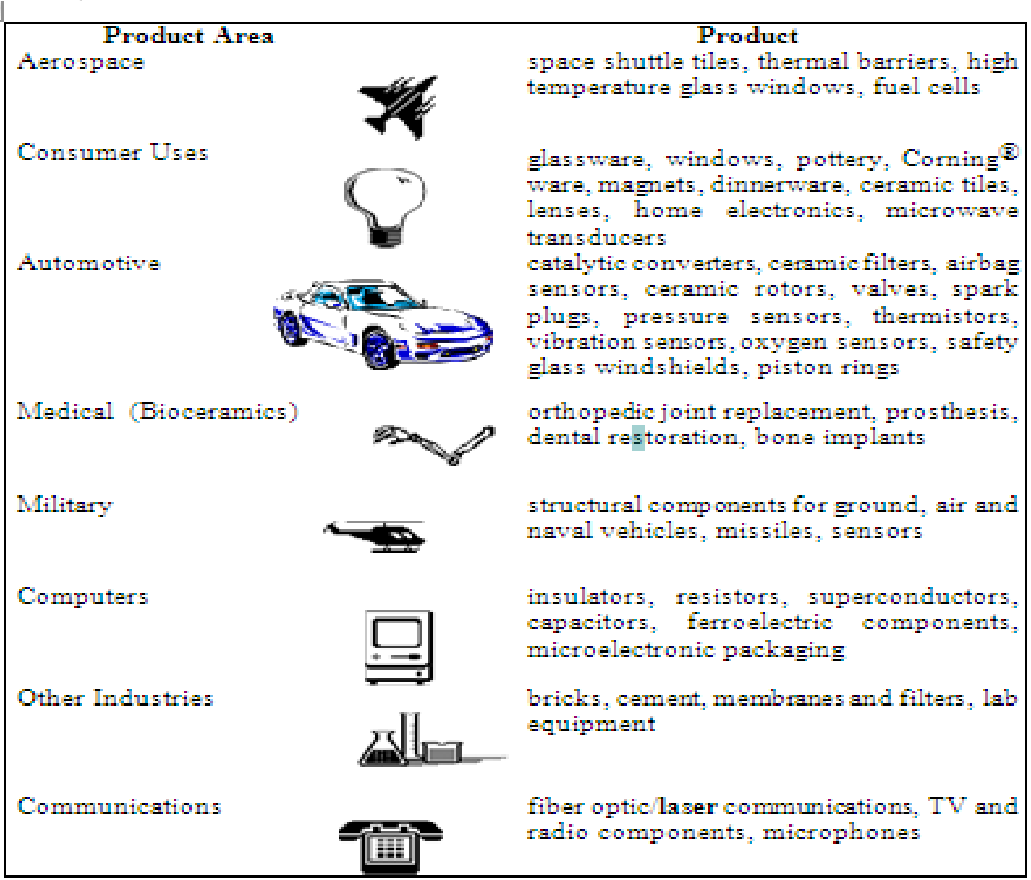
Objectives

1. To explore the ceramic materials through applications, properties, and processing.
2. To learn ceramic bonding mechanisms and how they influence properties.

Fundamental concept

Ceramics are materials that are composed of inorganic substances (usually a combination of metallic and nonmetallic elements). The electricity that kept that clock ticking all night was generated, stored, and traveled through a whole array of ceramic products such as transducers, resistors, and various **insulators**.

Ceramics can be divided into two classes: ***traditional and advanced***. Traditional ceramics include clay products, silicate glass and **cement**; while advanced ceramics consist of carbides (SiC), pure oxides (Al_2O_3), nitrides (Si_3N_4), non-silicate glasses and many others. Ceramics offer many advantages compared to other materials. They are harder and stiffer than steel; more heat and corrosion resistant than metals or polymers; less dense than most metals and their alloys; and their raw materials are both plentiful and inexpensive. Ceramic materials display a wide range of properties which facilitate their use in many different product areas.



Product Area	Product
Aerospace	space shuttle tiles, thermal barriers, high temperature glass windows, fuel cells
Consumer Uses	glassware, windows, pottery, Corning® ware, magnets, dinnerware, ceramic tiles, lenses, home electronics, microwave transducers
Automotive	catalytic converters, ceramic filters, airbag sensors, ceramic rotors, valves, spark plugs, pressure sensors, thermistors, vibration sensors, oxygen sensors, safety glass windshields, piston rings
Medical (Bioceramics)	orthopedic joint replacement, prosthesis, dental restoration, bone implants
Military	structural components for ground, air and naval vehicles, missiles, sensors
Computers	insulators, resistors, superconductors, capacitors, ferroelectric components, microelectronic packaging
Other Industries	bricks, cement, membranes and filters, lab equipment
Communications	fiber optic/laser communications, TV and radio components, microphones

Atomic Bonding:

Two types of bonding mechanisms occur in ceramic materials, **ionic** and **covalent**. Often these mechanisms co-exist in the same ceramic material. Each type of bond leads to different characteristics.

Ionic bonds most often occur between metallic and nonmetallic elements that have large differences in their **electronegativities**. Ionically-bonded **structures** tend to have rather high melting points, since the bonds are strong and non-directional.

The other major bonding mechanism in ceramic structures is the covalent bond. Unlike ionic bonds where electrons are transferred, atoms bonded covalently share electrons. Usually the elements involved are nonmetallic and have small electronegativity differences.

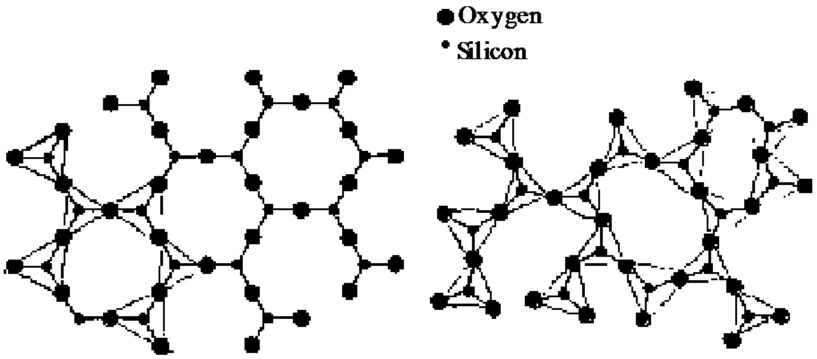
Many ceramic materials contain both ionic and covalent bonding. The overall properties of these materials depend on the dominant bonding mechanism. Compounds that are either mostly ionic or mostly covalent have higher melting points than compounds in which neither kind of bonding predominates.

Table 9. 1: Comparison of % Covalent and Ionic character with several ceramic compound's melting points.

Ceramic Compound	**Melting Point ˚C**	**% Covalent character**	**% Ionic character**
Magnesium Oxide	2798	27%	73%
Aluminum Oxide	2050	37%	63%
Silicon Dioxide	1715	49%	51%
Silicon Nitride	1900	70%	30%
Silicon Carbide	2500	89%	11%

Classification ceramic materials by structure

Ceramic materials can be divided by structure into two classes: **crystalline** and **amorphous** (**noncrystalline**). In crystalline materials, a **lattice** point is occupied either by atoms or ions depending on the bonding mechanism. These atoms (or ions) are arranged in a regularly repeating pattern in three dimensions. In contrast, in amorphous materials, the atoms exhibit only short-range order. Some ceramic materials, like silicon dioxide (SiO_2), can exist in either form. A crystalline form of SiO_2 results when this material is slowly cooled from a temperature. Rapid cooling favors noncrystalline formation since time is not allowed for ordered arrangements to form.



Crystalline Silicon dioxide
(regular pattern)

Amorphous Silicon dioxide
(random pattern)

Fig. 9.1. Comparison in the physical strucuture of both crystalline and amorphous Silicon dioxide.

The type of bonding (ionic or covalent) and the internal structure (crystalline or amorphous) affects the properties of ceramic materials.

Mechanical Properties

Ceramics are strong, hard materials that are also resistant to corrosion (durable). These properties, along with their low densities and high melting points, make ceramics attractive structural materials.

The principal limitation of ceramics is their brittleness, i.e., the tendency to fail suddenly with little plastic deformation. This is of particular concern when the material is used in structural applications. In metals, the delocalized electrons allow the atoms to change neighbors without completely breaking the bond structure. This allows the metal to deform under stress. Work is done as the bonds shift during deformation. But, in ceramics, due to the combined ionic and covalent bonding mechanism, the particles cannot shift easily. The ceramic breaks when too much force is applied, and the work done in breaking the bonds creates new surfaces upon cracking.

Brittle fracture occurs by the formation and rapid propagation of cracks. In crystalline solids, cracks grow through the grains (transgranular) and along cleavage planes in the crystal. The resulting broken surface may have a grainy or rough texture. Amorphous materials do not contain grains and regular crystalline planes, so the broken surface is more likely to be smooth in appearance.

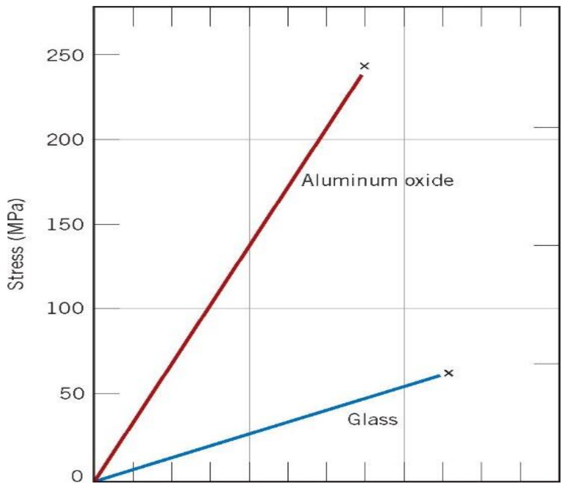


Fig. 9.2.Typical stress-strain behavior to fracture for aluminum oxide and glass.

The theoretical strength of a material is the tensile stress that would be needed to break the bonds between atoms in a perfect solid and pull the object apart. But all materials, including ceramics, contain minuscule structural and fabrication flaws that make them significantly weaker than the ideal strength. Any flaw, such as a pore, crack, or inclusion, results in stress concentration, which amplifies the applied stress. Pores also reduce the cross-sectional area over which a load is applied. Thus, denser, less porous materials are generally stronger. Similarly, the smaller grain size the better the mechanical properties.

In fact, ceramics are the strongest known monolithic materials, and they typically maintain a significant fraction of their strength at elevated temperatures. For example, silicon nitride (Si_3N_4, = 3.5 g/cm3) turbocharger rotors have a fracture strength of 830 MPa at 22 ° C and 560 MPa at 1200 ° C.

Compressive strength is important in ceramics used in structures such as buildings or refractory bricks. The compressive strength of a ceramic is usually much greater than their tensile strength. To make up for this, ceramics are sometimes prestressed in a compressed state. Thus, when a ceramic object is subjected to a tensile force, the applied load has to overcome the compressive stresses (within the object) before additional tensile stresses can increase and break the object.

Safety glass (thermal tempered glass) is one example of such a material. Ceramics are generally quite inelastic and do not bend like metals. The ability to deform reversibly is measured by the elastic modulus. Materials with strong bonding require large forces to increase space between particles and have high values for the modulus of elasticity. In amorphous materials, however, there is more free space for the atoms to shift to under an applied load. As a result, amorphous materials such as glass are more easily flexed than crystalline materials such as alumina or silicon nitride.

The fracture toughness is the ability to resist fracture when a crack is present. It depends on the geometry of both the object and the crack, the applied stress, and the length of the crack. Composites are being developed which retain the desirable properties of the ceramics while reducing their tendency to fracture. For example, the introduction of carbon fiber whiskers inhibits crack propagation through a ceramic and improves toughness.

Glass ceramics such as those that are used to make ovenware are composed of a matrix of glass in which tiny ceramic crystals grow, such that the final matrix is actually composed of fine crystalline grains (average size < 500 nm). Because their grain size is so small, these materials are transparent to light. The presence of the crystals improves the mechanical and thermal properties of the glass--the glass ceramics are strong, resistant to thermal shock, and good thermal conductors.

Thermal Properties

The most important thermal properties of ceramic materials are heat capacity, thermal expansion coefficient, and thermal conductivity. Many applications of ceramics, such as their use as insulating materials, are related to these properties.

Thermal energy can be either stored or transmitted by a solid. The ability of a material to absorb heat from its surrounding is its **heat capacity**. In solid materials at T > 0 K, atoms are constantly vibrating. The **atomic vibrations** are also affected by the vibrations of adjacent atoms through bonding. Hence, vibrations can be transmitted across the solid.

Ceramics generally have strong bonds and light atoms. Thus, they can have high frequency vibrations of the atoms with small disturbances in the crystal lattice. The result is that they typically have both high heat capacities and high melting temperatures.

Although the thermal conductivity is affected by faults or defects in the crystal structure, the insulating properties of ceramics essentially depend on microscopic imperfections. The transmission of either type of wave (phonon or photon) is interrupted by **grain** boundaries and pores, so that more porous materials are better insulators. The use of ceramic insulating materials to line kilns and industrial furnaces are one application of the insulating properties of ceramic materials.

The electron mechanism of heat transport is relatively unimportant in ceramics because charge is localized. This mechanism is very important, however, in metals which have large numbers of free (delocalized) electrons

Table 9.2: Comparison of thermal properties of different ceramic materials.

Material	**Melting Temp.(^{o}C)**	**Heat Capacity (J/kg·K)**	**Coefficient of Linear Expansion 1/^{o}Cx10^{-6}**	**Thermal Conductivity (W/m·K)**
Aluminum metal	660	900	23.6	247
Copper metal	1063	386	16.5	398
Alumina	2050	775	8.8	30.1
Fused silica	1650	740	0.5	2.0
Soda-lime glass	700	840	9.0	1.7

Ceramic Processing:

Processing of ceramic materials describes the way in which ceramic objects (e.g., glass windows, turbocharger rotor blades, optical fibers, capacitors) are produced.

Processing begins with the raw materials needed to produce the finished components, and includes many individual steps that differ significantly depending on the type of ceramic material, crystalline versus glass.

Processing of Crystalline Ceramics	**Glass Processing**
Raw Material Selection	Raw Material Selection
Preparation	Melting
Consolidation	Pouring
Sintering	**Annealing**

Raw material selection involves obtaining and preparing the right materials for the final product. Traditional ceramics use various forms of clay. Glass makers start with primarily silica.

For crystalline ceramics, the characteristics of the raw materials (powders) such as their particle size and purity are very important as they affect the structure (e.g., grain size) and properties (e.g., strength) of the final component. Since strength increases with decreasing grain size, most starting powders are milled (or ground) to produce a fine powder (diameter < 1 µm). Since dry powders are difficult to shape, processing additives like water, polymers, etc. are added to improve their plasticity.

Consolidation involves forming the ceramic mixture into the specified shape. There are many techniques available for this step. Sintering is the final step in the process. Sintering at high temperatures (800˚ to 1800˚ C) causes densification that gives the ceramic product its strength and other properties. During this process, the individual ceramic particles coalesce to form a continuous solid network and pores are eliminated. Typically, the **mictrostructure** of the sintered product contains dense grains, where an individual grain is composed of many starting particles.

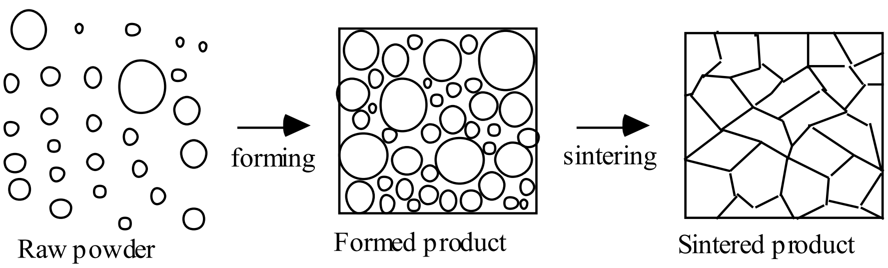
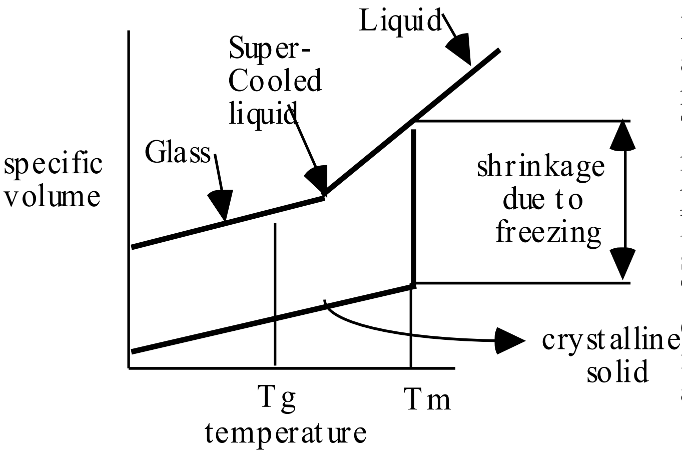


Fig. 9.3. Microstructure of raw, formed, and sintered ceramic products

Glass processing is different from crystalline processing. One of the considerations that must be examined is the solidifying behavior of glass. Glasses are most commonly made by rapidly quenching a melt. This means that the elements making up the glass material are unable to move into positions that allow them to form the crystalline regularity. The result is that the glass structure is disordered or amorphous.

One of the most notable characteristics of glasses is the way they change between solid and liquid states. Unlike crystals, which transform abruptly at a precise temperature (i.e., their melting point) glasses undergo a gradual transition. Between the melting temperature (T_m) of a substance and the so-called **glass transition temperature (T_g)**, the substance is considered a **supercooled** liquid. When glass is worked between T_g and T_m, one can achieve virtually any shape. The glass blowing technique is a demonstration of the ability to deform a glass.



In the area between T and Tm, the crystallin material remains solid The amorphous (glass material however, passes through a phas known as a super-cooled liquid. This is when the glass can be easily deforme if the applied stresses are sufficiently high.

Fig. 9.4. Temperature graph for a typical ceramic material

Glass processing does not require an optimum size particle (although smaller pieces melt faster). The selections of glass raw materials and chemical additives (which, for example, can alter the color of the glass) are heated up (700° - 1600° C), melted and finally poured onto or into a quick-cool form or plate. There are four different forming techniques used to fabricate glass.

Technique	**Application**
Pressing	Table ware
Blowing	Jars
Drawing	Windows
Fiber forming	Fiber optics

During the glass formation, there may be stresses that have been introduced by rapid cooling or special treatments that the glass needs (such as layering or strengthening). Additional heat treatment is needed to “heal” the glass. Annealing, in which the glass is heated to the **annealing point** (a temperature just below the **softening point**) and then slowly cooled to room temperature, is one such process. Tempering is also a follow-up heat treatment in glass processing in which the glass is reheated and cooled in oil or a jet of air so that the internal and external parts have different properties. The tempering reduces the tendency of glass to fail. Tempered glass can then be used in conditions prone to stresses like car windows.

Materials and Equipment:

1. Simples of ceramic beams and glasses.
2. Ruler.
3. Weight.

Procedure:

1. Measure the ceramic beam‘s mass, length, width, and thickness. Record.
2. Calculate the ceramic beam’s density.
3. Write chemical composition, atomic bonding, structure, according to the literature indicate mechanical properties and applications of the ceramic.
4. Measure the glasses mass, length, width, and thickness. Record.
5. Calculate the glasses density.
6. Write chemical composition, atomic bonding, structure, according to the literature indicate mechanical properties and applications of the glasses.
7. Fill the protocol report.

Questions:

1. What is ceramic? Describe traditional and advanced ceramics.
2. Applications of ceramics.
3. Explain two types of bonding mechanisms occur in ceramic materials.
4. Classification ceramic materials by structure.
4. Describe mechanical properties of ceramic.
5. Describe thermal properties of ceramic.
6. Describe electrical properties of ceramic.
7. Processing of Crystalline Ceramics.
8. Why glass processing is different from crystalline processing?
9. List different forming techniques used to fabricate glass.
10. Which reasons of glass heat treatment?

LABORATORY WORK 9
CERAMICS
PROTOCOL №1
Ceramic

Chemical composition, % wt.____

Atomic bonding____
Structure____
Processing ____

Mechanical properties:

Yield Strength**,** MPa ________________________________
Tensile strength, MPa ________________________________
Elongation, % ____

Mass, g	Length, mm	Width, mm	Thickness, mm	Volume, mm^3	Density. g/mm^3

Applications:____
____

PROTOCOL №2
Glass

Chemical composition, % wt.____

Atomic bonding____
Structure____
Processing ____

Mechanical properties:

Yield Strength**,** MPa ________________________________
Tensile strength, MPa ________________________________
Elongation, % ____

Mass, g	Length, mm	Width, mm	Thickness, mm	Volume, mm^3	Density. g/mm^3

Applications:____

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Conclusion:

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Student’s signature   Teacher’s signature

“____”____________20___ y.   “____”_____________20___ y.

LABORATORY WORK № 10

POLYMERS

Objectives

1. To learn classes of polymers, their applications and processing.
2. To compare mechanical properties of some thermoplastics

Scientific principles

Plastics are commonly known as synthetic resins or polymers. The term polymer comprises ‘poly’ means ‘many’ and ‘mers’ means ‘parts’. Thus, the term, polymer represents a substance built up of several repeating units, each unit being known as a monomer. Thousands of such units or monomers join together in a polymerization reaction to form a ‘polymer’.

Polymers are substances containing a large number of structural units joined by the same type of linkage. These substances often form into a chain-like structure. Polymers in the natural world have been around since the beginning of time. Starch, cellulose, and rubber all possess polymeric properties. Today, the polymer industry has grown to be larger than the aluminum, copper and steel industries combined.

Applications of Polymers

Polymers already have a range of applications that far exceeds that of any other class of material available to man. Current applications extend from adhesives, coatings, foams, and packaging materials to textile and industrial fibers, **elastomers,** and structural plastics. Polymers are also used for most **composites**, electronic devices, biomedical devices, optical devices, and precursors for many newly developed high-tech ceramics.

Agriculture and Agribusiness

Polymeric materials are used in and on soil to improve aeration, provide mulch, and promote plant growth and health.

Medicine

Many biomaterials, especially heart valve replacements and blood vessels, are made of polymers like Dacron, Teflon and polyurethane.

Consumer Science

Plastic containers of all shapes and sizes are light weight and economically less expensive than the more traditional containers. Clothing, floor coverings, garbage disposal bags, and packaging are other polymer applications.

Industry

Automobile parts, windshields for fighter planes, pipes, tanks, packing materials, insulation, wood substitutes, adhesives, matrix for composites, and elastomers are all polymer applications used in the industrial market.

Sports

Playground equipment, various balls, golf clubs, swimming pools, and protective helmets are often produced from polymers.

Properties of plastics

1. Plastics are light in weight and at the same time they possess good toughness strength

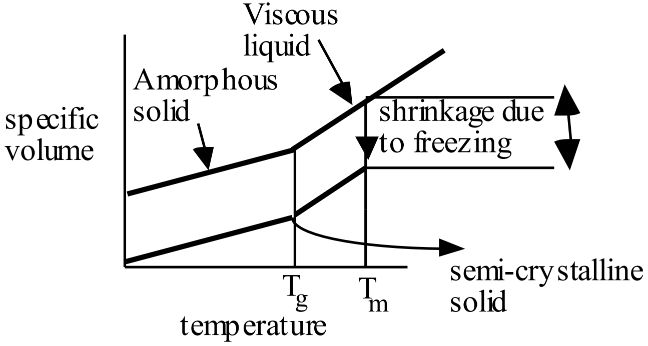
and rigidity.

2. They are less brittle than glass, yet they can be made equally transparent and smooth.
3. Their high dielectric strength makes them suitable for electric insulation.
4. They resist corrosion and the action of chemicals.
5. The ease with which they can be mass-produced contributes greatly to their popularity as wrappers and bags.
6. They possess the property of low moisture absorption.
7. They can be easily molded to desired shapes.
8. They can easily be made colored.
9. They are bad conductance of heat.
10. They are hard, rigid and heat resistance.
11. They possesses good deformability, good resiatance against weather conditions, good colorability, good damping characteristics and good resistance to peeling.

Polymer Physical Structure

Segments of polymer molecules can exist in two distinct physical structures. They can be found in either **crystalline** or **amorphous** forms. Crystalline polymers are only possible if there is a regular chemical structure (e.g., homopolymers or alternating copolymers), and the chains possess a highly ordered arrangement of their segments. Crystallinity in polymers is favored in symmetrical polymer chains, however, it is never 100%. These semi-crystalline polymers possess a rather typical liquefaction pathway, retaining their solid state until they reach their melting point at **T_m**.

Amorphous polymers do not show order. The molecular segments in amorphous polymers or the amorphous **domains** of semi-crystalline polymers are randomly arranged and entangled. Amorphous polymers do not have a definable **T_m** due to their randomness. At low temperatures, below their glass transition temperature **(T_g)**, the segments are immobile and the sample is often brittle. As temperatures increase close to **T_g**, the molecular segments can begin to move. Above **T_g**, the mobility is sufficient (if no crystals are present) that the polymer can flow as a highly viscous liquid. The **viscosity** decreases with increasing temperature and decreasing molecular weight. These effects can most easily be seen on a specific volume versus temperature graph.



In the are between Tg and Tm, the semi-crystalline polymer is a tough solid. The amorphous material changes to a viscous liquid after Tg. This is when the material can be easily deformed.

Fig.10.1. Specific Volume versus Temperature graph.

Classification of Plastics

Plastics are broadly classified into **thermo plastics** and **thermo-setting plastics**.

Polymers can be separated into two different groups depending on their behavior when heated. Polymers with linear molecules are likely to be **thermoplastic**. These are substances that soften upon heating and can be remolded and recycled. They can be semi-crystalline or amorphous. The other group of polymers is known as **thermosets**. These are substances that do not soften under heat and pressure and cannot be remolded or recycled. They must be remachined, used as fillers, or incinerated to remove them from the environment.

Thermo Plastics

Those plastics which can be easily softened again and again by heating are called **thermoplastic**. They can be reprocessed safely. They retain their plasticity at high temperature, i.e. they preserve an ability to be repeatedly formed by heat and pressure. Therefore, they can be heated and reshaped by pressing many times. On cooling they become hard. They can be very easily shaped into tubes, sheets, films, and many other shapes as per the need.

Thermoplastics are generally carbon containing polymers synthesized by addition or condensation polymerization. This process forms strong **covalent bonds** within the chains and weaker secondary **Van der Waals** bonds between the chains. Usually, these secondary forces can be easily overcome by thermal energy, making thermoplastics moldable at high temperatures. Thermoplastics will also retain their newly reformed shape after cooling.

Types of Thermo Plastics

Amorphous: Polystyrene, Acrylonitrite-butadiene-styrene. Mrthacrylate. P.V.C (Polyvinyl chloride), Polychloroacetal, Polycarbonate etc.

Crystalline: Polyethylene, Polyamides, Polyacetal.Polypropylene

The reason for the re-softening of thermoplastic resins with heat is that they are composed of linear or long chain molecules. Application of heat weakens the intermolecular bonds by increasing thermal agitation of the molecules, and the material softens and thus plastic can be easily molded and remolded without damage

Thermo-Setting Plastics

Those plastics which are hardened by heat, effecting a non-reversible chemical change, are called **thermo-setting**. Alternatively these plastics materials acquire a permanent shape when heated and pressed and thus cannot be easily softened by reheating.

Thermosets have the same Van der Waals bonds that thermoplastics do. They also have a stronger linkage to other chains. Strong covalent bonds chemically hold different chains together in a thermoset material. The chains may be directly bonded to each other or be bonded through other molecules. This "cross-linking" between the chains allows the material to resist softening upon heating. Thus, thermosets must be machined into a new shape if they are to be reused or they can serve as powdered fillers.

Although thermosets are difficult to reform, they have many distinct advantages in engineering design applications including:

1.High thermal stability and insulating properties.
2.High rigidity and dimensional stability.
3.Resistance to creep and deformation under load.
4.Light-weight.

Thermosetting resins: Phenol-formaldehyde resins, Polyester resins, Epoxy resins, Silicone resins

Thermosetting resins cannot be softened again by the application of heat. The reason for the above phenomenon is that the thermosetting plastics consist of linear, relatively low molecular weight thermoplastic polymer chains with cross-links which bond the chains together with primary valence bonds.

Other thermosetting compounds are phenol furfural, polysters, alkyds, and polyurethanes. The most common thermosetting compound is phenol formaldehyde. Phenol formaldehyde is called as bakelite due to the name of its inventor Bakelite. It is the most commonly and widely used plastic. It is made by the reaction of phenol with formaldehyde.

Comparison Between Thermo Plastic and Thermosetting Plastic

The comparison between thermo plastic and thermosetting plastic is given in Table 9.1.

Table 9.1. Comparison between Thermo Plastic and Thermosetting Plastic

S.No	Thermo Plastic	Thermosetting Plastic
1	They can be repeatedly softened by heat and hardened by cooling.	Once hardened and set, they do not soften with the application
2	They are comparatively softer and less strong.	They are more stronger and harder than thermoplastic resins
3	Objects made by thermoplastic resins can not be used at comparatively higher temperature as they will tend to soften under heat.	Objects made by thermosetting resins can be used at comparatively higher temperature without damage
4	They are usually supplied as granular material	They are usually supplied in monomeric or partially polymerized material form in which they are either liquids or partially thermoplastic solids.
5	Applications. Toys, combs, toilet goods, photographic films, insulating tapes, hoses, electric insulation, etc.	Applications. Telephone receivers, electric plugs, radio and T.V. cabinets, camera bodies, automobile parts, tapes, hoses, circuit breaker switch

Additions in Polymer

To make polymer more for further processing of products, plastics, and some other material are added to the polymers before or during polymerization. These materials are

Catalysts

They are also known accelerator or hardener. They act as catalysts to accelerate the chemical reactions during polymerization of plastics.

Fillers

Fillers are added to synthetic resins for increasing strength, stiffness and thermal resistance of the plastics. These are clay, talc, alumina, carbon black, calcium carbonate, wood flour, mica, quartz, asbestos, glass fibres etc.

Modifiers

Modifiers are added to plastics for improving mechanical properties

Plasticizers

Plasticizers are fluids of high molecular weight. They are added for softening the resins at forming temperature and to improve their toughness at the finished stage and to impart flexibility to their finished products.

Stabilizers

The additions of stabilizers to plastics help in preventing deterioration due to the action of heat and light.

Initiators

Initiators help in starting the reaction i.e. polymerization.

Dyes and pigments

Dyes and pigments are the coloring agents, added to impart different colors and shades to plastic materials.

Polymer Processing

There are five basic processes to form polymer products or parts. These include; injection molding, compression molding, transfer molding, blow molding, and extrusion. Compression molding and transfer molding are used mainly for thermosetting plastics. Injection molding, extrusion and blow molding are used primarily with thermoplastics.

Table 9.2: Comparison of polymer processing techniques for thermoplastics and thermosets.

Process	Thermoplastic (TP) or Thermoset (TS)	Advantages	Disadvantages
Injection Molding	TP, TS	It has the most precise control of shape and dimensions, is a highly automatic process, has fast cycle time, and the widest choice of materials.	It has high capital cost, is only good for large numbers of parts, and has large pressures in mold (20,000 psi).
Compression Molding	TS	It has lower mold pressures (1000 psi), does minimum damage to reinforcing fibers (in composites), and large parts are possible.	It requires more labor, longer cycle than injection molding, has less shape flexibility than injection molding, and each charge is loaded by hand.
Transfer Molding	TS	It is good for encapsulating metal parts and electronic circuits.	There is some scrap with every part and each charge is loaded by hand.
Blow Moldng	TP	It can make hollow parts (especially bottles), stretching action improves mechanical properties, has a fast cycle, and is low labor.	It has no direct control over wall thickness, cannot mold small details with high precision, and requires a polymer with high melt strength.
Extrusion	TP	It is used for films, wraps, or long continuos parts (ie. pipes).	It must be cooled below its glass transition temperature to maintain stability.

Table 9.3. Major Plastic Resins and Their Uses

Resin Code	Resin Name	Common Uses	Examples of Recycled Products

1	Polyethylene Terephthalate (PET or PETE)	Soft drink bottles, peanut butter jars, salad dressing bottles, mouth wash jars	Liquid soap bottles, strapping, fiberfill for winter coats, surfboards, paint brushes, fuzz on tennis balls, soft drink bottles, film
2	High density Polyethylene (HDPE)	Milk, water, and juice containers, grocery bags, toys, liquid detergent bottles	Soft drink based cups, flower pots, drain pipes, signs, stadium seats, trash cans, re-cycling bins, traffic barrier cones, golf bag liners, toys
3	Polyvinyl Chloride or Vinyl (PVC-V)	Clear food packaging, shampoo bottles	Floor mats, pipes, hoses, mud flaps
4	Low density Polyethylene (LDPE)	Bread bags, frozen food bags, grocery bags	Garbage can liners, grocery bags, multi purpose bags
5	Polypropylene (PP)	Ketchup bottles, yogurt containers, margarine, tubs, medicine bottles	Manhole steps, paint buckets, videocassette storage cases, ice scrapers, fast food trays, lawn mower wheels, automobile battery parts.
6	Polystyrene (PS)	Video cassette cases, compact disk jackets, coffee cups, cutlery, cafeteria trays, grocery store meat trays, fast-food sandwich container	License plate holders, golf course and septic tank drainage systems, desk top accessories, hanging files, food service trays, flower pots, trash cans

Materials and Equipment:

1. Samples of the Thermoplastic (TP) or Thermoset (TS).
2. Ruler.
3. Weight.
4. Brinell Testing Machine.

Procedure:

1. Measure the Thermoplastic mass, length, width, and thickness. Record.
2. Calculate the Thermoplastic density.
3. Write chemical composition, structure, according to the literature indicate mechanical properties and applications of the Thermoplastic.
4. Measure the Thermoset mass, length, width, and thickness. Record.
5. Calculate the Thermoset density.
6. Write chemical composition, structure, according to the literature indicate mechanical properties and applications of the Thermoset.
7. Find the hadness of the Thermoplastic and Thermoset by converting the diameter of the impression to Brinell Hardness Number (BHN).
8. Write the results of every measuring in the protocol.
9. Write to average of the three reading BHN values.
10. Fill in the protocol report.

Questions:

1.What is plastics?
2. What is polymers? List natural and synthetic polymers.
3.Applications of polymers.
4.Describe properties of plastics.
5.Explain polymer Physical Structure.
6.Classification of plastics.
7. What is Thermoplastics? Name any and describe their.
8.What is Thermosets? Name any and describe their.
9.Comparison Between Thermo Plastic and Thermosetting Plastic.

10.What will happen when we heating Thermoplastics?

11.What will happen when we heating Thermosets?

12. List the additions in polymer.

13.List polymer processing.

LABORATORY WORK 10

POLYMERS

PROTOCOL №1

Thermoplastic

Name

Structure____

Processing ____

Mechanical properties:

Yield Strength**,** MPa _________________________

Tensile strength, MPa _________________________

Elongation, % ______________________________

Mass, g	Length, mm	Width, mm	Thickness, mm	Volume, mm^3	Density. g/mm^3

Applications:_______________________________________

____

PROTOCOL №2

Thermoset

Name

Structure____

Processing ____

Mechanical properties:

Yield Strength**,** MPa _________________________

Tensile strength, MPa _________________________

Elongation, % ______________________________

Mass, g	Length, mm	Width, mm	Thickness, mm	Volume, mm^3	Density. g/mm^3

Applications:_______________________________________

____

Protocol №3
Hardness Brinell test

Plastic	*D*, mm	Load *P*, N	d_{i}, mm	BHN, MPa	Average BHN, MPa

Conclusion:

____

____

____

____

____

____

Student’ssignature   Teacher’s signature
“____”___________20___ y.   “____”____________20___ y.

Glossary Metals

alloy: a substance that has metallic properties and is made up of two or more chemical elements, of which at least one is a metal.

annealing: a heat treatment of a metal designed to produce a soft, ductile condition. Typically the metal is heated and allowed to cool slowly.

anode: electrode at which electrons are released during corrosion. The half reaction at the anode is called oxidation and the metal is said to be oxidized. The anode is the electrode that disintegrates during corrosion.

bronze: An alloy composed of tin and copper.

cathode: electrode which accepts electrons during corrosion. The half reaction at the cathode is called reduction and the metal is said to be reduced. The cathode is not destroyed during corrosion.

cathodic protection: a more active metal is placed next to a less active metal. The more active metal will serve as an anode and will be corroded instead of the less active metal. The anode is then called a sacrificial anode.

cold-working: a permanent deformation of a metal below its crystallization temperature. Deforming the metal creates more dislocations which entangle, pinning them and thereby strengthening the metal.

corrosion: oxidation-reduction reaction where electrons are released at the anode and taken up at the cathode.

dislocations: linear defects in a crystal.

ductile: can be drawn or stretched into wire and other shapes.

elastic deformation: materials return to their original shape after a small load or stress is applied.

face-centered cubic: crystal arrangement of close-packed layers of particles where three layers of particles alternate positions. This layering is known as ABCABC.

failure: ultimate separation of metal parts due to applied loads. i.e. it breaks.

fatigue: the application and release of stresses as metal is used which cause small cracks to grow, during many cycles of application, until they fracture.

grain: a crystal (ordered arrangement of atoms).

grain boundary: the interface between the grains or crystals.

Hall Process: an electrolytic technique to refine aluminum from its ore.

hardening: heating and rapidly cooling steel.

heat treating: modification of properties and structure of alloys by specific heating and cooling cycles.

hexagon closest packing (HCP): crystal arrangement of layers of particles where two layers alternate positions. The layering is known as ABAB.

malleable: can be hammered into a sheet.

martensite: a super-saturated solid solution of carbon in ferrite. The carbon atoms distort the BCC ferrite into a BC-tetragonal structure.

metallic bonding: bond formed by positive ions surrounded by a cioud of valence electrons.

ore: a natural mineral deposit that contains enough valuable minerals to make it profitable to mine at the current technology.

oxide: a compound of oxygen with some other chemical element.

oxidation: the half of an electrochemical reaction where electrons are released. Oxidation occurs at the electrode called the anode.

pinned: the dislocations in a crystal get tangled or attached to atoms of an alloying agent.

plastic deformation: materials remain deformed after a load is added and then removed.

quenched: cooled rapidly.

reduction: the half of an electrochemical reaction where electrons are taken up. Reduction occurs at the cathode.

reduction of metals: changing a metal ion to a neutral atom by the addition of electrons.

steel: an iron-carbon alloy, malleable in some temperature range as initially cast. Steel usually contains some other alloying elements such as silicon, manganese, etc. as well as impurities such as sulfur and phosphorus.

strength: a measure of the ability of a material to support a load.

stress: the internal forces produced by application of an external load, tending to displace component parts of the stressed material. It is defined as the force (load) divided by the area on which it acts.

toughness: the ability to aborb energy of deformation without breaking. High toughness requires both high strength and high ductility.

unit cell: The smallest repeating array of atoms in a crystal.

GLOSSARY Ceramic

Abrasive: A hard material used to grind, cut or wear.

Absorption: The inclusion of the energy of a photon within a substance.

Amorphous: A noncrystalline substance, atoms lack long range order.

Annealing: Heat treatment to alter properties.

Annealing point (glass): Temperature at which stresses are removed.

Brittle fracture: A break that occurs by rapid crack propagation.

Capacitance (C): Charge storing capability.

Cement: A material that binds particles together in a mixture.

Ceramic: A compound of metallic and nonmetallic elements.

Color: Wavelengths of light perceived by the eye.

Component: A part, or device.

Conductivity: The ability to carry an electric current (electricity) or thermal energy (heat).

Covalent bond: Bonding by sharing electrons.

Crystalline: A solid with a repeating three-dimensional unit cell.

Crystal structure: The orderly arrangement of the atoms or ions within a crystal.

Diamagnetism: Weakly repelled from a magnetic field.

Dielectric: An insulator.

Dielectric constant: Relative electrical permittivity of a material as compared to a perfect vacuum.

Dielectric (breakdown) strength: The amount of electricity needed to start an electric current flow in a dielectric material.

Ductile fracture: Break accompanied by large plastic deformation.

Elastic deformation: Change in shape that returns when a stress is removed.

Elastic Modulus: Ratio of stress to strain in elastic deformation, measure of elasticity.

Electric field: The gradient of voltage.

Electronegativity: The attraction of an atom for shared electrons.

Electron volt (eV): Unit of energy equivalent to the energy gained by an electron when it falls through an electric potential of one volt.

Excited state: An energy state to which an electron may move by the absorption of energy.

Fiber Optics: The technology of transferring information as light pulses through long thin fibers, usually made of glass.

Firing: High temperature processing to increase densification in a product.

Fluorescence: Light that is emitted a short period of time after an electron has been excited.

Fracture toughness (K_C): Measure of a material's resistance to crack propagation.

Glass: An amorphous solid showing characteristic specific volume behavior over a certain temperature range.

Glass - ceramic: Crystalline ceramic material that was formed by heat treating glass.

Glass transition temperature (T_g): Temperature at which a glass changes from a supercooled liquid into a solid.

Grain: Individual crystal in a **polycrystalline** material.

Grain boundary: The boundary between grains (or crystals) that are misoriented with respect to one another.

Green ceramic body: Ceramic object that is dried but not fired.

Ground state: Lowest electron energy state.

Hardness: Resistance to deformation.

Heat capacity: Heat required to produce a unit increase in temperature per quantity of material.

Imperfection: Flaw, any deviation from perfection, as in a crystal.

Index of refraction: Ratio of the speed of light in a vacuum to the speed of light in a medium.

Insulator: Material that does not conduct electricity (electrical) or heat (thermal).

Ionic bond: Electrostatic force between oppositely charged ions.

Laser: Source of coherent light (Light Amplification by Stimulated Emission of Radiation).

Lattice: The regular arrangement of points in a crystal.

Magnetic field strength: Intensity of an applied magnetic field.

Microstructure: Structural features that can be observed with a microscope.

Noncrystalline: Amorphous, with no long-range atomic order.

Piezoelectric: Material that produces an electrical response to a mechanical force.

Plastic deformation: Permanent deformation, change of shape.

Polycrystalline: Composed of more than one crystal or grain.

Porcelain: A durable ceramic composite made by firing clay, feldspar and quartz together.

Reflection: Deflection of light at the interface between two materials.

Refraction: Bending of light as it passes from one medium into another.

Refractory: Material that can be exposed to high temperature without deterioration.

Resistivity: Measure of resistance to passage of electrical current (reciprocal of conductivity).

Semiconductor: Nonmetallic material that has a relatively narrow energy band gap.

Sintering: Coalescence of individual ceramic particles into a continuous solid phase at a high temperature.

Slip: Mixture of clay with water that can be poured into a mold.

Slip casting: Method of making ceramic objects by pouring slip into a mold.

Softening point (glass): Maximum temperature a glass can be heated before it permanently deforms.

Smart materials: Materials able to detect a change in the environment and react to it.

Specific volume: Volume per unit mass, reciprocal of density.

Strain: Change in length of a sample in the direction of an applied stress.

Stress: Force applied to a sample divided by its cross-sectional area.

Structural clay products: Ceramic objects made mainly of clay and used in structural applications.

Structure: Arrangement of internal components.

Superconductivity: Disappearance of electrical resistivity at low temperatures.

Supercooling: Cooling below the normal temperature for a phase change, without the change occurring.

Tensile strength: Maximum stress without fracture.

Thermal expansion coefficient, linear: Fractional change in length divided by change in temperature, a measure of a materials tendency to expand when heated.

Thermal stress: Residual stress caused by a change in temperature.

Thermal tempering: The introduction of residual compressive stresses to increase the strength of glass.

Toughness: Energy absorbed by a material as it fractures, a measure of its resistance to fracture.

Transgranular fracture: Fracture by crack propagation through the grains.

Translucent: Transmits light diffusely.

Transparent: Transmits light clearly.

Unit cell: The basic repeating unit in a crystal.

Whiteware: Clay-based ceramic that turns white after firing.

Glossary Polymers

Abbreviations:

HDPE: high density polyethylene
LDPE: low density polyethylene
PET: polyethylene terephthalate
PP: polypropylene
PS: polystyrene
PVA: polyvinyl alcohol
PVC: polyvinyl chloride

addition polymerization: a chemical reaction in which simple molecules are linked together to form long chain molecules.

amorphous: non-crystalline polymer or non-crystalline areas in a polymer.

Bakelite: a polymer produced by the condensation of phenol and formaldehyde.

branched polymer: polymer having smaller chains attached to the polymer backbone.

cellulose: a natural polymer found in wood and other plant material.

composite polymer: a filled or reinforced plastic.

condensation polymer: one in which two or more molecules combine resulting in elimination of water or other simple molecules, with the process being repeated to form a long chain molecule.

configuration: related chemical structure produced by the making and breaking of primary valence bonds.

copolymer: a macromolecule consisting of more than one type of building unit.

creep: cold flow of a polymer.

cross-linking: occurs when primary valence bonds are formed between separate polymer chain molecules.

crystalline polymer: polymer with a regular order or pattern of molecular arrangement and a sharp melting point.

dimer: a polymer containing two monomers.

domains: sequences or regions in block copolymers.

elastomer: a type of polymer that exhibits rubber-like qualities.

Ekonol: a moldable, high temperature polymer.

end group: functional group at the end of a chain in polymers, e.g. carboxylic group.

extrusion: a fabrication process in which a heat-softened polymer is forced continually by a screw through a die.

filler: a relatively inert material used as the discontinuous phase of a polymer composite.

free radical: A chemical component that contains a free electron which covalently bonds with a free electron on another molecule.

homopolymer: a macromolecule consisting of only one type of building unit.

initiation: the start of a chain reaction with a source such as free radicals, peroxides, etc.

kevlar: a high strength polymer which can withstand high temperatures.

linear: polymers made up of one long continuous chain, without any excess appendages or attachments.

macromolecule: a polymer.

material: a substance useful for structural purposes.

monomer: smallest repeating unit of a polymer.

nylon: a polymer used commonly in the textiles industry.

oligomer: a low molecular weight polymer in which the number of repeating units is approximately between two and ten.

polyethylene: the most extensively produced polymer.

polyester: a polymer with a COOR repeating unit.

polymer: a high molecular weight macromolecule made up of multiple repeating units.

polymerization: the chemical reaction in which high molecular mass molecules are formed from monomers.

polystyrene: a polymer commonly used in packaging.

propagation: the continuous successive chain extension in a polymer chain reaction.

T_g: glass transition temperature below which a polymer is a hard glassy material.

thermoplastic: a polymer which may be softened by heat and hardened by cooling in a reversible physical process.

thermoset: a network polymer obtained by cross-linking a linear polymer to make it infusible or insoluble.

T_m: melting temperature.

Van der Waals forces: intermolecular attractions.

viscosity: the resistance to flow as applied to a solution or a molten solid.

vinyl chloride: the monomer used in PVC production.

vulcanization: cross-linking with heat and sulfur to toughen a polymer.

Appendix 1

Composition and Applications of Few Typical Materials

No	Alloy	Composition	Uses
1	Duralmin,	95% Aluminium + 4% Copper+ 0.5% Manganese + 0.5% Magnesium	Light structures, extruded sections and sheet
2	Gun metal	90% copper + 10% zinc	Small valves, fittings for water services
3	Monel	67% Ni + 28% Copper + remaining carbon, iron and Manganese	Valve parts for superheated steam turbine blades
4	Phosphor bronze	90% Copper + 9.7% Tin + 0.3% Phosphorus	Bearings, worm wheels, rods sheets
5	High carbon steel	0.8% to 1.5% Carbon + remaining iron	Files, dies for wire drawing, clutch disc
6	Spheroidal CI	3.2%-4.5% carbon 1-4% Si 0.1-8% Mn 0.1% P 0-3.5% Ni 0.05-0.1% Mn	For high wear resistance
7	Wrought iron	99% Pig Iron + 0.12% Carbon + 0.25% Phosphorus + 0.05 % Sulphur	Chains, crane hooks, railway couplings

Appendix 2

Room-Temperature Yield Strength and Plane Strain Fracture Toughness Data for Selected Engineering Materials

	Yield Strength		K_{Ic}	
Material	*MPa*	*ksi*	*MPa*	*ksi*
	Metals			
Aluminum alloy (7075-T651)	495	72	24	22
Aluminum alloy[a] (2024-T3)	345	50	44	40
Titanium alloy[a] (Ti-6Al-4V)	910	132	55	50
Alloy steel[a] (4340 tempered 260°C)	1640	238	50.0	45.8

Alloy steel[a] (4340 tempered 425°C)	1420	206	87.4	80.0
	Ceramics			
Concrete			0.2-1.4	0.18-1.27
Soda-lime glass	—	—	0.7-0.8	0.64-0.73
Aluminum oxide	—	—	2.7-5.0	2.5-4.6
	Polymers			
Polystyrene (PS)	25.0-69.0	3.63-10.0	0.7-1.1	0.64-1.0
Poly(methyl methacrylate) (PMMA)	53.8-73.1	7.8-10.6	0.7-1.6	0.64-1.5
Polycarbonate (PC)	62.1	9.0	2.2	2.0

Appendix 3

AISI/SAE and UNS Designation Systems and Composition Ranges for Plain Carbon Steel and Various Low-Alloy Steels

AISI/SAE Designation[a]	*UNS Designation*	*Composition Ranges (wt% of Alloying Elements in Addition to C)*[b]		
		Ni	*Cr*	*Mo*
10xx, Plain carbon	G10xx0			
11xx, Free machining	G11xx0			
12xx, Free machining	2xx0			
13xx	G13xx0			
40xx	G40xx0			0.20-0.30
41xx	G41xx0		0.80-1.10	0.15-0.25
43xx	G43xx0	1.65-2.00	0.40-0.90	0.20-0.30
46xx	6xx0	0.70-2.00		0.15-0.30
48xx	G48xx0	3.25-3.75		0.20-0.30
51xx	G51xx0		0.70-1.10	
61xx	1xx0		0.50-1.10	
86xx	6xx0	0.40-0.70	0.40-0.60	0.15-0.25
92xx	2xx0			

[a] The carbon concentration, in weight percent times 100, is inserted in the place of "xx" for each specific steel.

[b] Except for 13xx alloys, manganese concentration is less than 1.00 wt%.
Except for 12xx alloys, phosphorus concentration is less than 0.35 wt%.
Except for 11xx and 12xx alloys, sulfur concentration is less than 0.04 wt%.
Except for 92xx alloys, silicon concentration varies between 0.15 and 0.35 wt%.

Appendix 4

Mechanical Characteristics of Hot- Rolled Material and Typical Applications for Various Plain Low-Carbon and High-Strength, Low-Alloy Steels

AISI/SAE or ASTM Number	*Tensile Strength [MPa (ksi)]*	*Yield Strength [MPa (ksi)]*	*Ductility [%EL in 50 mm (2 in.)]*	*Typical Applications*
		Plain Low-Carbon Steels		
1010	325 (47)	180 (26)	28	Automobile panels, nails, and wire
1020	380 (55)	210 (30)	25	Pipe; structural and sheet steel
A36	400 (58)	220 (32)	23	Structural (bridges and buildings)
A516 Grade 70	485 (70)	260 (38)	21	Low-temperature pressure vessels
		High-Strength, Low-Alloy Steels		
A440	435 (63)	290 (42)	21	Structures that are bolted or riveted
A633 Grade E	520 (75)	380 (55)	23	Structures used at low ambient temperatures
A656 Grade 1	655 (95)	552 (80)	15	Truck frames and railway cars

Appendix 5

Typical Applications and Mechanical Property Ranges for Oil-Quenched and Tempered Plain Carbon **and** Alloy Steels

AISI Number	UNS Number	Tensile Strength *[MPa* (*ksi*)]	*Yield Strength [MPa* (*ksi*)]	*Ductility [%EL in 50 mm (2 in.)]*	*Typical Applications*
		Plain Carbon steels			
1040	G10400	605-780 (88-113)	430-585 (62-85)	33-19	Crankshafts, bolts
1080[a]	G10800	800-1310 (116-190)	480-980 (70-142)	24-13	Chisels, hammers
1095[a]	G10950	760-1280 (110-186)	510-830 (74-120)	26-10	Knives, hacksaw blades
		Alloy Steels			
4063	G40630	786-2380 (114-345)	710-1770 (103-257)	24-4	Springs, hand tools
4340	G43400	980-1960 (142-284)	895-1570 (130-228)	21-11	Bushings, aircraft tubing
6150	G61500	815-2170 (118-315)	745-1860 (108-270)	22-7	Shafts, pistons, gears

Appendix 6

Designations, Compositions, and Applications for Tool Steels

AIS Number	*UNS Number*	*Composition*						*Typical Applications*
		C	*Cr*	*Ni*	*Mo*	*W*	*V*	
M1	T11301	0.85	3.75	0.30 max	8.70	1.75	1.20	Drills, saws; lathe and planer tools
A2	T30102	1.00	5.15	0.30 max	1.15	—	0.35	Punches, embossing dies
D2	T30402	1.50	12	0.30 max	0.95	—	1.10 max	Cutlery, drawing dies
O1	T31501	0.95	0.50	0.30 max	—	0.50	0.30 max	Shear blades, cutting tools
S1	T41901	0.50	1.40	0.30 max	0.50 max	2.25	0.25	Pipe cutters, concrete drills
W1	T72301	1.10	0.15 max	0.20 max	0.10 max	0.15 max	0.10 max	Blacksmith tools, woodworking tools

The balance of the composition is iron. Manganese concentrations range between 0.10 and 1.4 wt%, depending on the alloy; silicon concentrations between 0.20 and 1.2 wt%, depending on the alloy.

Appendix 7

Designations, Compositions, Mechanical Properties, and Typical Applications for Austenitic, Ferritic, Martensitic, and Precipitation-Hardenable Stainless Steels

URNS Number	*Composition (wt%)*[a]	*Conditions*	*Tensile Strength [MPa* (ksi)]	*Yield Strengt [MPa* (ksi)]	*Ductility [%EL in mm (2 in.)] 50*	*Typical Applications*
S40900	0.08 C, 11.0 Cr1.0 Mn, 0.50 Ni, 0.75 Ti,	Annealed	380 (55)	205 (30)	20	Automotive exhaust components, tanks for agricultural sprays
S44600	0.20 C, 25 Cr,1.5 Mn	Annealed	515 (75)	275 (40)	20	Valves (high temperature), glass molds, chambers
S30400	0.08 C, 19 Cr, 9 Ni, 2.0 Mn	Annealed	515 (75)	205 (30)	40	Chemical and food processing equipment, cryogenic vessels
S31603	0.03 C, 17 Cr,12 Ni, 2.5 Mo, 2.0 Mn	Annealed	485 (70)	170 (25)	40	Welding construction
S41000	0.15 C, 12.5 Cr 1.0 Mn,	Annealed Q & T	485 (70)	275 (40) 620 (90)	20 12	Rifle barrels, cutlery, jet engine parts
S44002	0.70 C, 17 Cr,0.75 Mo, 1.0 Mn	Annealed Q & T	725 (105) 1790 (260)	415 (60) 1650	20 5	Cutlery, bearings, surgical tools

[a] The balance of the composition is iron.

[b] Q & T denotes quenched and tempered.

Designations, Minimum Mechanical Properties, Approximate Compositions, and Typical Applications for Various Gray, Nodular, Malleable, and Compacted Graphite Cast Irons

Grade	URNS Number	Composition (wt%)[a]	Matrix Structure	Mechanical Properties Tensile Strength [MPa (ksi)]	 Yield Strength [MPa (ksi)]	 Ductility [%EL in 50 mm (2 in.)]	Typical Applications
			Gray Iron				
SAE G1800	FI0004	3.40-3.7 C, 2.55 Si, 0.7 Mn	Ferrite + pearlite	124 (18)	—	—	Miscellaneous soft iron castings in not a
SAE G2500	FI0005	3.2-3.5 C, 2.20 Si, 0.8 Mn	Ferrite + pearlite	173(25)	—	—	Small cylinder cylinder plates,
SAE G4000	FI0008	3.0-3.3 C, 2.0 Si, 0.8	Pearlite	276 (40)	—	—	Diesel engine cylinders,
			Ductile (Nodular) Iron				
ASTM 60-	F32800	3.5-3.8 C, 2.0-2.8 Si,	Ferrite	414 (60)	276(40)	18	Pressure- as valve and
100-	F34800	0.05 Mg, <0.20 Ni,	Pearlite	689 (100)	483 (70)	3	High- machine
120-90-02	F36200	<0.10 Mo	Tempered martensite	827 (120)	621 (90)	2	Pinions, gears,
			Malleable Iron				

32510	F22200	2.3-2.7 C, 1.0-1.75 Si,	Ferrite	345 (50)	224 (32)	10	General engineering service at normal and elevated temperatures
45006	F23131	24-2.7 C, 1.25-1.55 Si,	Ferrite + pearlite	448 (65)	310 (45)	6	
		<0.55 Mn					
Compacted Graphite Iron							
ASTM Grade 250 л	l -	3.1-4.0 C, 1.7-3.0 Si, 0.015-0.035 Mg,	Ferrite	250(36)	175 (25)	3	Diesel engine
Grade 450 1 “	I -	0.06-0.13 Ti	Pearlite	450(65)	315 (46)		brake discs for high-speed trains

The balance of the composition is iron.

Appendix 9

Compositions, Mechanical properties and Applications for Copper Alloys

				Mechanical Properties			
Alloy Name	*UNS Number*	*Composition (wt%)^a*	*Condition*	*Tensile Strength*	*Yield Strength*	*Ductility [%EL in*	*Typical Applications*
			Wrought Alloys				
Electrolytic tough pitch	C11000	0.04 O	Annealed	220 (32)	69 (10)	45	Electrical wire, rivets, screening, gaskets, pans, nails, roofing
Beryllium copper	C17200	1.9 Be, 0.20 Co	Precipitation hardened	1140-1310 (165-190)	965-1205 (140-175)	4-10	Springs, bellows, firing pins, bushings, valves, diaphragms
Cartridge brass	C26000	30 Zn	Annealed Cold-worked (H04 hard)	300 (44) 525 (76)	75 (11) 435 (63)	68 8	Automotive radiator cores, ammunition components,
Phosphor bronze, 5%A	C51000	5 Sn, 0.2 P	Annealed Cold-worked (H04 hard)	325 (47) 560 (81)	130 (19) 515 (75)	64 10	Bellows, clutch disks, diaphragms, fuse clips, springs, welding rods

Copper-nickel, 30%	C71500	30 Ni	Annealed Cold-worked (H02 hard)	380 (55) 515 (75)	125 (18) 485 (70)	36 15	Condenser and heat-exchanger components, saltwater
				Cast Alloys			
Leaded yellow brass	C85400	29 Zn, 3 Pb, 1 Sn	As cast	234 (34)	83(12)	35	Furniture hardware, radiator fittings, light fixtures, battery
Tin bronze	C90500	10 Sn, 2 Zn	As cast	310 (45)	152 (22)	25	Bearings, bushings, piston rings, steam fittings,
Aluminum bronze	C95400	4 Fe, 11 Al	As cast	586 (85)	241 (35)	18	Bearings, gears, worms, bushings, valve seats

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a The balance of the composition is copper.

Compositions, Mechanical properties and Applications for Aluminum Alloys

Aluminum Association Number	*URNS Number*	*Composition (wt%)*[a]	*Condition (Temper Designation)*	*Tensile Strength [MPa (ksi)]*	*Yield Strength [MPa (ksi)]*	*[%EL in 50 mm(2*	*Typical Applications/ Characteristics*
			Wrought, Nonheat-Treatable Alloys				
1100	A91100	0.12 Cu	Annealed (O)	90(13)	35(5)	35-45	Food/chemical handling and storage equipment, heat exchangers, light reflectors
3003	A93003	0.12 Cu, 1.2 Mn	Annealed (O)	110(16)	40(6)	30-40	pressure vessels and piping
5052	A95052	2.5 Mg, 0.25 Cr	Strain Hardened (H32)	230(33)	195(28)	12-18	Aircraft fuel and oil lines, appliances, rivets, and wire
			Wrought, Heat-Treatable Alloys				
2024	A92024	4.4 Cu, 0.6 Mn 1.5 Mg,	Heat-treated (T4)	470 (68)	325 (47)	20	Aircraft structures, rivets, truck machine products screw wheels,

6061	A96061	1.0 Mg, 0.6 Si, 0.30 Cu, 0.20 Cr	Heat-treated (T4)	240 (35)	145 (21)	22-25	Trucks, canoes, furniture, pipelines railroad car
7075	A97075	5.6 Zn, 2.5 Mg, 1.6 Cu 0.23 Cr	Heat-treated (T6)	570 (83)	505 (73)	11	Aircraft structural applications
			Cast, Heat-Treatable Alloys				
295.0	A02950	4.5 Cu, 1.1 Si	Heat-treated (T4)	221 (32)	110 (16)	8.5	Flywheel and rear-axle housings, bus aircraft wheels, crankcases
356.0	A03560	7.0 Si, 0.3 Mg	Heat-treated (T6)	228 (33)	164 (24)	3.5	Aircraft pump parts, automotive transmission cases, water-cooled cylinder blocks

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TThe balance of the composition is aluminum.

Appendix 11

Room-Temperature Mechanical Properties (in Tension) for Various Materials

Material	*Yield Strength* *MPa*	*ksi*	*Tensile Strength* *MPa*	*ksi*	*Ductility, %EL* *[in 50 mm (2 in.)]*[a]
Metal Alloys[b]					
Molybdenum	565	82	655	95	35
Titanium	450	65	520	75	25
Steel (1020)	180	26	380	55	25
Nickel	138	20	480	70	40
Iron	130	19	262	38	45
Brass (70 Cu-30 Zn)	75	11	300	44	68
Copper	69	10	200	29	45
Aluminum	35	5	90	13	40
Ceramic Materials[c]					
Zirconia (ZrO_2)[d]			800-1500	115-215	
Silicon nitride (Si_3N_4)	—	—	250-1000	35-145	—
Aluminum oxide (Al_2O_3)	—	—	275-700	40-100	—
Silicon carbide (SiC)	—	—	100-820	15-120	—
Glass-ceramic (Pyroceram)	—	—	247	36	—
Mullite ($3Al_2O_3$-$2SiO_2$)	—	—	185	27	—
Spinel ($MgAl_2O_4$)	—	—	110-245	16-36	—
Fused silica (SiO_2)	—	—	110	16	—
Magnesium oxide (MgO)	—	—	105	15	—
Soda-lime glass	—	—	69	10	—
Polymers					
Nylon 6,6	44.8-82.8	6.5-12	75.9-94.5	11.0-13.7	15-300
Polycarbonate (PC)	62.1	9.0	62.8-72.4	9.1-10.5	110-150
Poly(ethylene terephthalate) (PET)	59.3	8.6	48.3-72.4	7.0-10.5	30-300
Poly(methyl methacrylate) (PMMA)	53.8-73.1	7.8-10.6	48.3-72.4	7.0-10.5	2.0-5.5
Poly(vinyl chloride) (PVC)	40.7-44.8	5.9-6.5	40.7-51.7	5.9-7.5	40-80
Phenol-formaldehyde	—	—	34.5-62.1	5.0-9.0	1.5-2.0
Polystyrene (PS)	25.0-69.0	3.63-10.0	35.9-51.7	5.2-7.5	1.2-2.5
Polypropylene (PP)	31.0-37.2	4.5-5.4	31.0-41.4	4.5-6.0	100-600
Polyethylene—high density	26.2-33.1	3.8-4.8	22.1-31.0	3.2-4.5	10-1200
Polytetrafluoroethylene	13.8-15.2	2.0-2.2	20.7-34.5	3.0-5.0	200-400
Polyethylene—low density	9.0-14.5	1.3-2.1	8.3-31.4	1.2-4.55	100-650

For polymers, percent elongation at break.

Property values are for metal alloys in an annealed state.

The tensile strength of ceramic materials is taken as flexural strength. Sintered and containing approximately 5% porosity.

Appendix12

Vickers (and Knoop) Hardnesses for Eight Ceramic Materials

Material	*Vickers Hardness*	*Knoop Hardness*	*Comments*
Diamond (carbon)	130	103	Single crystal, (100) face
Boron carbide	44.2	—	Polycrystalline, sintered
Aluminum oxide	26.5	—	Polycrystalline, sintered,
Silicon carbide	25.4	19.8	Polycrystalline, reaction
Tungsten carbide	22.1	—	Fused
Silicon nitride	16.0	17.2	Polycrystalline, hot pressed
Zirconia (ZrO_2)	11.7	—	Polycrystalline, 9 mol% Y_2O_3
Soda-lime glass	6.1	—	

Appendix 13

The densities (in g/ml) of the plastics:

HDPE	0.952 to 0.965
LDPE	0.917 to 0.940
PET	1.29 to 1.4
PP	0.900 to 0.910
PS (in solid form)	1.04 to 1.05
PS (in foam form)	variable but always less than 1
PVC (rigid)	1.30 to 1.58
PVC (flexible)	1.16 to 1.35

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