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

Department of building mechanics

Study guide and laboratory reports on

"Technology of Structural materials and Material Science"

Part 1

"Technology of Structural materials"

for students of "Engineering mechanics" *field of study 6.050502*

Student ____

Faculty ____

Course ________________________ Group ___________________________

Ternopil
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The notes and laboratory reports have been approved at the meeting of building mechanics department (minutes № 1 from 25 August 2016)

The notes and laboratory reports have been approved by the Mechanical Engineering Faculty methodological committee (minutes № 1 from 29 August 2016)

Contents

Introduction

"Technology of Structural materials and Material Science" is one of the basic technical disciplines in the syllabus for "Engineering mechanics" field of study.

During the implementation of laboratory work considerable attention is given to the educational and experimental work for the study of materials that are used in different branches of an industry and manufacturing technology; alloy's mechanical properties (tensile strength, hardness, toughness); forming technology, welding, cutting, milling and powder metallurgy.

After every practical class in the laboratory, students will fill the laboratory report. The content of the laboratory class corresponds with the syllabus of the course "Material Science" for students of the "Engineering mechanics" field of study.

The purpose of this manual is to provide guidelines for the students in preparation for independent laboratory work and to project its results in the laboratory reports.

Safety during lab activities

The laboratory classes for “Technology of Structural materials and 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 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 and impact strength

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.
3. To be able to calculate toughness.

Scientific principle

1.***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:

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

where $F_0 = (\pi d_0^2) / 4,\ mm^2$ (1.3),

d_0 - original diameter of sample, mm (look at the fig.1.1.).

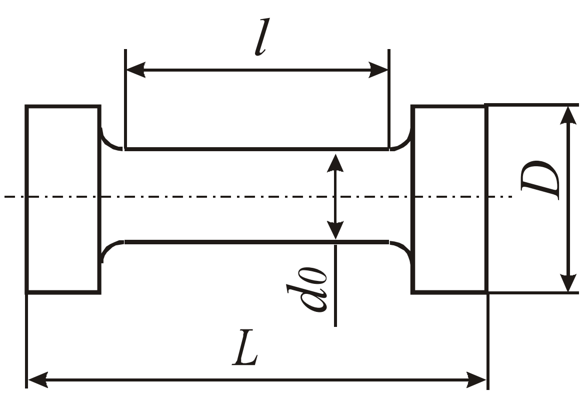


Fig.1.1. Test sample

Fig.1.2 shows the stress-strain diagram of a ductile material where the linear portion of the graph indicates elastic deformation.

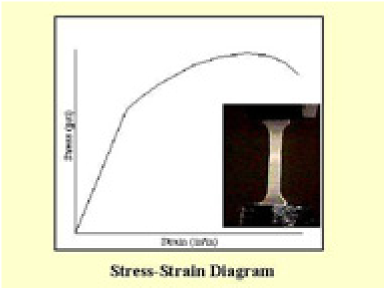


Fig. 1.2. Stress -Strain Diagram

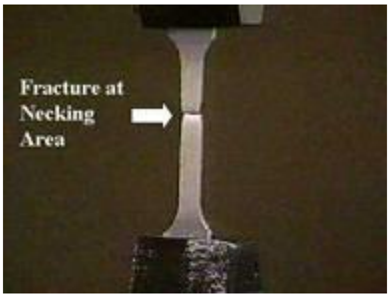


Fig. 1.3.Fracture of a Flat Tensile Test Specimen

<u>Modulus of Elasticity</u>: 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).

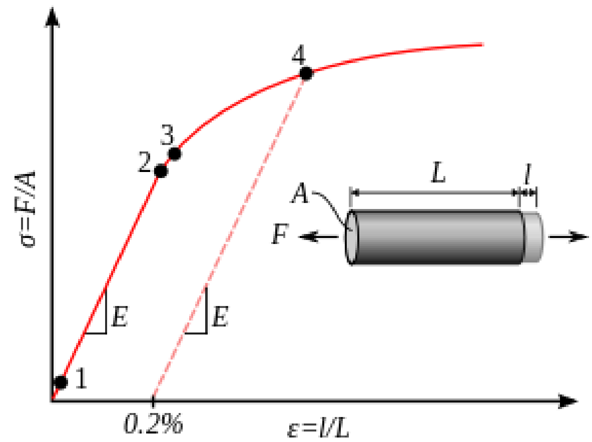


Fig.1.4. Stress-strain curve for nonferrous alloys. 1: True elastic limit 2: Proportionality limit 3: Elastic limit 4: Offset yield strength

Fig. 1.5. Sample after fracture

<u>Modulus of Elasticity</u>: 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)

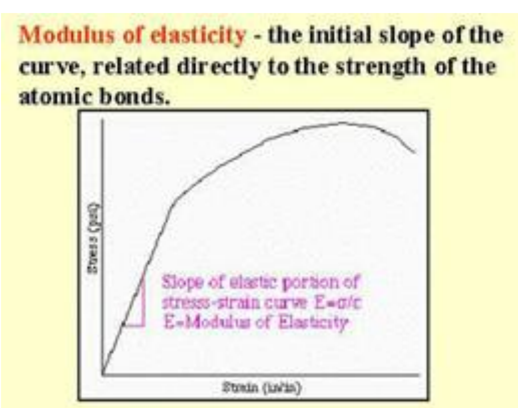
$$\mathbf{E = \sigma/\varepsilon} \qquad (1.4)$$

<u>Strength</u> is a measure of the ability of a material to support a load.

It is one of the most important mechanical characteristics of constructional materials. Strength depends on the nature of the material, the presence of impurities and alloying elements, temperature.

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

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



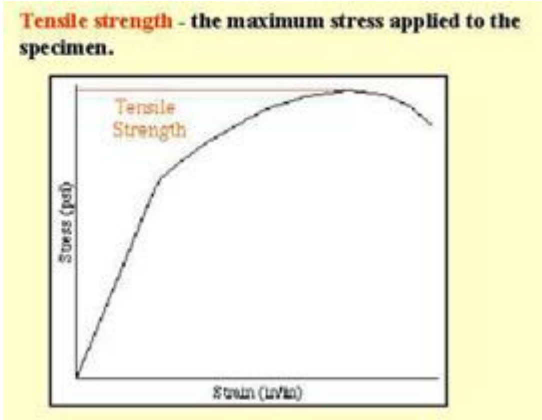


Fig.1.6. Modulus of Elasticity

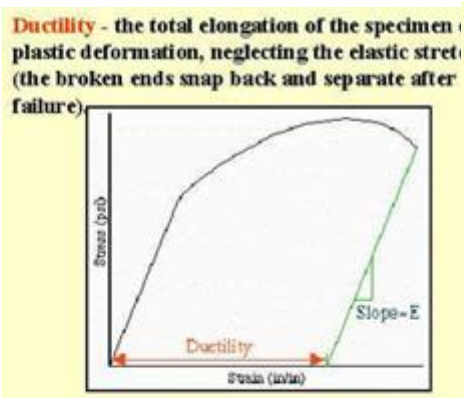
Fig 1.7.Tensile Strength

<u>Ductility:</u> 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)

<u>Toughness</u> 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.



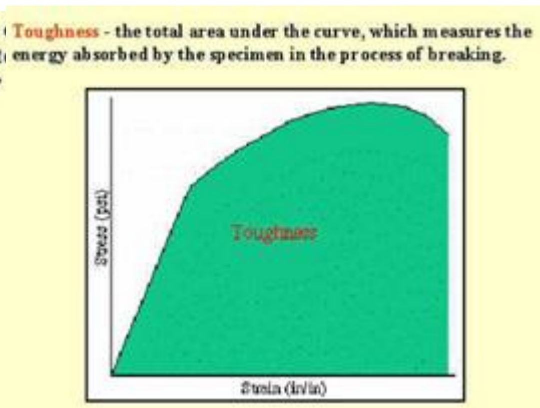


Fig.1.8. Ductility

Fig.1.9. Toughness

Fig.1.9. Tensile Test Machine

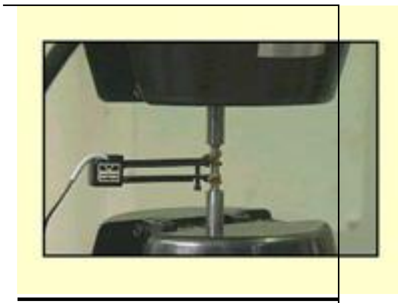


Fig.1.10. Extensometer

Impact strength

Impact is measured by the energy transfer (i.e., in units of work) when a body with inertia collides with a part over a very short time. Examples are the striking of a hammer to break stones, or the shaping of metallic shapes using the *drop forging* process. Impact strength is measured in terms of the energy transfer from a pendulum strike to break a fixed size sample that has a notch (see figure below). Usually, materials with high impact toughness are those with high ductility and high strength – namely, materials with high toughness.

Impact strength characterizes the behavior of the material under shock (dynamic) loads and is numerically equal to the work spent on the deformation and fracture the sample of these loads are reduced to a single cross-sectional area of the sample at the place of destruction (J/m^2). Called dynamic load at which the force is applied at high speed (immediately).

Alloys that have an ample supply of plasticity during static load can break brittle under dynamic loading. The tendency of metals to brittle fracture increases with speed of loading, temperature decrease, increase in grain size, increasing contents of harmful impurities such as phosphorus, sulfur, oxygen, hydrogen and others.

Main schemes load during impact tests – tension, compression, bending and torsion. The choice of specific schemes for load tests spend according to with the terms of the real exploitation loads of material in construction. Dynamic loading perceive details of stamps, hand tools (hammer, chisel, punch), grind to forge and press equipment and more.

Impact test of samples with the notch bend the most common. These tests are regulated by the state standard. The method is based on the destruction of the sample with the hub in the middle for a single impact loading on the pendulum copra. According to test results determine the impact strength and the relative narrowing of the sample after fracture.

For testing large samples of copra is used with a supply of energy 7500..2500 J testing of non-metallic materials, copra with a maximum reserve of energy 10 J.

According to standardized testing methods impact strength bend using prismatic samples with a size 10x10x55 mm with three types of concentrators (Figure 1.11): V-like with a radius of 0.25 mm and an angle 45^0; U-like with a radius rounding 1 mm; concentrator as a fatigue crack. According impact strength indicates KCV, KCU and KC.

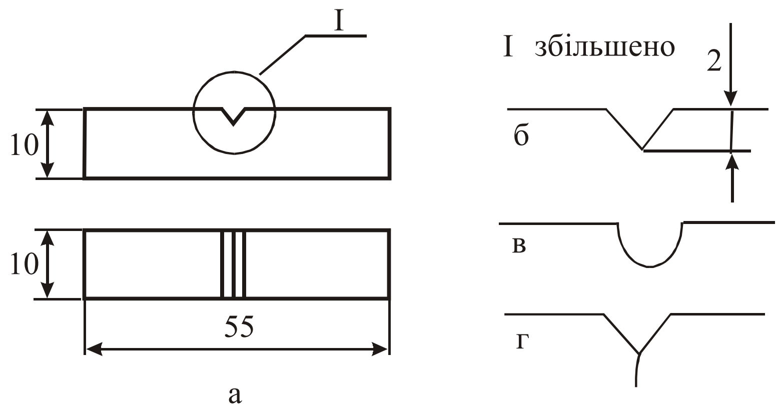


Fig. 1.11. The shape and size of samples to test for impact bending (a) V-like concentrator (b), U-like concentrator (c) and concentrator, which ends a crack (d).

Scheme of copra pendulum shown in Fig. 1.12.

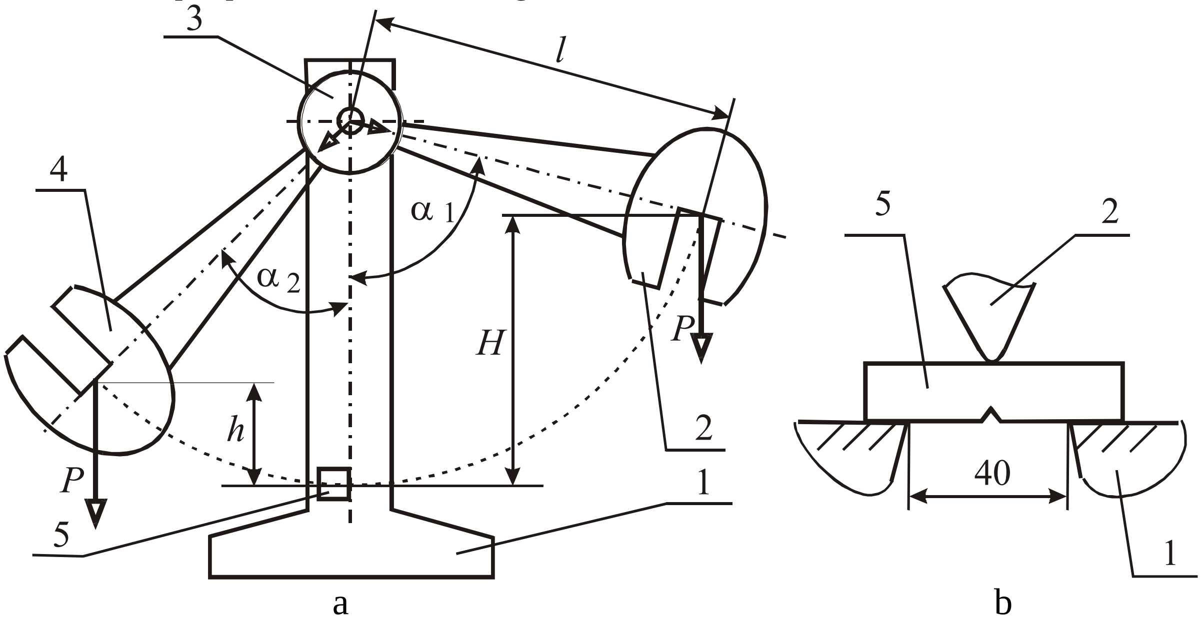


Fig.1.12.Design model of pendulum copra (a) and scheme of test (b): 1 - entablature, 2 - position of the hammer before the impact 3 - counting scale with arrows 4 - position of the hammer after impact, 5 – sample

The potential energy of the pendulum with mass *m* in the upper position (before the impact marked 2 in Fig. 3.3) determined by the formula

$$E_1=PH=mgH, \tag{1.8}$$

H – height of the center of mass of the hammer 2 axis 5 of the sample before impact, m;

m – mass of the hammer, kg;

P – weight of the hammer, N.

Falling pendulum destroys the sample, consuming the energy E_1, and rises to a height *h* due residue (not spent) energy E_2.

It is clear that the residual energy of the pendulum after impact (mark 4. Figure 3.3)

$$E_2=Ph=mgh, \tag{1.9}$$

The work of destruction is defined as the energy lost by the formula

$$A=E_1-E_2=PH-Ph=mg(H-h) \tag{3.4}$$

Constructively a pendulum Machine equipped with scale 3, where the arrows indicate starting angle of the pendulum α_1 and final α_2. Therefore, the calculation is better to use no height values before and after the impact as well corresponding angles. After easy trigonometric transformations of the formula (3.4) we get:

$$A=mgl(\cos\alpha_2-\cos\alpha_1), \quad (3.5)$$

l – length of the pendulum from the axis of rotation to the center of mass of the hammer, m;

α_1, α_2 – is hoisting angles of the pendulum, respectively, before and after impact (destruction of the sample).

Size *mgl=Pl* is constant for pendulum copra.

During conducting of tests raising the pendulum at angle α_1, and after the destruction of the sample record angle α_2. Knowing the constant pendulum *Pl* and angles α_1 and α_2, tables or calculated (equation 3.5) find the work of destruction.

Impact strength determine by the formula:

$$KC=A/F, \quad (3.6)$$

F – cross-section area of the sample in the cross-section (Figure 1.13).

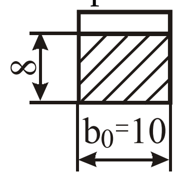


Figure 1.13.Cross-section of the sample

The value of impact strength at the shock bending the sample with a crack not enough characterized a constructional materials by tendency to brittle fracture. This is due to the fact that the KCT is a characteristic of resistance to the destruction of a specific sample at a given load in the laboratory. In addition, the impact strength is an integral characteristic, which takes into account the energy of nucleation and crack propagation energy. But in the real anisotropic metal always is available ready to crack for nucleation of which do not need energy consumption. Therefore, the experimentally determined characteristics of impact strength can only be used as a comparable for different materials, but not for the design characteristics that would guarantee the safety from the destruction under dynamic loads.

Equipment:

1. Stress - strain diagram.
2. Tensile Test Machine.
3. Specimens of metal alloys.

Procedure:

1. For given original and final sizes of sample, gauge and stress-strain diagram: measure and calculate $\boldsymbol{\varepsilon, \sigma_{ts}, \delta, \psi}$ and write the results in the protocol 1.
2. Understand thoroughly the operation of each machine, and check its operation before proceeding.
3. Determination of impact strength of material.

Questions:

1. What is strain?
2. What is stress?
3. What is strength?
4. Plot a stress-strain diagram for brittle materials.
5. Plot a stress-strain diagram for ductile materials.
6. How is it possible to determine modulus of elasticity using a stress-strain diagram?
7. How is it possible to determine tensile strength using a stress-strain diagram?
8. What are the indicators of ductility? Write formulas.
9. What is toughness and how can it be determined?
10. What is impact strength and how can it be determined?

LABORATORY REPORT № 1

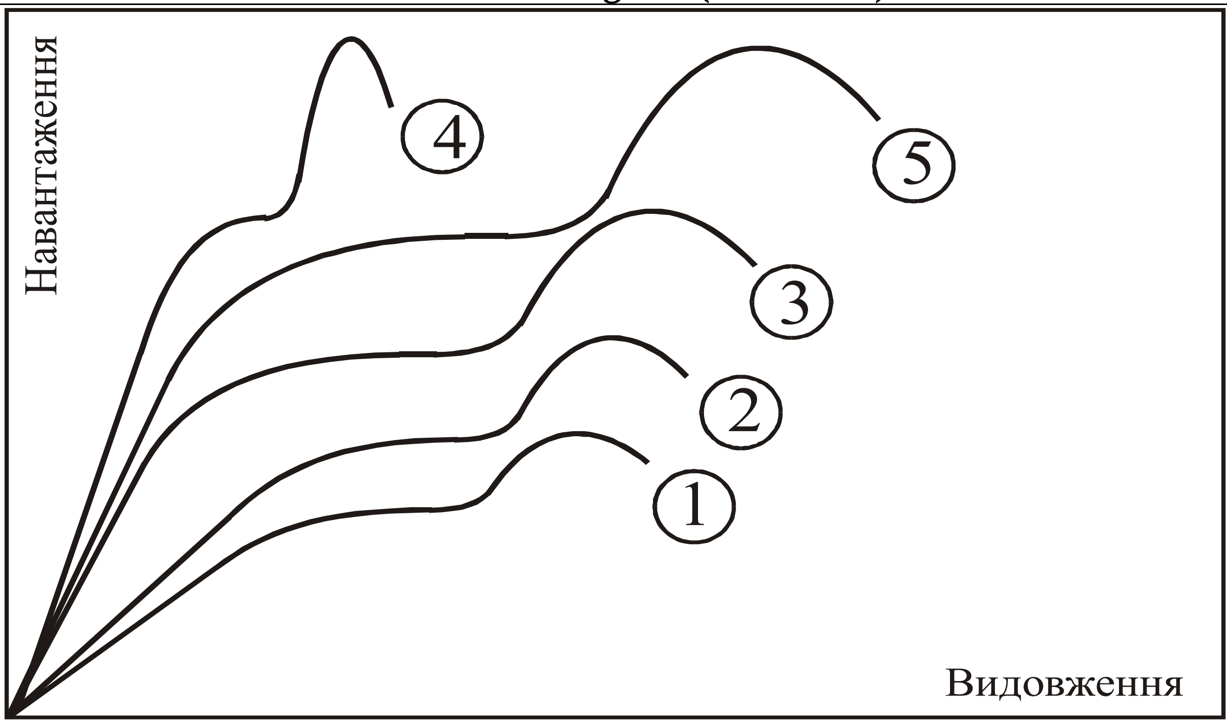
Mechanical properties: tensile test

Protocol №1

1.***Tensile Test***

Type of sample	Cylinder
Mатеrial	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

Determination of impact strength of materials
Individual task (Variant for calculation of № of students in the list)

Characteristics of pendulum copra and sample	Elevation angle of the pendulum					
	After impact, α_2, grad	Before impact, α_1, grad.				
		130	**125**	**120**	**115**	**110**
Length of the pendulum *l* = 1m	**45**	V1	V2	V3	V4	V5
Weight of hammer *m* = 30 kg	**50**	V6	V7	V8	V9	V10
Sample prismatic	**55**	V11	V12	V13	V14	V15
Size 10x10x55 mm	**60**	V16	V17	V18	V19	V20
Incision V-like, 2 mm	**65**	V21	V22	V23	V24	V25
Job of destruction A, J						
Impact strength KCV, MJ/mm^2						

____________________________ ______________________________

Student’s signature Teacher’s signature

“____” _____________20___ y. “____” _______________20___ y.

Laboratory work 2

Mechanical properties: hardness test

Objectives:

1. To conduct typical engineering hardness tests and to be able to understand the correlation between hardness numbers and the properties of materials.
2. To learn the advantages and limitations of the common hardness test methods.

Scientific principle

Hardness is the resistance to indentation (ability of material to resist to introduction in himsolid). 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:

$$\sigma_{ts} = k \times BHN, \qquad (2.1)$$

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.

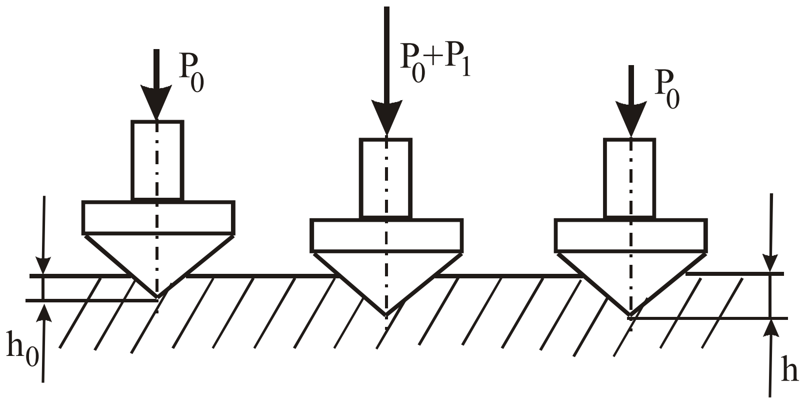


Fig. 2.1. Scheme of putting loads during Rockwell test

Major loads for Standard Rockwell tests are 450, 600, 1000 or 1500N. 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.

Advantages of the Rockwell test:

- high control productivity;
- possibility of sample hardness determination without calculations;
- simple maintenance;
- high measurement accuracy compared to other methods;
- maintainance of surface quality after measurement (few visible traces of the penitrator);
- possibility of process automatization.

Disadvantages of the Rockwell test:

- disability of testing mixed structured alloys, brittle products, curved surfaces with a radius of curvature less than 15 mm, samples with thickness less than 8 times of depth of the penitrator

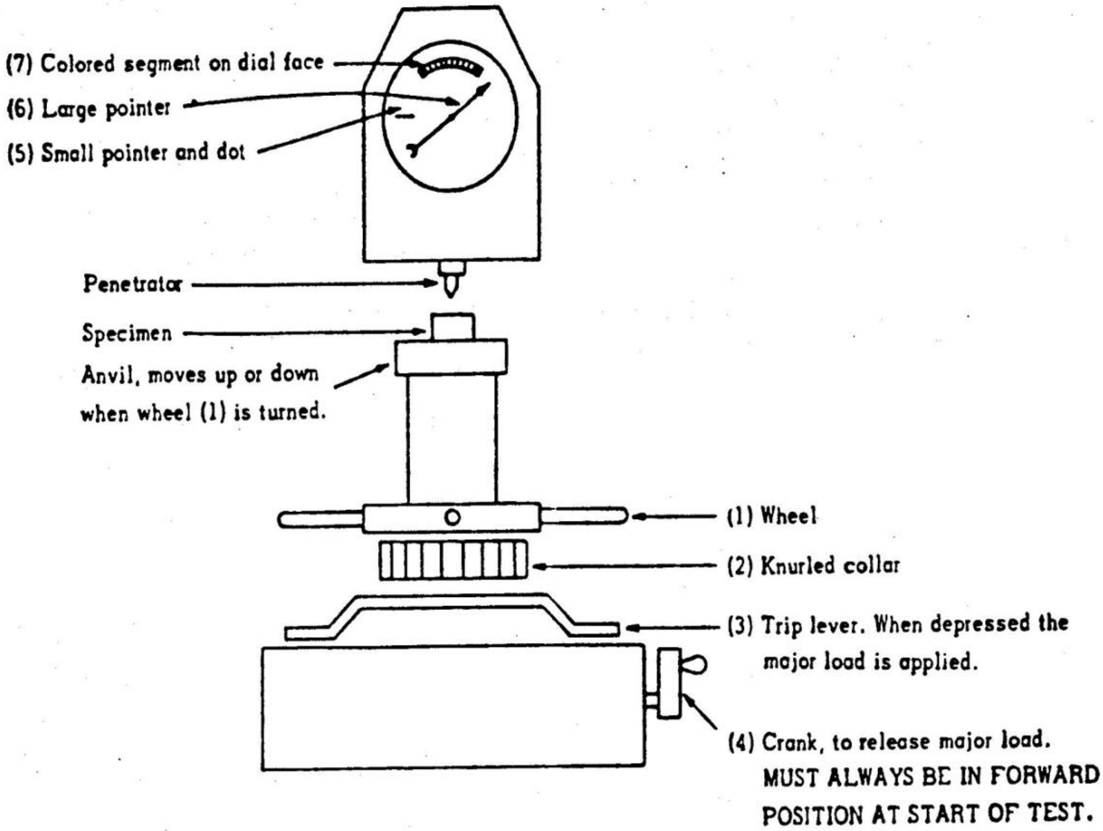


Fig.2.2.Rockwell Testing Machine.

Operation of Hardness Testing Equipment:

(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) counterclockwise). 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.2.3).

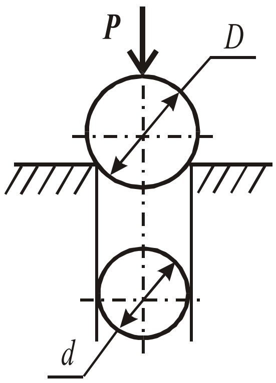


Fig.2.3. Scheme of putting load during Brinell test

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):

$$\mathbf{BHN} = \frac{2P}{\pi\,(D - (D^2 - d^2)^{1/2})\,D}, \ \mathbf{MPa} \qquad (2.2)$$

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.

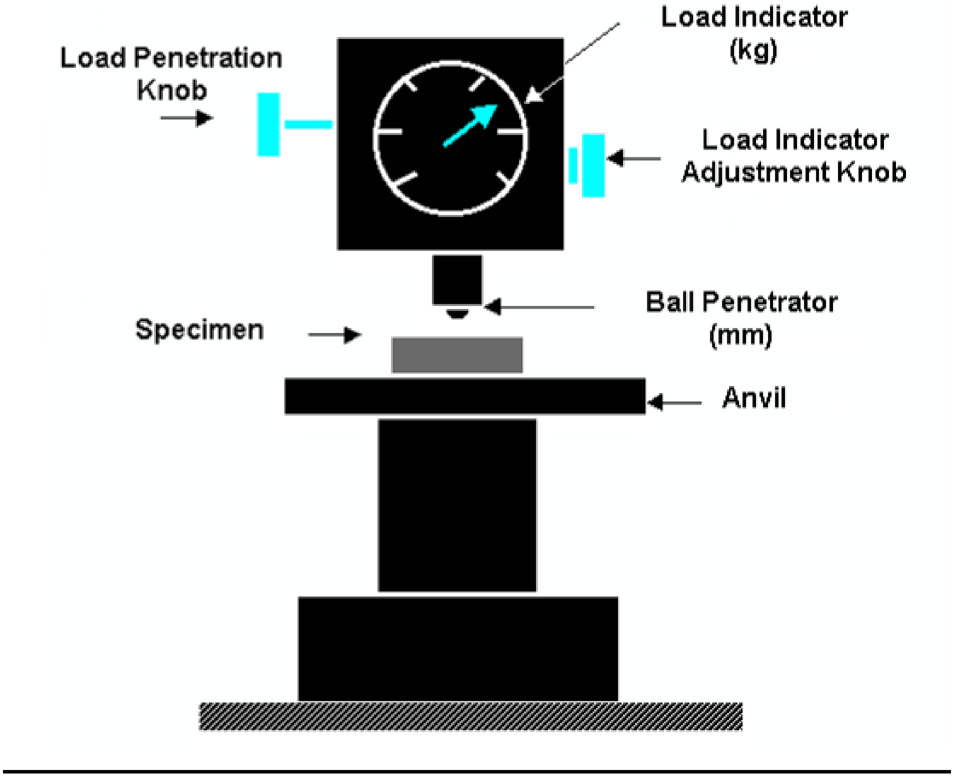


Fig.1.13 .Brinell Testing Machine

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. Rockwell Testing Machine.
2. BrinellTesting Machine.
3. Rockwell and Brinell Hardness Test Specimens of metal alloys.

Procedure:

1. Understand thoroughly the operation of each machine, and check its operation before proceeding.
2. 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.
3. 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 hardness?
2. What types of hardness tests do you now?
3. How tensile strength depends on hardness?
4. What penetrators are used in Rockwell tests?
5. What loads are used in Rockwell tests?
6. What scales and hardness numbers are used in Rockwell tests?
7. Draw the scheme of putting loads during Rockwell test.
8. Describe advantages of the Rockwell test.
9. Describe disadvantages of the Rockwell test.
10. What penetrators are used in Brinell tests?
11. Draw the scheme of putting load during Brinell test.
12. What loads are used in Brinell tests?
13. How to calculate Brinell hardness number?

LABORATORY REPORT № 2

Mechanical properties: hardness test

Protocol №1

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 №2

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 3

METAL FORMING

Objectives:

1.To learn the metal forming processes and the advantages and disadvantages different kinds of bulk deformation processes and sheet-forming processes.

2. Determination the coefficient of K_0 and of plain steel sample after drawing.

Scientific principle

Plastic Deformation Processes - operations that induce shape changes on the workpiece by plastic deformation under forces applied by various tools and dies

There are two kinds of plastic deformation processes: Bulk Deformation Processes and Sheet-Forming Processes.

Bulk Deformation Processes. These processes involve large amount of plastic deformation. The cross-section of workpiece changes without volume change. The ratio *cross-section area/volume* is small. For most operations, hot or warm working conditions are preferred although some operations are carried out at room temperature.

Sheet-Forming Processes. In sheet metalworking operations, the cross-section of workpiece does not change—the material is only subjected to shape changes. The ratio *cross-section area/volume* is very high. Sheet metalworking operations are performed on thin (less than 6 mm) sheets, strips or coils of metal by means of a set of tools called punch and die on machine tools called stamping presses. They are always performed as cold working operations.

Work-hardening. It is an important material characteristic since it determines both the properties of the workpiece and process power. It could be removed by annealing.

Temperature in metal forming.

There are three temperature ranges - cold, warm, and hot working:

Cold working is metal forming performed at room temperature (20°C-0,3Tm)

Advantages: better accuracy, better surface finish, high strength and hardness of the part, no heating is required.

Disadvantages: higher forces and power, limitations to the amount of forming, additional annealing for some material is required, and some material are not capable of cold working.

Warm working is metal forming at temperatures above the room temperature but bellow the recrystallization one (0,3Tm-0,5Tm)

Advantages: lower forces and power, more complex part shapes, no annealing is required.

Disadvantages: some investment in furnaces is needed.

Hot working involves deformation of preheated material at temperatures above the re-crystallization temperature (0,5Tm-0,75Tm). Tm is the work metal melting temperature

Advantages: big amount of forming is possible, lower forces and power are required, forming of materials with low ductility, no work hardening and therefore, no additional annealing is required.

Disadvantages: lower accuracy and surface finish, higher production cost, and shorter tool life.

BULK DEFORMATION PROCESSES

Classification of Bulk Deformation Processes

Rolling - compressive deformation process in which the thickness of a plate is reduced by squeezing it through two rotating cylindrical rolls.

Forging - workpiece is compressed between two opposing dies so that the die shapes are imparted to the work.

Extrusion - work material is forced to flow through a die opening taking its shape.

Drawing - diameter of a wire or bar is reduced by pulling it through a die opening (bar drawing) or a series of die openings (wire drawing).

Rolling

Rolling is a Bulk Deformation Process in which the thickness of the work is reduced by compressive forces exerted by two opposing rolls.

The preheated at 1200 ^{o}C cast ingot (the process is known as *soaking*) is rolled into one of the three intermediate shapes called *blooms*, *slabs*, or *billets*.

Bloom has a square cross section of 150/150 mm or more

Slab (40/250 mm or more) is rolled from an ingot or a bloom

Billet (40/40 mm or more) is rolled from a bloom

These intermediate shapes are then rolled into different products as illustrated in the figure:

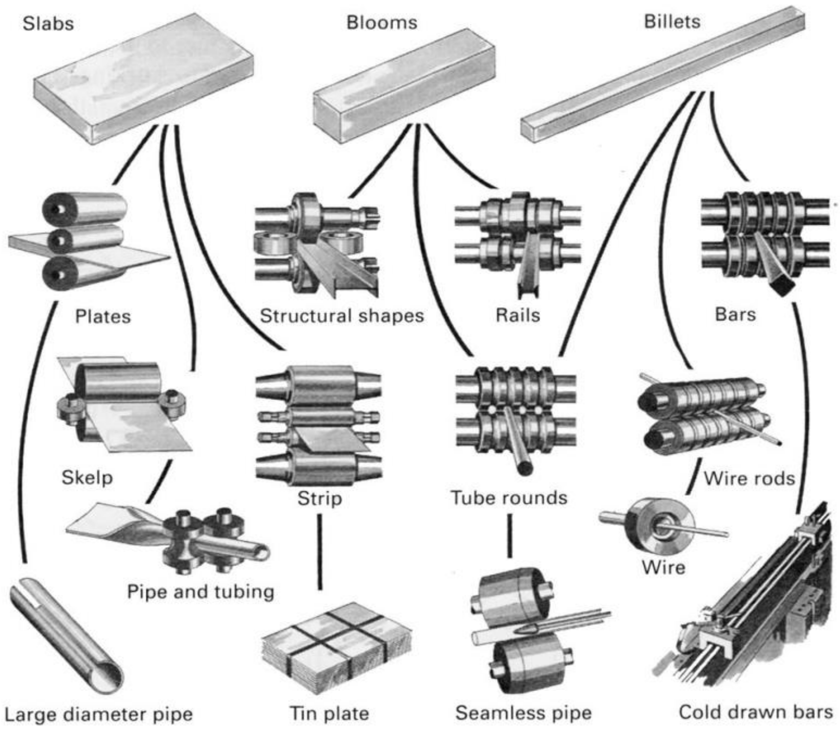


Fig.3.1. Production steps in rolling

Flat rolling

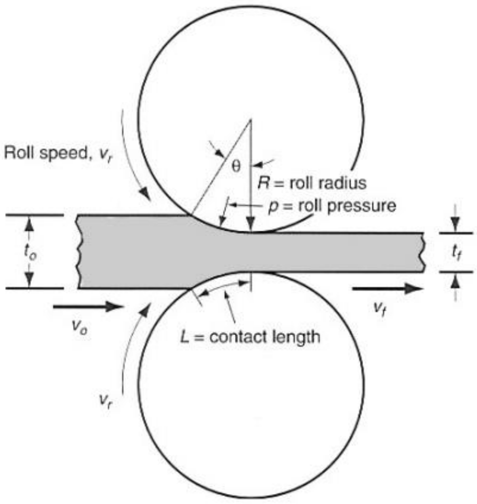


Fig 3.2.Flat rolling

The work is squeezed between two rolls so that it thickness is reduced by an amount called the *draft.*

$d = t_o - t_f$

If the draft is expressed as a fraction of the starting block thickness, it is called *reduction*, r:

$r = d/t_o$

Rolling increases the work width from an initial value of wo to a final one of w_f, and this is called *spreading*.

The inlet and outlet volume rates of material flow must be the same, that is,

$t_o w_o v_o = t_f w_f v_f$

Shape rolling

The work is deformed by a gradual reduction into a contoured cross section (I-beams, L-beams, U-channels, rails, round, squire bars and rods, etc.).

Ring rolling

Thick-walled ring of small diameter is rolled into a thin-walled ring of larger diameter:

Thread rolling

Threads are formed on cylindrical parts by rolling them between two thread dies:

Ring rolling used to reduce the wall thickness and increase the diameter of a ring (fig.3.3.)

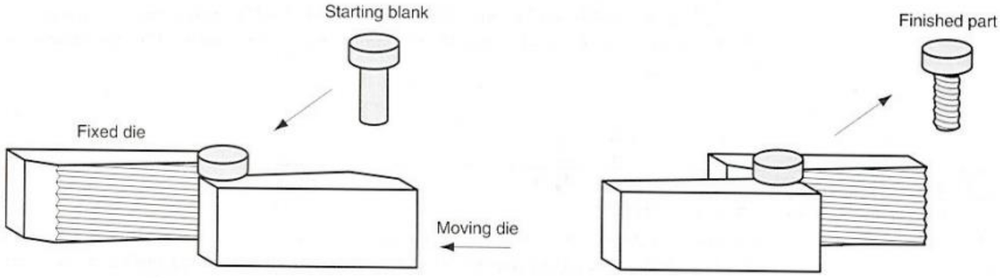


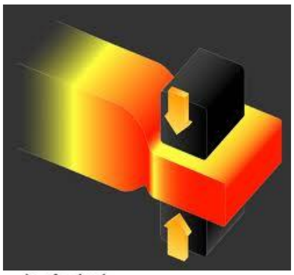
Fig.3.3.Thread rolling with flat dies

Gear rolling

Gear rolling is similar to thread rolling with three gears (tools) that form the gear profile on the work.

Forging

Forging is a Bulk Deformation Process in which the work is compressed between two dies. According to the degree to which the flow of the metal is constrained by the dies there are three types of forging:***Open-die forging,Impression-die forging,Flashless forging***



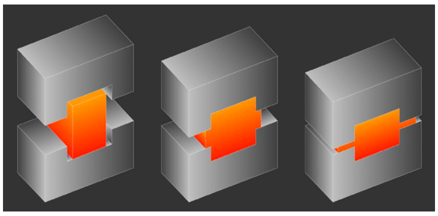
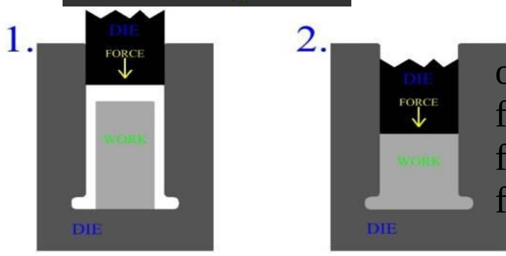


Fig.3.4. Three types of forging: (a) open-die forging, (b) impression die forging, and (c) flashless forging



Open-die forging. Known as *upsetting*, it involves compression of a work between two flat dies, or platens.

Impression-die forging. In impression-die forging, some of the material flows radially outward to form a flash:

Flashless forging. The work material is completely surrounded by the die cavity during compression and no flash is formed. Most important requirement in flashless forging is that the work volume must equal the space in the die cavity to a very close tolerance. For force estimation, the same equation as in impression-die forging is applied.

Coining

Special application of flashless forging in which fine detail in the die are impressed into the top and bottom surfaces of the workpiece. There is a little flow of metal in coining.

Extrusion

Extrusion is a Bulk Deformation Process in which the work is forced to flow through a die opening to produce a desired cross-sectional shape.

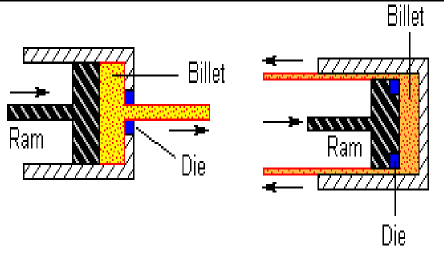
Extrusion is performed in different ways therefore different classifications are available:

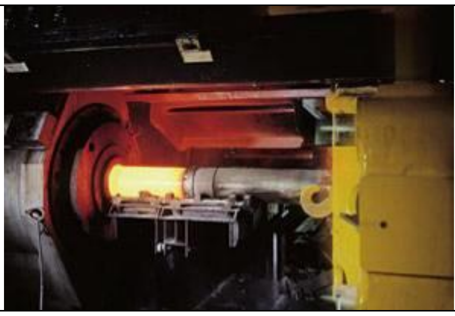
Direct and indirect extrusion
Hot and cold extrusion
Continuous and discrete extrusion

Direct and indirect extrusion

Direct extrusion to produce hollow or semihollow cross section. Direct extrusion to produce solid cross section. Schematic shows the various equipment components (fig.3.5.).

In indirect extrusion (backward, inverse extrusion) the material flows in the direction opposite to the motion of the ram to produce a solid (top) or a hollow cross section (bottom).





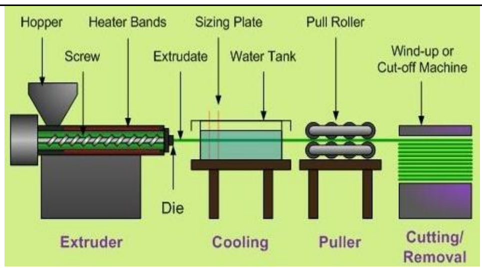


Fig. 3.5. Three types of Extrusion: *Direct and indirect extrusion(a), Hot extrusion(b), Continuous extrusion (c)*

Drawing

Wire and Bar Drawing is a Bulk Deformation Process in which the cross-section of a bar, rod or wire is reduced by pulling it through a die opening, as in the next figure:

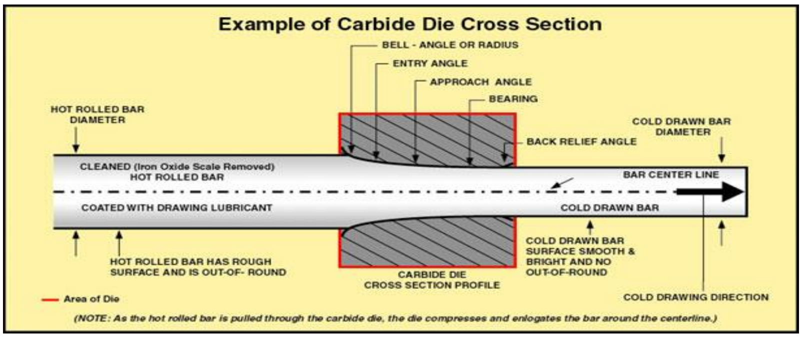


Fig.3.6.Drawing

Bar drawing is a single-draft operation. By contrast, in wire drawing the wire is drawn through a series of dies, between 4 and 12. The draft, d, is defined as

$$d = D_o - D_f$$

and reduction, r, is given by

$$r = d/D_o$$

SHEET METALWORKING

Classification of Sheet Metalworking Processes

Basic sheet metalworking operations(fig. 3.7.): (a) **bending**, (b) **drawing**, and (c) **shearing**; (1) as punch first contacts sheet and (2) after cutting. Force and relative motion are indicated by F and v.

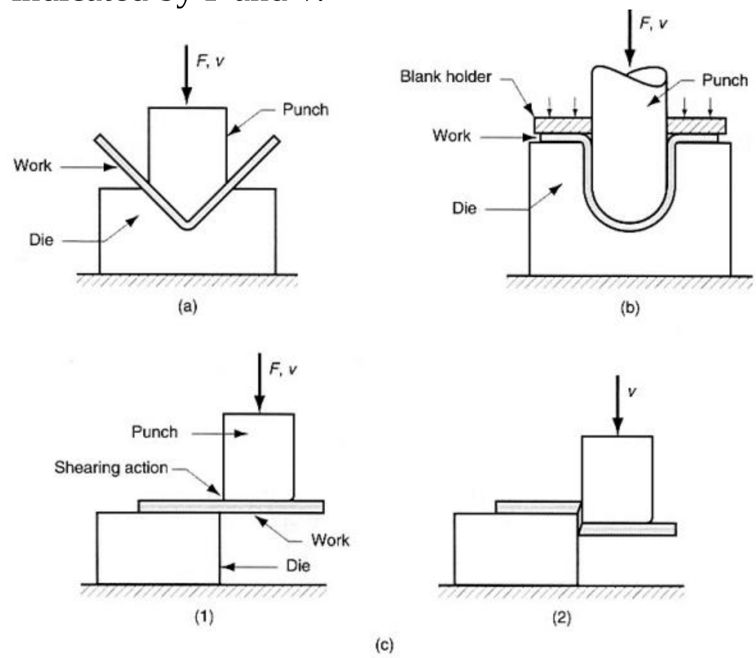


Fig.3.7. Basic sheet metalworking operations

Cutting Operations

Shearing is a sheet metal cutting operation along a straight line between two cut-ting edges by means of a power shear.

Blanking and punching

Blanking and punching are similar sheet metal cutting operations that involve cutting the sheet metal along a closed outline. If the part that is cut out is the desired product, the operation is called *blanking* and the product is called *blank*. If the remaining stock is the desired part, the operation is called *punching*.

Bending operations

Bending is defined as the straining of the sheet metal around a straight edge (fig.3.8.):

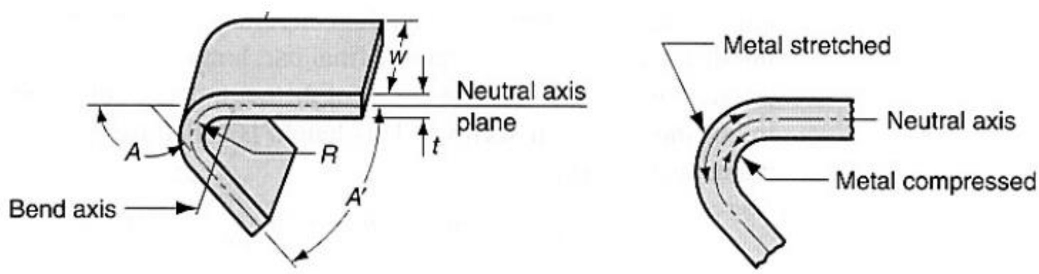


Fig.3.8. Bending of sheet metal

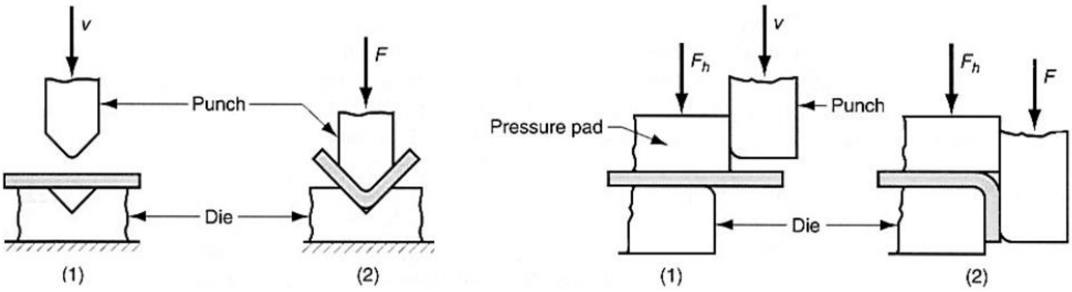


Fig.3.9. Bending operations involve the processes of *V-bending* and *edge bending*: (*Left*) V-bending, and (*Right*) edge bending; (1) before and (2) after bending

V-bending—sheet metal is bent along a straight line between a V-shape punch and die. ***Edge bending***—bending of the cantilever part of the sheet around the die edge.

Deep drawing

Deep drawing is a sheet-metal operation to make hollow-shaped parts from a sheet blank:

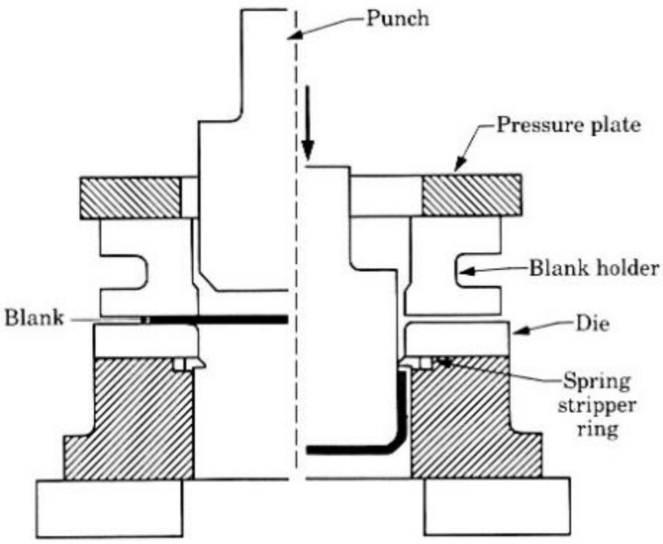


Fig.3.10. Deep drawing of a cup-shaped part: (*Left*) start of the operation before punch contacts blank, and (*Right*) end of stroke

Clearance

Clearance is the distance between the punch and die and is about 10% greater than the stock thickness:

$c = 1.1t$

Measures of drawing

Two measures of the severity of a deep drawing operation are used,

Drawing ratio DR defined as

$$DR = D_b/D_p$$

Here D_b is the blank diameter and D_p is the punch diameter.

DR must be less than 2.0 for a feasible operation. If it is more than 2.0, the progressive deep drawing is applied.

Thickness-to-diameter ratio t/Db. It is desirable to be greater than 1% to avoid wrinkling. The blank diameter can be calculated by setting the initial blank volume equal to the final volume of the part and solving for diameter Db.

Equipment:

1. Stamp for sheet punching.
2. Samples of plain steel .
3. Calipers.

Procedure:

1. To do sheet punching, measuring D_u.
2. To calculate coefficient K_0 and collar height H
3. To write down the results of each measuring in the protocol 3.

Questions:

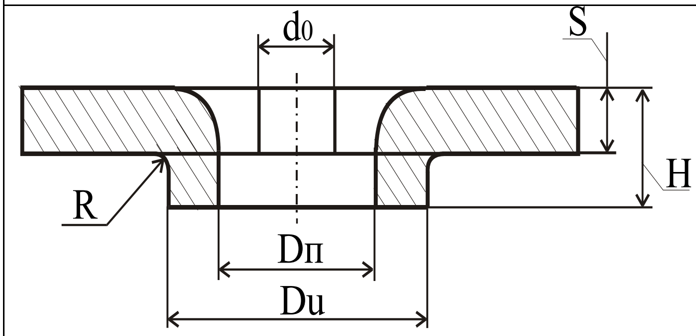
1. What are Plastic Deformation Processes?
2. What types of Plastic Deformation Processes do you know?
3. Explain Bulk Deformation Processes.
4. Explain Sheet-Forming Processes.
5. What kinds of metal forming exist depending on temperature?
6. Describe advantages and disadvantages of cold working.
7. Describe advantages and disadvantages of warm working.
8. Describe advantages and disadvantages of hot working.
9. Classification of Bulk Deformation Processes.
10. What is rolling? Draw the scheme of rolling.
11. What are the intermediate forms of blanks used for rolling.
12. What kinds of rolling do you know? Describe them.
13. What is Forging? Classification of forging.
14. What is Extrusion? Classification of extrusion.
15. Explain Direct and indirect extrusion.
16. What is drawing? Draw the scheme of Wire and Bar Drawing.
17. How to calculate draft and reduction during drawing?
18. Classification of Sheet Metalworking Processes
19. Draw the scheme of bending.
20. Draw the scheme of drawing.
21. Draw the scheme of shearing.
22. Describe Cutting Operations.
23. Describe Bending operations.
24. What is Deep drawing.
25. Measures of drawing. Write formulas.

LABORATORY WORK № 3

METAL FORMING

Sheet punching

Calculate the coefficient K_0 and collar height H if sheet thickness S = 1,2 mm, R = 1 mm. The value of d_0 and D_u select from a table (option V for number of student in the group list)

Sketch of blanks and details	d_0, mm	Diameter D_u				
		10	10,5	11	11,5	12
	5	V1	V2	V3	V4	V5
	5,5	V6	V7	V8	V9	V10
	6	V11	V12	V13	V14	V15
	6,5	V16	V17	V18	V19	V20
	7	V21	V22	V23	V24	V25

$K_o = d_o/(D_u - 2S)$,

K_0 =

$H = 0,5(D_u + 2(R+S) - d_o - \pi(R+0,5S))$

H=

____

____

Student's signature — Teacher's signature

"____"____________20___ y. — "____"_____________20___ y.

Laboratory work 4

WELDING OF METALS

Objectives:

1.To learn types of welding processes and advantages and disadvantages different kinds of fusion welding and solid-state welding.

2. To determinate welding's regimes (diameter of electrode, power of the welding current and welding velocity).

Scientific principle

Types of welding processes

Welding is a fabrication process that joins materials, usually metals. Welding is a material joining process for a permanent combining of two (or more) parts that involves melting and subsequent solidification of the material from two parts thus forming a strong joint between them. This is often done by melting the work-pieces and adding a filler material to form a pool of molten material that cools to become a strong joint, but sometimes pressure is used in conjunction with heat, or by itself, to produce the weld. There are eight welding processes which are divided into three categories depending on the heat source (fig.4.1.).

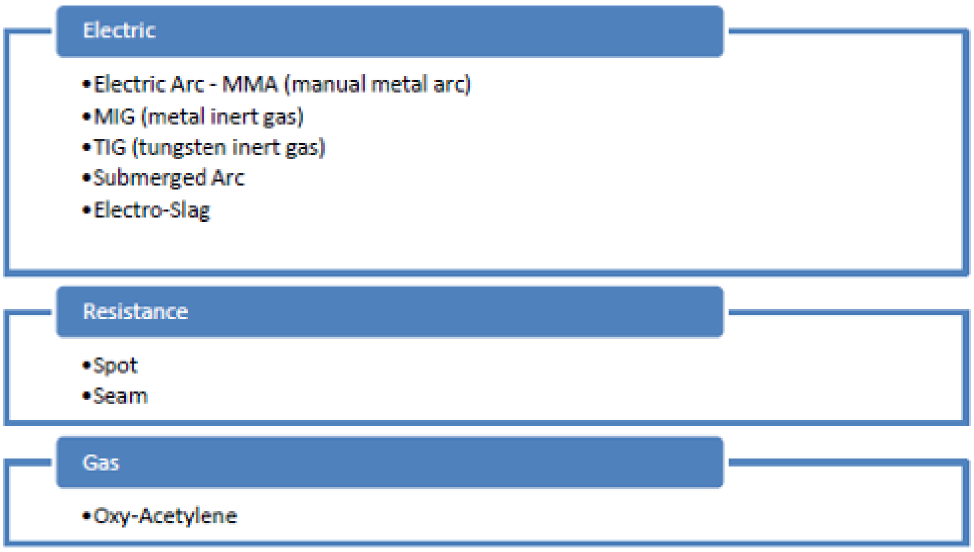


Fig.4.1. Categories of welding processes depending on the heat source

There are two groups of welding processes according to the state of the base material during the welding process:

-*Liquid-state welding* (*fusion welding*), and

- *Solid-state welding.*

Fusion welding is by far the more important category. In fusion welding, the base material is heat to melt. The most important processes in this group fall in the following categories:

Arc welding: heating and melting of the material is accomplished by an electric arc;

Oxyfuel gas welding: an oxyfuel gas produces a flame to melt the base material;

Resistance welding: the source of heat is the electrical resistance on the interface between two parts held together under pressure.

In **solid-state welding**, two parts are jointed together under pressure or a combination of pressure and heat. If heat is applied, the contact temperature is below the melting point of the base metal. Two welding processes are the most popular from this group,

Diffusion welding: parts coalesce by solid-state diffusion;

Friction welding: coalescence is achieved by the heat of friction between two parts.

FUSION WELDING

Arc welding

Arc welding (AW) is a fusion welding process in which coalescence of the metals is achieved by the heat from an electric arc between an electrode and the work. A generic AW process is shown in the figure 4.2:

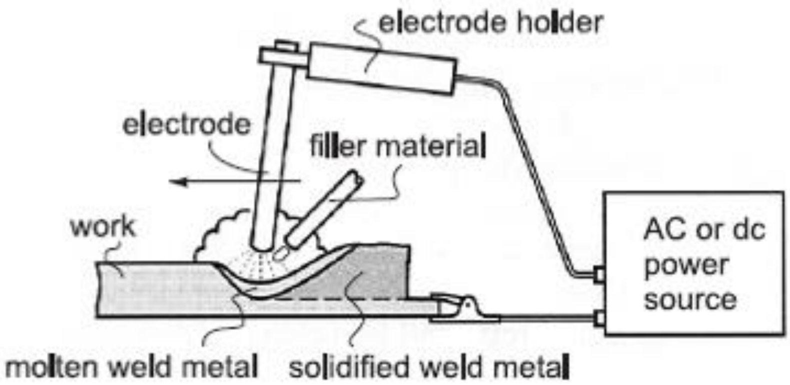


Fig.4.2. Arc welding process

An electric arc is a discharge of electric current across a gap in a circuit. To initiate the arc in an AW process, the electrode is brought into contact with the work and then quickly separated from it by a short distance. The electric energy from the arc thus formed produces temperatures of 5000° C or higher, sufficiently hot to melt any metal.

A pool of molten metal, consisting of base metal(s) and filler metal (if one is used), is formed near the tip of the electrode.

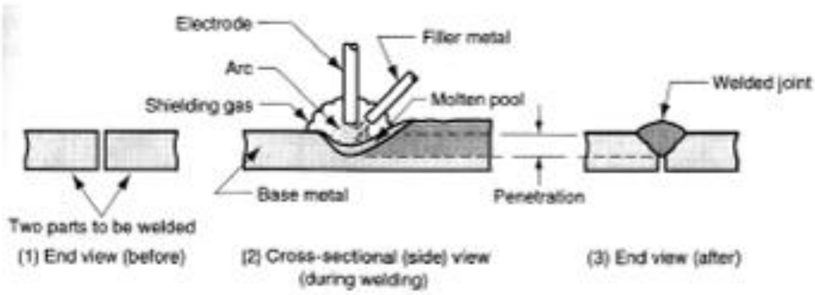


Fig.4.3.The basic configuration of an arc welding operation

In most arc welding processes, filler metal is added during the operation to increase the volume and strength of the weld joint. As the electrode is moved along the joint, the molten weld pool solidifies in its wake. Movement of the electrode relative to the work is accomplished by either a human welder (manual welding) or by mechanical means (machine welding, automatic welding, or robotic welding). In manual arc welding, the quality of the weld joint is very dependent on the skill and experience of the human welder. The weld quality is much better in the machine, automatic, and robotic welding. Electrodes in AW process are classified as *consumable*, which melts continuously in the process of arc welding thus providing the required filler material, and *non-consumable*, which resist melting by the arc. The filler material must be supplied separately.

Fig.4.4. Electrodes for manual arc welding

Different types of the weld joints are showen below on the figure 4.5.

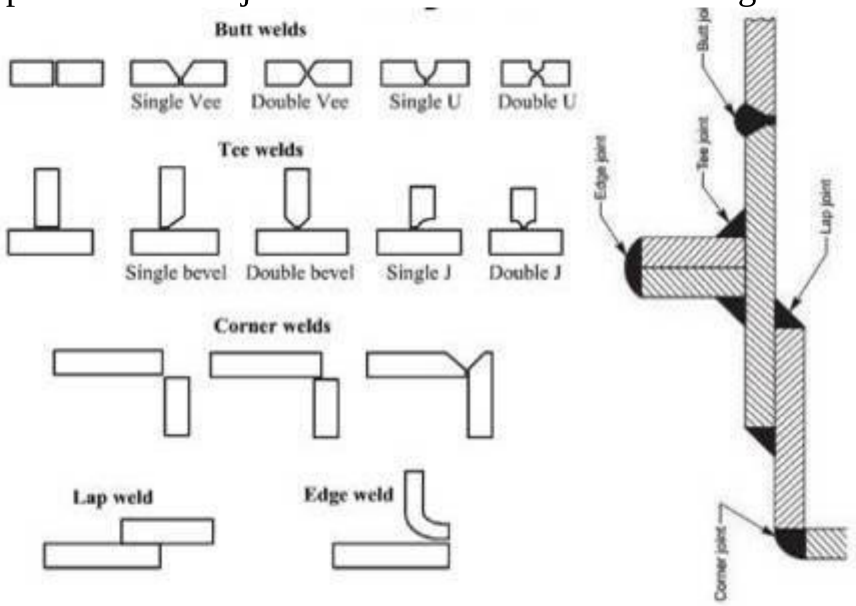


Fig.4.5. Weld joints

The effects of welding

Wherever a weld has caused metal to melt there will be an adjacent heat affected zone (HAZ). The size of the heat-affected zone will depend on the size of the weld being laid, the number of runs used to lay the weld, the thickness of the parent material and the electric current used for welding.

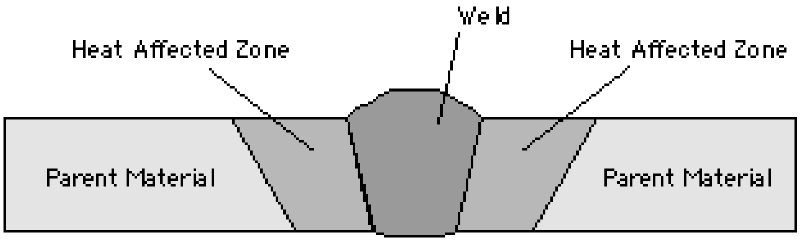


Fig 4.6. The main zone of the weld joint

Shielded Metal Arc Welding

Shielded Metal Arc Welding (SMAW) is an arc welding process that uses a consumable electrode consisting of a filler metal rod coated with chemicals that provide flux and shielding. The process is illustrated in the figure 4.7:

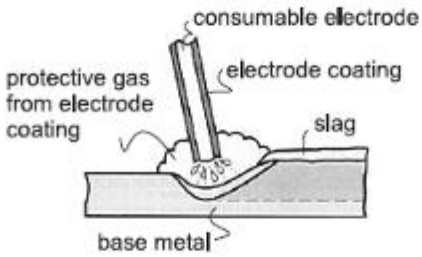


Fig 4.7. Shielded metal arc welding operation

The coated welding stick (SMAW is sometimes called ***stick welding***) is typically 200 to 450 mm long and 1.5 to 9.5 mm in diameter. The heat of the welding process melts the coating to provide a protective atmosphere and slag for the welding operation. During operation the bare metal end of the welding stick is clamped in an electrode holder connected to the power source. The holder has an insulated handle so that it can be held and manipulated by a human welder. Currents typically used in SMAW range between 30 and 300 A at voltages from I5 to 45 V depending on the metals being welded, electrode type and length and depth of weld penetration required.

Shielded metal arc welding is usually performed manually. Common applications include construction, pipelines, machinery structures, shipbuilding, fabrication job shops, and repair work. It is preferred over oxyfuel welding for thicker sections above 5 mm because of its higher power density. The equipment is portable and low cost, making SMAW highly versatile and probably the most widely used of the AW welding processes. Base metals include steels, stainless steels, cast irons, and certain nonferrous alloys.

More than 50% industrial arc welding is done by this method.

Submerged Arc Welding

Submerged arc welding (SAW) is an arc welding process that uses a continuous, consumable bare wire electrode. The arc shielding is provided by a cover of granular flux. The electrode wire is fed automatically from a coil into the arc. The flux is introduced into the joint slightly ahead of the weld arc by gravity from a hopper, as shown in the figure 4.8.

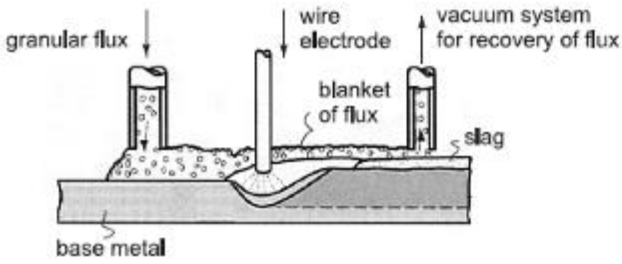


Fig. 4.8. Submerged arc welding operation

The blanket of granular flux completely submerges the arc welding operation, preventing sparks, spatter, and radiation that are so hazardous in other arc welding processes. The portion of the flux closest to the arc is melted, mixing with the molten weld metal to remove impurities and then solidifying on top of the weld joint to form a glasslike slag. The slag and infused flux granules on top provide good protection from the atmosphere and good thermal insulation for the weld area. This results in relatively slow cooling and a high-quality weld joint.

The infused flux remaining after welding can be recovered and reused. The solid slag covering the weld must be chipped away usually by manual means. This process is widely used for automated welding of structural shapes, longitudinal and circumferential seams for large-diameter pipes, tanks, and pressure vessels. Because of the gravity feed of the granular flux, the parts must always be in a horizontal orientation.

Gas Metal Arc Welding

Gas Metal Arc Welding (GMAW) is an arc welding process in which the electrode is a consumable bare metal wire and shielding is accomplished by flooding the arc with a gas. The bare wire is fed continuously and automatically from a spool through the welding gun, as illustrated in the figure 4.9.

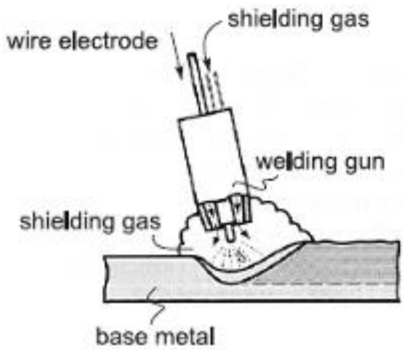


Fig.4.9. Gas metal arc welding operation

Wire diameters ranging from 1 to 6 mm are used in GMAW, the size depending on the thickness of the pats being joined. Gases used for shielding include inert gases such as argon and helium and active gases such as carbon dioxide. Selection of gases depends mainly on the metal being welded. Inert gases are used for welding aluminum alloys and stainless steel and in this case the process is often referred to as **MIG/MAG welding** (for metal-inert gas/metal-argon welding). In welding steel, carbon dioxide (CO_2), which is less expensive than inert gases, is used. Hence, the term **CO_2 welding** is applied.

Arc welding with non-consumable electrodes

Gas Tungsten Arc Welding

Gas Tungsten Arc Welding (GTAW) is an arc welding process that uses a non-consumable tungsten electrode and an inert gas for arc shielding. Shielding gases typically used include argon, helium or a mixture of these gases. The GTAW process can be implemented with or without a filler metal. The figure 4.10. illustrates the latter case.

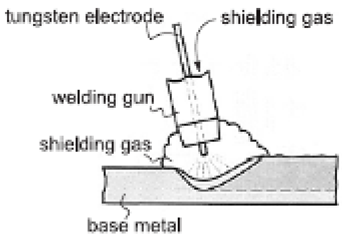


Fig.4.10. Gas Tungsten Arc Welding

When thin sheets are welded to close tolerances, filler metal is usually not added. When a filler metal is used, it is added to the weld pool from a separate rod or wire. The term ***TIG welding*** (tungsten inert gas welding) is often applied to this process. GTAW is applicable to nearly all metals in a wide range of stock thickness. It can also be used for joining various combinations of dissimilar metals. Its most common applications are for aluminum and stainless steel. The process can be performed manually or by machine and automated methods for all joint types. Advantages of GTAW in the applications to which it is suited include high-quality welds, no weld spatter because no filler metal is transferred across the arc, and little or no post-weld cleaning because no flux is used.

Plasma Arc Welding

Plasma Arc Welding (PAW) is a special form of gas tungsten arc welding in which a plasma arc is directed at the weld area. The tungsten electrode is contained in a specially designed nozzle that focuses a high-velocity stream of inert gas (for example, argon or argon-hydrogen mixtures, and helium) into the region of the arc to produce a high-velocity plasma jet of small diameter and very high-energy density, as in the figure 4.11:

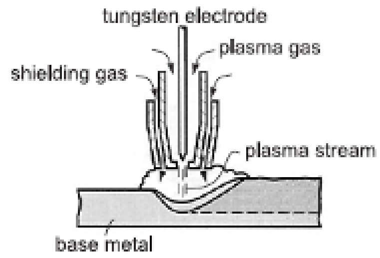


Fig.4.11. Plasma Arc Welding

Temperatures in plasma arc welding reach 30,000° C or greater, hot enough to melt any known metal. Plasma Arc Welding is used as a substitute for GTAW in applications such as automobile subassemblies, metal cabinets, door and window frames, and home appliances. The process can be used to weld almost any metal, including tungsten.

Weld quality in arc welding

The rapid heating and cooling in localized regions of the work during fusion welding, especially arc welding, result in thermal expansion and contraction, which cause transverse and longitudinal residual stresses in the weldment. These stresses is likely to cause distortion of the welded assembly: (*Left*) transverse and longitudinal residual stress pattern; and (*Right*) likely distortion in the welded assembly (fig.4.12).

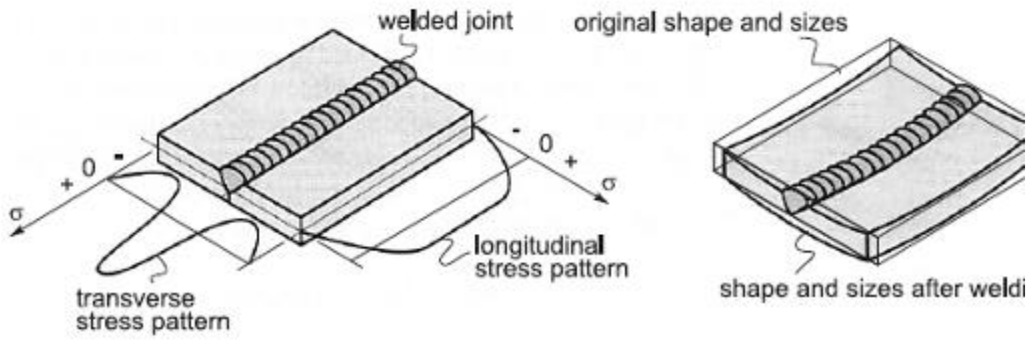


Fig.4.12. Transverse and longitudinal residual stresses in the weldment

The welding begins at one end and travels to the opposite end of the welded joint. As it proceeds, the molten metal quickly solidifies behind the moving arc. The portions of the work immediately adjacent to the weld bead become extremely hot and expand, while portions removed from the weld remain relatively cool. This results in an additional shrinkage across the width of the weldment.

Various techniques can be employed to minimize distortion in a weldment. Some of these techniques include the following:

Welding fixtures that physically restrain movement of the parts during welding;

Tack welding at multiple points along the joint to create a rigid structure prior to continuous welding;

Preheating the base parts, which reduces the level of thermal stresses experienced by the parts;

Stress relief *heat treatment* of the welded assembly.

In addition to residual stresses and distortion in the final assembly, other defects can also occur in welding (fig.4.13).

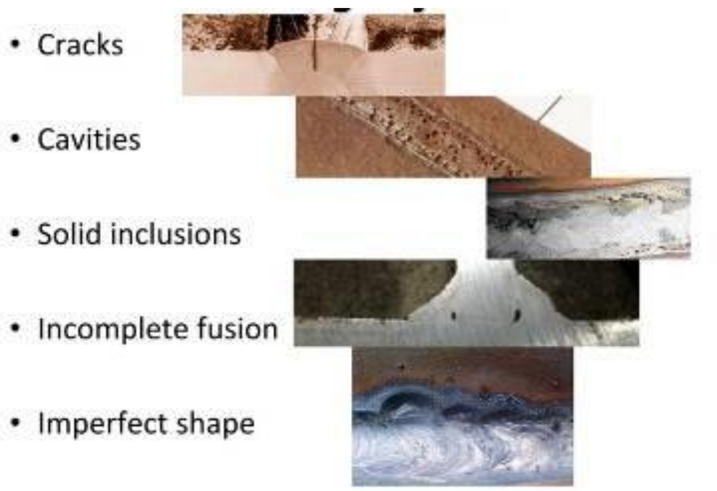


Fig.4.13. Welding defects

Cracks**:** Fracture-type interruptions either in the weld or in the base metal a djacent to the weld. This type is perhaps the most serious welding defect because it constitutes a discontinuity in the metal that causes significant reduction in the strength of the weldment. Generally, this defect can and must be repaired.

Cavities**:** These include various porosity and shrinkage voids. ***Porosity*** consists of small voids in the weld metal formed by gases entrapped during solidification. Porosity usually results from inclusion of atmospheric gases, or contaminants on the surfaces.

Shrinkage voids are cavities formed by shrinkage during solidification.

Solid inclusions**:** Solid inclusions are any nonmetallic solid material entrapped in the weld metal. The most common form is slag inclusions generated during the various welding processes that use flux.

Incomplete fusion**:** Fusion does not occur throughout the entire cross section of the joint.

Oxyfuel gas welding

Oxyfuel gas welding is the term used to describe the group of fusion operations that burn various fuels mixed with oxygen to perform welding or cutting and separate metal plates and other parts. The most important oxyfuel gas welding process is oxyacetylene welding.

Oxyacetylene welding (OAW) is a fusion welding process performed by a high-temperature flame from combustion of acetylene and oxygen. The flame is directed by a welding torch and a filler metal in the form of rod is added if the process is applied to weld. Composition of the filler must be similar to that of the base metal. A typical oxyacetylene welding operation is sketched in the figure 4.14. Oxyfuel gas welding operation. Oxyacetylene welding uses equipment that is relatively inexpensive and portable. It is therefore an economical, versatile process that is well suited to low-quantity production and repair jobs.

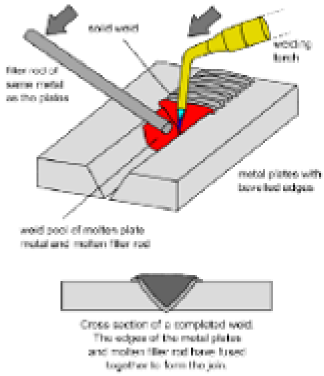


Fig 4.14. Oxyacetylene welding.

It is rarely used on the welding of sheet and plate stock thicker than 6 mm because of the advantages of arc welding in such applications. Although OAW can be mechanized, it is usually performed manually and is hence dependent on the skill of the welder to produce a high-quality weld joint.

RESISTANCE WELDING

Resistance welding (RW) is a group of fusion welding processes that utilizes a combination of heat and pressure to accomplish coalescence. The heat required is generated by electrical resistance to current flow at the interface of two parts to be welded. The resistance welding processes of most commercial importance are **spot and seam welding.**

Resistance Spot Welding

Resistance spot welding (RSW) is a resistance welding process in which fusion of the base metal is achieved at one location by opposing electrodes. The cycle in a spot welding operation consists of the steps depicted in the figure 4.15:

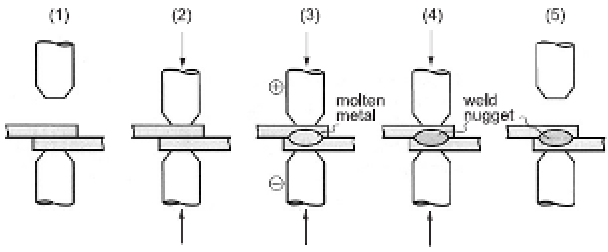


Fig.4.15. Steps in a spot welding cycle: (1) parts inserted between open electrodes, (2) electrodes close and force is applied, (3) weld time (current is switched), (4) current is turned off but force is maintained, and (5) electrodes are opened, and the welded assembly is removed

A spot welding machine (fig 4.16) holds two pieces of thin metal together with a strong force while an electric current is applied through the clamping arms. The electrical resistance at the junction causes the electrical current to heat the local spot. The combination of heat and pressure produces a fusion weld. This process is common in joining car body panels, with the small round spots clearly visible at the edges of a panel.

Fig 4.16. A spot welding unit with sheet metal in place

Resistance spot welding is widely used in mass production of automobiles, appliances, metal furniture, and other products made of sheet metal of thickness 3 mm or less. Because of its widespread industrial use, various machines and methods are available to perform spot welding operations. The equipment includes rocker arm and press-type spot welding machines for larger work.

For large, heavy work, portable spot welding guns are available in various sizes and configurations. They are widely used in automobile final assembly plants to spot-weld the sheet-metal car bodies. Human workers operate some of these guns, but industrial robots have become the preferred technology.

Resistance Seam Welding

In **Resistance Seam Welding** (RSEW), the electrodes are two rotating wheels as shown in the figure 4.17:

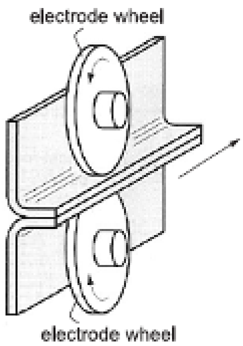


Fig 4.17. Resistance Seam Welding

In the process of welding, a series of overlapping spot welds is made along the lap joint. The process is capable of producing airtight joints, and its industrial applications include the production of gasoline tanks, automobile mufflers, and various others fabricated sheet-metal containers. The spacing between the weld nuggets in resistance seam welding depends on the motion of the electrode wheels relative to the application of the weld current. In the usual method of operation, called ***continuous motion welding***, the wheel is rotated continuously at a constant velocity, and current is turned on at timing intervals consistent with the desired spacing between spot welds along the seam so that overlapping weld spots are produced.

SOLID-STATE WELDING

The solid-state welding group includes the oldest joining process as well as some of the most modern.

Forge welding is a welding process in which the components to be joined are heated to hot working temperatures and then forged together by hammer or other means. Considerable skill was required by the craftsmen who practiced it to achieve a good weld. The process is of historic significance in the development of manufacturing technology; however, it is of minor commercial importance today.

Cold Roll Welding

Cold roll welding is a solid-state welding process accomplished by applying high pressure by means of rolls between clean contacting surfaces at room temperature (fig.4.18):

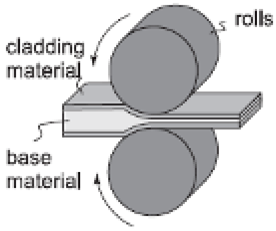


Fig 4.18. Cold Roll Welding operation

Metals to be welded must be very ductile and free of work hardening. Contact surfaces must be exceptionally clean. Metals such as soft aluminum, copper, gold and silver can be readily cold-welded. For small parts, the forces may be applied by simple handoperated tools. For heavier work, powered presses are required to exert the necessary force. Applications of cold welding include cladding stainless steel to mild steel for corrosion resistance, making bimetallic strips for Cold welding (also cladding) process measuring temperature, and producing sandwich strips for coins.

Diffusion Welding

Diffusion Welding is a solid-state welding process that results from the application of heat and pressure, usually in a controlled atmosphere, with sufficient time allowed for solid-state diffusion and coalescence to occur. Temperatures are well below the melting points of the metals, and plastic deformation at the surfaces is only minimal.

Applications of diffusion welding include the joining of high-strength and refractory metals in the aerospace and nuclear industries. The process is used to join both similar and dissimilar metals, and in the latter case a filler layer of a different metal is often sandwiched between the two base metals to promote diffusion. A limitation of the process can be the time required for diffusion to occur between the faying surfaces; this time can range from seconds to hours.

Explosion welding

Explosion Welding is a solid-state welding process in which rapid coalescence of two metallic surfaces is caused by the energy of a detonated explosive.

Explosion welding is commonly used to bond two dissimilar metals, in particular to clad one metal on top of a base metal over large areas. Applications include production of corrosion-resistant sheet and plate stock for making processing equipment in the chemical and petroleum industries. The term *explosion cladding* is used in this context. No filler metal is used in explosion welding, and no external heat is applied.

Friction welding

Friction welding is a solid-state welding process in which coalescence is achieved by frictional heat combined with pressure. The heat is generated by the friction between the two components surfaces, usually by rotation of one part relative to the other. Then the parts are driven toward each other with sufficient force to form a metallurgical bond. The sequence is portrayed in the figure 4.19 for the typical application of this operation, welding of two cylindrical parts.

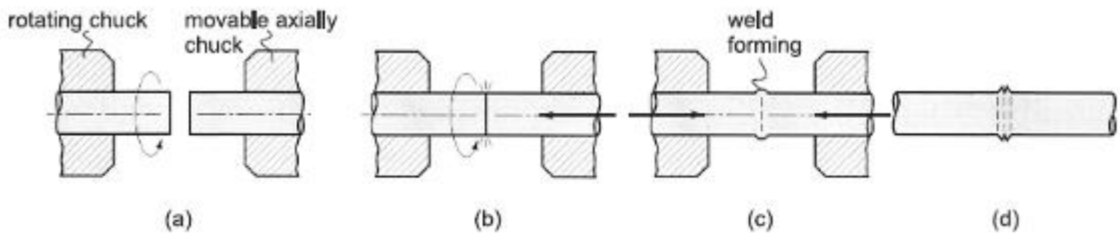


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Fig 4.19**.** Friction welding operation

The axial compression force upsets the parts, and the material displaced produces a flash. The flash must be subsequently trimmed to provide a smooth surface in the weld region. No filler metal, flux, or shielding gases are required. Machines used for friction welding have the appearance of an engine lathe. They require a powered spindle to turn one part at high speed and a means of applying an axial force between the rotating part and the non-rotating part. With its short cycle times, the process is suitable for mass production. It is applied in the welding of various shafts and tubular parts of similar or dissimilar metals. One typical application of friction welding is to coalesce medium-carbon steel shanks to carbide tips in producing twist drills. Friction welding: (a) no contact, (b) parts brought into contact to generate friction heat, (c) rotation stops and axial pressure applied, (d) final product showing the flash.

Equipment:

1. AC or DC power source.
2. Electrodes.
3. Filler material.
4. Electrode holder.
5. Spot welding machine.
6. Samples of plain steel .

Procedure:

1. To do manual arc welding.
2. To do spot welding process.
3. To calculate welding’s regimes.
4. To write down the results of each measuring in the protocol.

Questions:

1. What is welding?
2. What types of welding depending on the heat source do you now?
3. What types of welding according to the state of the base material do you now?
4. Explain fusion welding Processes.
5. Explain Solid-state welding Processes.
6. What kinds of fusion welding do you now?
7. What kinds of Solid-state welding do you now
8. Describe and draw Arc welding process.
9. Draw different types butt weld joints.
10. Draw different types tee weld joints.
11. Draw different types corner weld joints.
12. Draw lap and edge weld joints.
13. Describe and draw main zone of the weld joint.
14. What is electrode? Classification of electrodes.
15. Describe and draw Shielded metal arc welding operation.
16. Describe and draw Submerged arc welding operation.
17. Describe and draw Gas Tungsten Arc Welding Process.
18. Explain various techniques can be employed to minimize distortion in a weldment.
19. Classification of welding defects
20. Explain Oxyfuel gas welding Processes.
21. Describe and draw Oxyacetylene welding
22. Explain Resistance welding Processes.
23. Describe and draw Resistance spot welding.
24. Describe and draw Resistance seam welding.
25. Describe and draw Cold Roll Welding operation
26. Describe Diffusion Welding.
27. Describe Explosion Welding.
28. Describe and draw Friction welding operation.

LABORATORY WORK № 4

WELDING OF METALS

Protocol № 1

Arc welding

Draw operational sketch and calculate the regimes of welding according with individual task by variant

(α_s – The coefficient surfacing of electrode, g/A·hrs. (in practical calculations for welding of construction steels are taking α_s=9,5 g/A·hrs.);

ρ – density of metal welded parts, kg/m^3 (for construction steels ρ=7800 kg/m^3);

p – parameter that characterizes the position of the seam in space (p = 1 for horizontal, p = 2 for the lower, p = 3 for the vertical weld)

Type of weld joint	The provisions of weld	The thickness of the workpieces *S*, mm				
		4	5	6	7	8
Butt	Horizontal	V1	V6	V11	V16	V21
Lap	Vertical	V2	V7	V12	V17	V22
Tee	Lower	V3	V8	V13	V18	V23
Corner	Horizontal	V4	V9	V14	V19	V24
Butt	Vertical	V5	V10	V15	V20	V25

Operational sketch	Calculation of regimes
	Diameter of electrode d_e=3,5+0,125S at 4mm≤S<20mm, Power of the welding current $I_w=d_e(20+6d_e)$ Welding velosity $V_w=1000I_w\alpha_s/[\rho(p+5)d_e]$ m/h

Student's signature   Teacher's signature

"____"____________20___ y.   "____"_____________20___ y.

LABORATORY WORK № 5

MACHINING TREATMENT OF METALS

Objectives:

1.To learn types of turning and milling processes.
2. To determinate cutting conditions in turning and milling.

Scientific principle

***Machining*:** term applied to all material-removal processes.

Metal cutting*:** the process in which a thin layer of excess metal (chip***) is removed by a wedge-shaped single-point or multipoint ***cutting tool*** with defined geometry from a ***workpiece,*** through a process of extensive plastic deformation.

Abrasive processes*:* material removal by the action of hard, abrasive particles that are usually in the form of a ***bonded wheel***. Each single particle acts like a single-point cutting tool. Since the particular geometry of a particle is not known, abrasive processes are referred to as ***machining with geometrically undefined tools***

Machining operations are capable of producing more precise dimensions and smooth surface finishes than all other manufacturing processes. They are performed after other processes, which create the general shape of the parts. Machining then provides the final geometry, dimensions and finish.

Turning is a machining process to produce parts round in shape by a single point tool on ***lathes.*** The tool is fed either linearly in the direction parallel or perpendicular to the axis of rotation of the workpiece, or along a specified path to produce complex rotational shapes. The ***primary*** motion of cutting in turning is the rotation of the workpiece, and the ***secondary*** motion of cutting is the feed motion.

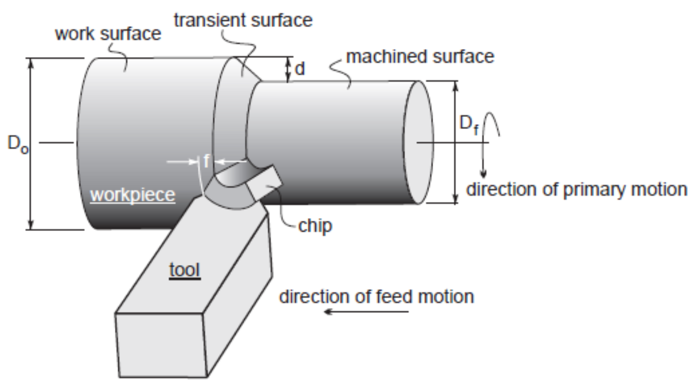


Fig. 5.1. Turning operation

Cutting conditions in turning

Cutting speed in turning V in **m/s** is related to the rotational speed of the workpiece by the equation:

$$\mathbf{V = \pi DN} \tag{5.1}$$

where D is the diameter of the workpiece, m;

N is the rotational speed of the workpiece, rev/s.

Cutting speed in turning V in **m/min** is related to the rotational speed of the workpiece by the equation:

$$V = \pi DN/1000 \qquad (5.2)$$

where D is the diameter of the workpiece, mm;

N is the rotational speed of the workpiece, rev/min.

Feed f in turning is generally expressed in mm/tr (millimetres per revolution).

The turning operation reduces the diameter of the workpiece from the initial diameter D_o to the final diameter D_f. ***Depth of cut***, d in mm:

$$d = (D_o – D_f)/2 \qquad (5.3)$$

Major time of turning T_o is determined by the formula:

$$T_o = (L_{cutting} + L_{turning} + L_{exit})\ I / f\ n, \ldots \qquad (5.4)$$

where $L_{cutting}$ - cutting length (for the smooth entry of the tool to the workpiece material) mm;

$L_{turning}$ - turning length, mm;

L_{exit} - length of the release of the tool from the area of processing, mm;

I - the amount of passes;

f - feed, mm / rev;

n - spindle speed, rev / min.

Operations in turning

Turning is not a single process but class of many and different operations performed on a lathe.

Turning of cylindrical surfaces

The lathe can be used to reduce the diameter of a part to a desired dimension. The resulting machined surface is cylindrical.

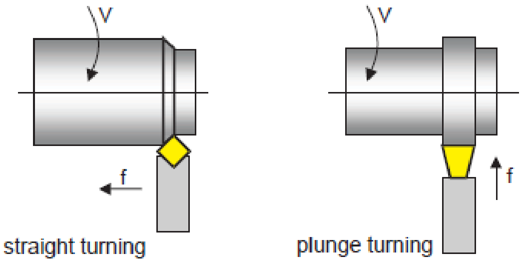


Fig.5.2. Turning of cylindrical surfaces

Turning of flat surfaces

A lathe can be used to create a smooth, flat face very accurately perpendicular to the axis of a cylindrical part. Tool is fed radially or axially to create a flat machined surface.

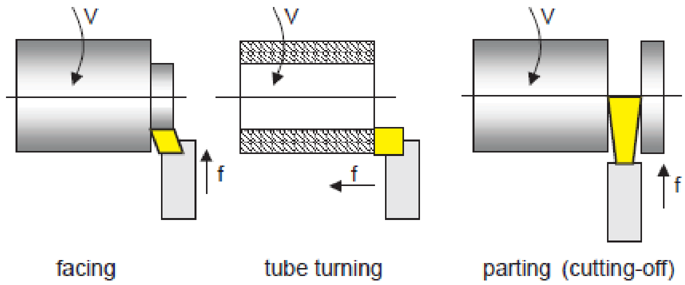


Fig.5.3. Turning of flat surfaces

Threading

Different possibilities are available to produce a thread on a lathe. Threads are cut using lathes by advancing the cutting tool at a feed exactly equal to the thread pitch. The single-point cutting tool cuts in a helical band, which is actually a thread. The procedure calls for correct settings of the machine, and also that the helix be restarted at the same location each time if multiple passes are required to cut the entire depth of thread. The tool point must be ground so that it has the same profile as the thread to be cut.

Another possibility is to cut threads by means of a *thread die* (external threads), or a *tap* (internal threads). These operations are generally performed manually for smal thread diameters.

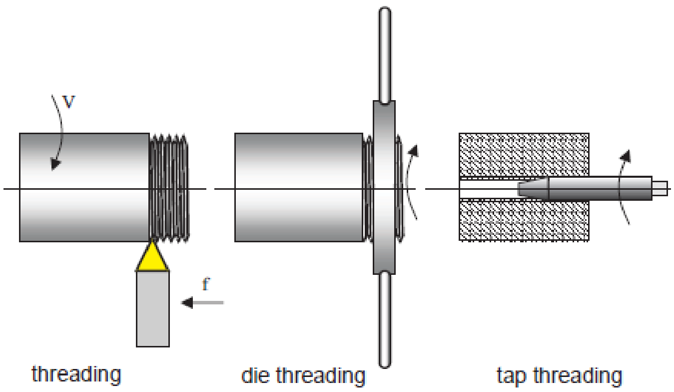


Fig.5.4. Threading

Form turning

Cutting tool has a shape that is imparted to the workpiece by plunging the tool into the workpiece. In form turning, cutting tool is complex and expensive but feed is linear and does not require special machine tools or devices.

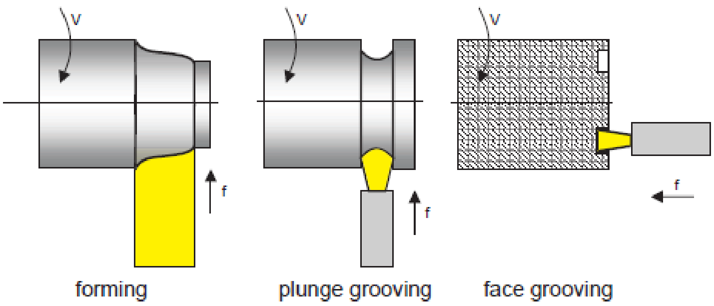


Fig.5.5. Form turning

Contour turning (profiling)

Cutting tool has a simple shape, but the feed motion is complex; cutting tool is fed along a contour thus creating a contoured shape on the workpiece. For profiling, special lathes or devices are required.

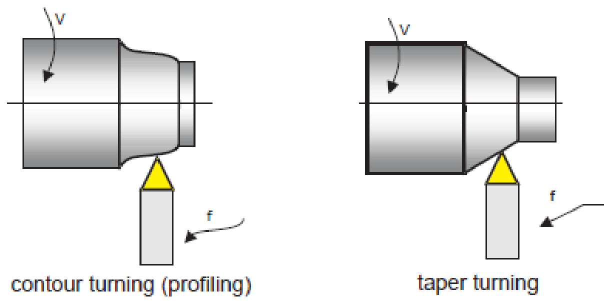


Fig.5.6. Contour turning (profiling)

Miscellaneous operations

Some other operations, which do not use the single-point cutting tool can be performed on a lathe, making turning one of the most versatile machining processes.

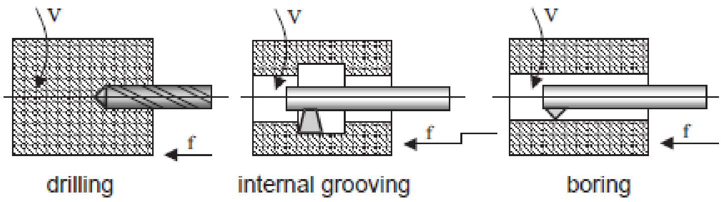


Fig.5.7. Miscellaneous operations

Knurling

This is not a machining operation at all, because it does not involve material removal. Instead, it is a metal forming operation used to produce a regular crosshatched pattern in the work surface.

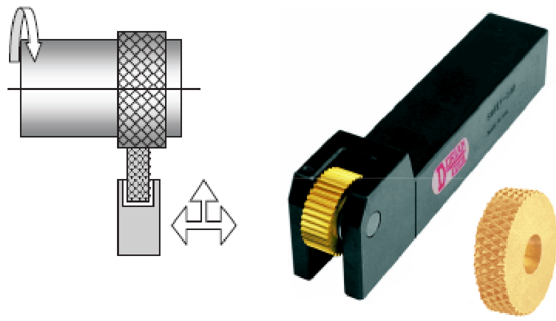


Fig.5.8. Knurling

Lathes

A lathe is a machine tool that rotates the workpiece against a tool whose position it controls. The *spindle* (see picture in the next page) is the part of the lathe that rotates. Various work holding attachments such as *three jaw chucks*, *collets*, and *centers* can be held in the spindle. The spindle is driven by an electric motor through a system of belt drives and gear trains. Spindle rotational speed is controlled by varying the geometry of the drive train. The *tailstock* can be used to support the end of the workpiece with a *center*, or to hold tools for drilling, reaming, threading, or cutting tapers. It can be adjusted in position along the *ways* to accommodate different length workpieces. The *tailstock barrel* can be fed along the axis of rotation with the *tailstock hand wheel*.

The *carriage* controls and supports the cutting tool. It consists of:

a *saddle* that slides along the *ways*;

an *apron* that controls the feed mechanisms;

a *cross slide* that controls transverse motion of the tool (toward or away from the operator);

a *tool compound* that adjusts to permit angular tool movement;

a *tool post* that holds the cutting tools.

There are a number of different lathe designs, and some of the most popular are discussed here.

Engine lathes

The basic, simplest and most versatile lathe. This machine tool is manually operated that is why itrequires skilled operators. Suitable for low and medium production, and for repair works.

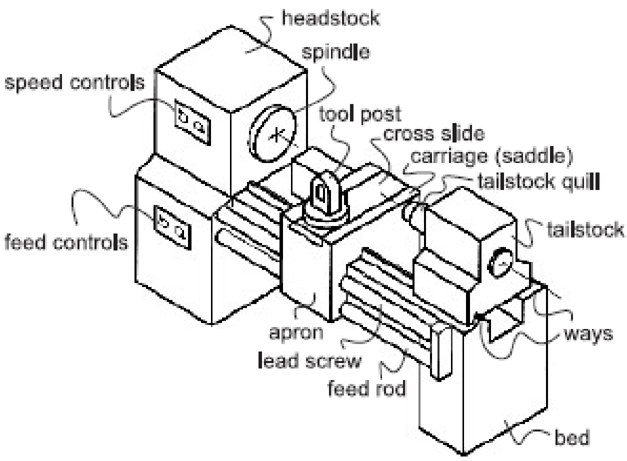


Fig.5.9. The principal components of an engine lathe

There are two **tool feed mechanism** in the engine lathes. These cause the cutting tool to move when engaged.

The *lead screw* will cause the apron and cutting tool to advance quickly. This is used for cutting threads, and for moving the tool quickly.

The *feed rod* will move the apron and cutting tool slowly forward. This is largely used for most of the turning operations.

Work is held in the lathe with a number of methods,

Between two *centres*. The workpiece is driven by a device called a *dog*. The method is suitable for parts with high *length-to-diameter ratio*.

A *3 jaw self-centering chuck* is used for most operations on cylindrical workparts. For parts with high *length-to-diameter ratio* the part is supported by center on the other end.

Collet consists of tubular bushing with longitudinal slits. Collets are used to grasp and hold barstock. A collet of exact diameter is required to match any barstock diameter.

A *face plate* is a device used to grasp parts with irregular shapes:

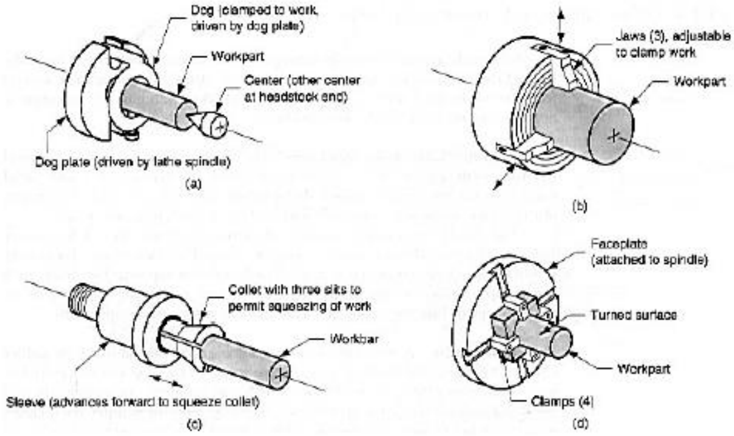


Fig. 5.10. Four work holding methods used in lathes: (a) mounting the work between centers using a dog, (b) three-jaw chuck, (c) collet, and (d) face plate for noncylindrical workparts.

Cutting tools

The geometry and nomenclature of cutting tools used in turning is standardized by ISO 3002/1-1982:

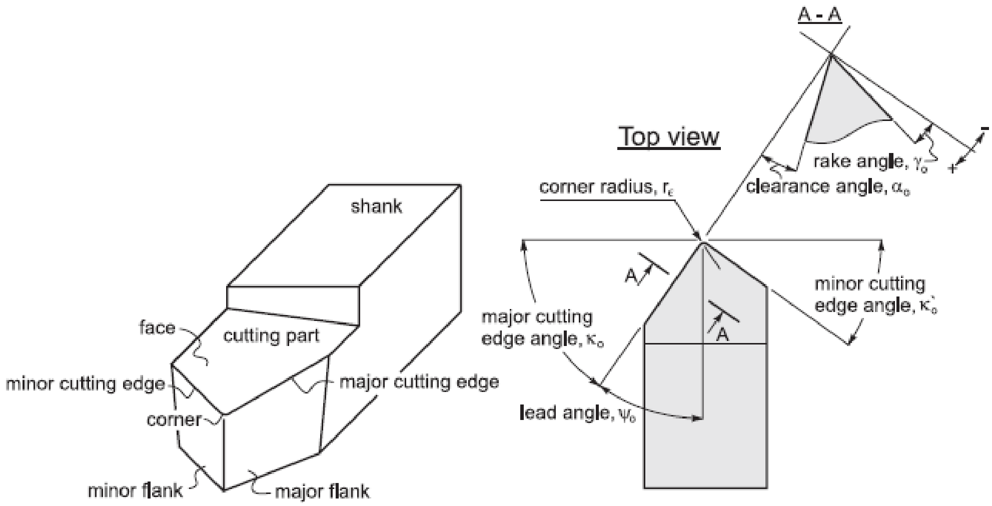
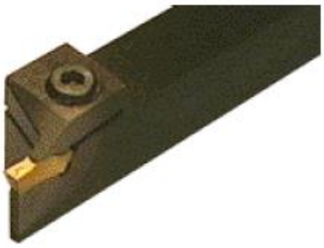


Fig.5.11. Cutting edges, surfaces and angles on the cutting part of a turning tool

The figure shows only the most important geometrical features of a turning cutting tool. Recommendations for proper selection of the cutting tool geometry are available in the reference materials.

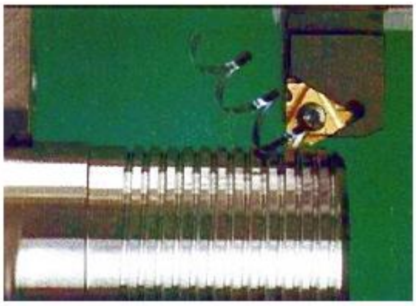
Cutting tool are available in different brazed or clamped designs for different operations. Some of the clamped tools are shown in the figures:

Cutting tool for straigth turning



Cutting tool for grooving

Cutting tool for profiling



Cutting tool for threading

Fig.5.12. Some of the clamped tools

MILLING

Milling is a process of producing flat and complex shapes with the use of multi-tooth cutting tool, which is called a *milling cutter* and the cutting edges are called *teeth*. The axis of rotation of the cutting tool is perpendicular to the direction of feed, either parallel or perpendicular to the machined surface.

The machine tool that traditionally performs this operation is a *milling machine*.

Milling is an interrupted cutting operation: the teeth of the milling cutter enter and exit the work during each revolution. This interrupted cutting action subjects the teeth to a cycle of impact force and thermal shock on every rotation. The tool material and cutter geometry must be designed to withstand these conditions. Cutting fluids are essential for most milling operations.

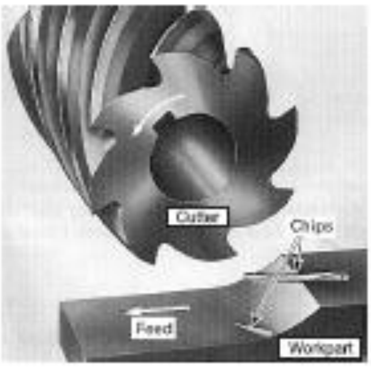


Fig. 5.13. Milling operation. The cutter is lifted to show the chips, and the work, transient, and machined surfaces.

Cutting conditions in milling

In milling, each tooth on a tool removes part of the stock in the form of a chip. The basic interface between tool and workpart is pictured below. This shows a only a few teeth of a peripheral milling cutter:

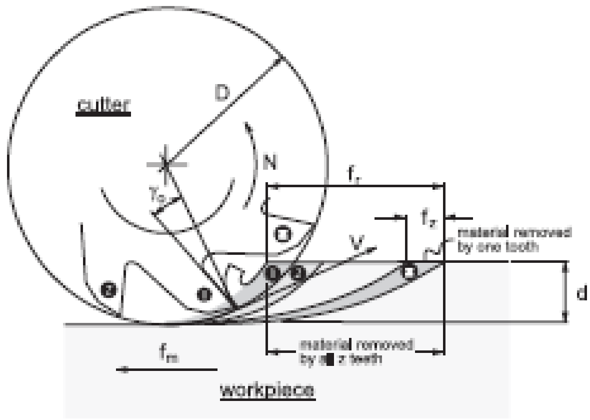


Fig. 5.14. Basics of a peripheral (slab) milling operation.

Cutting velocity V is the peripheral speed of the cutter is defined by

$$\mathbf{V = \pi DN,} \tag{5.3}$$

where D is the cutter outer diameter, and N is the rotational speed of the cutter.

As in the case of turning, cutting speed V is first calculated or selected from appropriate reference sources, and then the rotational speed of the cutter N,which is used to adjust milling machine controls is calculated. Cutting speeds are usually in the range of 0.1~4 m/s, lower for difficult-to-cut materials and for rough cuts, and higher for non-ferrous easy-to-cut materials like aluminum and for finishing cuts.

Three types of ***feed in milling*** can be identified:

feed per tooth $\mathbf{f_z}$: the basic parameter in milling equivalent to the feed in turning. Feed per tooth is selected with regard to the surface finish and dimensional accuracy required. Feeds per tooth are in the range of 0.05~0.5 mm/tooth, lower feeds are for finishing cuts;

feed per revolution $\mathbf{f_r}$**:** it determines the amount of material cut per one full revolutionof the milling cutter. Feed per revolution is calculated as

$$\mathbf{f_r = f_z z,} \tag{5.4}$$

z being the number of the cutter's teeth;

feed per minute $\mathbf{f_m}$: Feed per minute is calculated taking into account the rotational speed N and number of the cutter's teeth z,

$$\mathbf{f_m = f_z zN = f_r N}, \tag{5.5}$$

Feed per minute is used to adjust the feed change gears.

Productivity of milling $\boldsymbol{P_m}$ determined as the amount of details that are made for a certain period of time T (month, shift, hour):

$$\mathbf{P_m = T / T_d,} \tag{5.3}$$

where T_d - the time of one detail processing, min.

The main component of detail time processing is the **major technological time** $\mathbf{T_m}$**.** That time taken to directly change the state of the workpiece (shape, size). It is determined by the formula

$$\mathbf{T_m = L\ I / f_m,} \tag{5.4}$$

where L - the calculated length of the workpiece, mm;

I - the number of passes cutters.

The calculated length of the workpiece:

$$\mathbf{L} = l_1 + l + l_2, \quad (5.5)$$

where l_1 - length by cutting mills, mm;

l - milling workpiece length, mm;

l_2 – exit cutters, mm.

The lengths l_1, l, l_2 determined by used operating sketch of milling.

Types of milling

There are two basic types of milling, as shown in the figure 5.15:

down **(*climb*)** milling, when the cutter rotation is in the same direction as the motion of the workpiece being fed, and ***up*** **(*conventional*)** milling, in which the workpiece is moving towards the cutter, opposing the cutter direction of rotation:

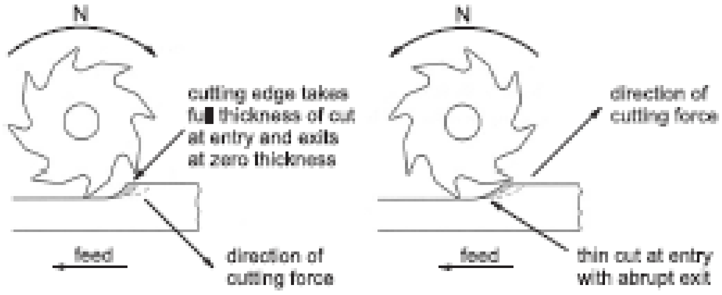


Fig. 5.15. Two types of peripheral milling.

In down milling, the cutting force is directed into the work table, which allows thinner workparts to be machined. Better surface finish is obtained but the stress load on the teeth is abrupt, which may damage the cutter.

In up milling, the cutting force tends to lift the workpiece. The work conditions for the cutter are more favourable. Because the cutter does not start to cut when it makes contact (cutting at zero cut is impossible), the surface has a natural waviness.

Milling Operations

Owing to the variety of shapes possible and its high production rates, milling is one of the most versatile and widely used machining operations. The geometric form created by milling fall into three major groups:

Plane surfaces: the surface is linear in all three dimensions. The simplest and most convenient type of surface;

Two-dimensional surfaces**:** the shape of the surface changes in the direction of two of the axes and is linear along the third axis. Examples include cams;

Three-dimensional surfaces**:** the shape of the surface changes in all three directions. Examples include die cavities, gas turbine blades, propellers, casting patterns, etc.

MILLING OF FLAT SURFACES

Peripheral Milling

In *peripheral milling*, also called *plain milling*, the axis of the cutter is parallel to the surface being machined, and the operation is performed by cutting edges on the outside periphery of the cutter. The primary motion is the rotation of the cutter. The feed is imparted to the workpiece.

Several types of peripheral milling are shown in the figure,

slab milling, the basic form of peripheral milling in which the cutter width extends beyond the workpiece on both sides;

slotting, also called *slot milling*, in which the width of the cutter, usually called *slotter*, is less than the workpiece width, creating a slot in the workpiece. The slotter has teeth on the periphery and over the both end faces. When only the one-side face teeth are engaged, the operations is known as the *side milling*, in which the cutter machines the side of the workpiece;

straddle milling, which is the same as side milling, only cutting takes place on both sides of the work. In straddle milling, two slotters mounted on an arbor work together;

when the slotter is very thin, the operation called *slitting* can be used to mill narrow slots (slits) or to cut a workpart in two. The slitting cutter (*slitter*) is narrower than the slotter and has teeth only on the periphery.

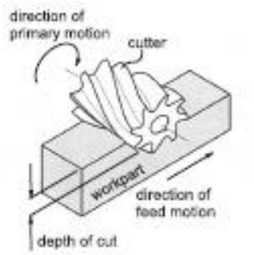


Fig.5.16. Peripheral slab milling operation

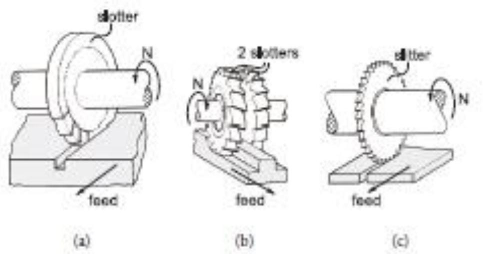


Fig. 5.17. Peripheral milling operations with narrow cutters: (a) slotting, (b) straddle milling, and (c) slitting.

Some of the advantages of peripheral milling include,

- More stable holding of the cutter. There is less variation in the arbor torque; Lower power requirements;
- Better work surface finish.

Face milling

In *face milling*, cutter is perpendicular to the machined surface. The cutter axis is vertical, but in the newer CNC machines it often is horizontal. In face milling, machining is performed by teeth on both the end and periphery of the face-milling cutter. Again up and down types of milling are available, depending on directions of the cutter rotation and feed.

Face milling is usually applied for rough machining of large surfaces. Surface finish is worse than in peripheral milling, and feed marks are inevitable. One advantage of the face milling is the high production rate because the cutter diameter is large and as a result the material removal rate is high. Face milling with large diameter cutters requires significant machine power.

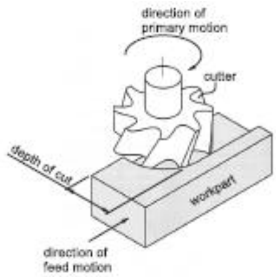


Fig. 5.18. Partial face milling operation. The facemilling cutter machines only one side of the workpiece.

Fig.5.19. Conventional face milling operation. The face-milling cutter machines the entire surface. The cutter diameter is greater than the workpart width.

End milling

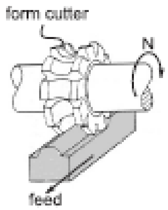
In *end milling*, the cutter, called *end mill*, has a diameter less than the workpiece width. The end mill has helical cutting edges carried over onto the cylindrical cutter surface. End mills with flat ends (so called *squire-end mills*) are used to produce pockets, closed or end key slots, etc.:

Fig.5.20. End milling operation used to cut a pocket in an aluminum workpart.

MILLING OF COMPLEX SURFACES

Milling is one of the few machining operations, which are capable of machining complex *two*- and *three-dimensional surfaces*, typical for dies, molds, cams, etc. Complex surfaces can be machined either by means of the cutter path (*profile milling* and *surface contouring*), or the cutter shape (*form milling*).

Form milling In form milling, the cutting edges of the peripheral cutter (called *form cutter*) have a special profile that is imparted to the workpiece. Cutters with various profiles are available to cut different two-dimensional surfaces. One important application of form milling is in gear manufacturing.



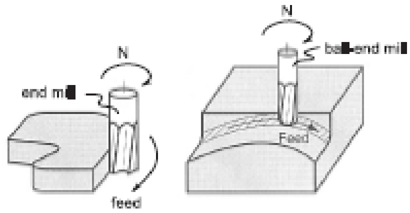


Fig. 5.21. Form milling of two dimensional surface.

Fig. 5.22. *(Left)* Profile milling of a cam, and (*Right*) Surface contouring of a complex three-dimensional surface.

Profile milling

In ***profile milling***, the conventional end mill is used to cut the outside or inside periphery of a flat part. The end mill works with its peripheral teeth and is fed along a curvilinear path equidistant from the surface profile.

Surface contouring.

The end mill, which is used in surface contouring has a hemispherical end and is called *ball-end mill*. The ball-end mill is fed back and forth across the workpiece along a curvilinear path at close intervals to produce complex three-dimensional surfaces. Similar to profile milling, surface contouring require relatively simple cutting tool but advanced, usually computer-controlled feed control system.

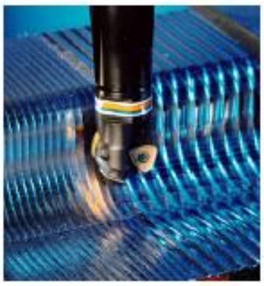


Fig. 5.23. Close-up view of a hemispherical ball-end mill with indexed carbide inserts used for rough cutting of a three-dimensional surface.

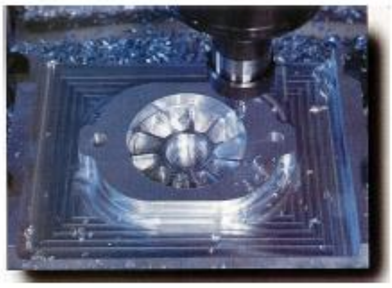


Fig. 5.24. Surface contouring of die cavity. The cutter used is a high-speed steel ball-end mill.

Milling machines

The conventional milling machines provide a primary rotating motion for the cutter held in the spindle, and a linear feed motion for the workpiece, which is fastened onto the worktable. Milling machines for machining of complex shapes usually provide both a rotating primary motion and a curvilinear feed motion for the cutter in the spindle with a stationary workpiece. Various machine designs are available for various milling operations. In this section we discuss only the most popular ones, classified into the following types:

Column-and-knee milling machines;

Bed type milling machines;

Machining centers.

Column-and-knee milling machines

The *column-and-knee milling machines* are the basic machine tool for milling. The name comes from the fact that this machine has two principal components, a *column* that supports the spindle, and a *knee* that supports the work table. There are two different types of column-and-knee milling machines according to position of the spindle axis: horizontal, and vertical.

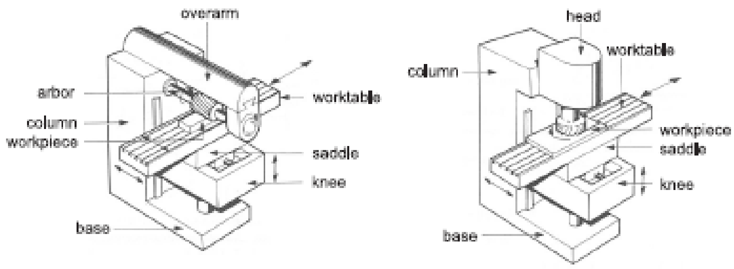


Fig.5.25. Two basic types of column-and-knee milling machines, (*Left*) horizontal, and (*Right*) vertical.

The column-and-knee milling machine is one of the most versatile machine tool suitable for most of the milling operations. There are many modifications of the basic type, some of them allow for worktable and/or head swivelling at an angular orientation to machine angular shapes on workparts.

Many of modern column-and-knee milling machines are CNC type used to machine complex shapes.

Fig. 5.26. CNC vertical column-and-knee milling machine.

Milling cutters

Classification of milling cutters according to their design include the following:
HSS cutters. Many cutters like end mills, slittingcutters, slab cutters, angular cutters, form cutters, etc., are made from high-speed steel (HSS).

Brazed cutters: Very limited number of cutters (mainly face mills) are made with brazed carbide inserts. This design is largely replaced by mechanically attached cutters.

Mechanically attached cutters: The vast majority of cutters are in this category. Carbide inserts are either clamped or pin locked to the body of the milling cutter.

Fig.5.27. Assortment of high-speed steel milling cutters.

High-speed steel is the cutting tool material that is used to produce cutting tools of complex designs for low to medium cutting speeds.

Classification of milling cutters may also be associated with the various milling operations. The figures 5.28 illustrate two of the most important types of milling cutters, end mills and ball-end mills.

Fig.5.28. Two of the most widely used types of milling cutters with mechanically attached carbide inserts, (*Left*) end mills, and (*Right*) ball-end mills.

Equipment:

1. Engine lathe.
2. Cutting tools.
3. Equipment to knurling.
4. Vertical column-and-knee milling machine.
5. High-speed steel milling cutters.
6. Simples for straight turning and knurling. Material – plain steel or brass.
7. Simple for plane surface milling. Material – plain steel or aluminum alloy.

Procedure:

1. To do straight turning.

2. To do knurling.
3. To do plane surface milling.
4. Calculate major time T_m for turning and milling, and collar height H
5. To write down the results of each measuring in the protocol .

<u>Questions:</u>

1. What is metal cutting?.
2. Explain the main motions during cutting.
3. List elements of cutting conditions. Write the formula for calculating cutting conditions.
4. List operations in turning.
5. List part of the lathe.
6. Draw the scheme turning of cylindrical surfaces.
7. Draw the scheme turning of flat surfaces.
8. Draw the scheme form turning.
9. What is cutting fluid?
10. Which tool is used for cutting
11. What is milling.
12. Which tool is used for milling?
13. List cutting conditions at milling.
14. Draw the scheme down milling.
15. Draw The Scheme Up Milling
16. List milling Operations of flat surfaces.
16. List milling Operations of complex surfaces.
17. List Milling Machines.
18. List milling cutters.

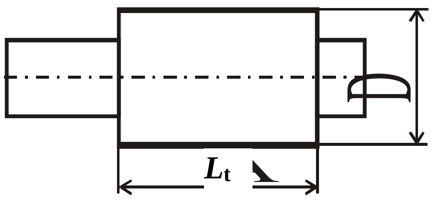
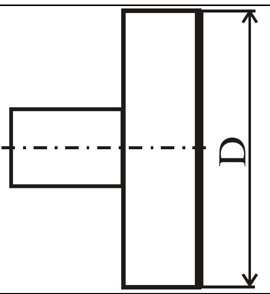
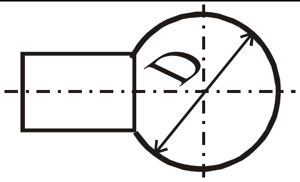
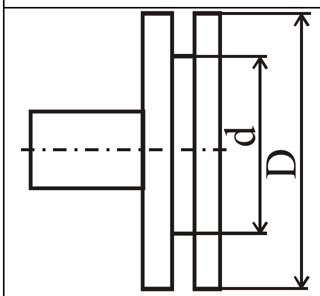
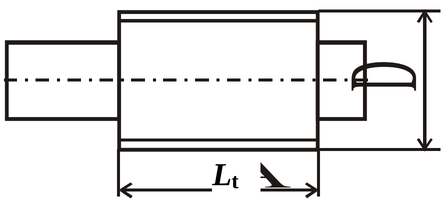
LABORATORY WORK № 5

MACHINING TREATMENT OF METALS

Protocol № 1

Turning

Choose a cutting tool, draw operational sketch and calculate the major time of turning for given surfaces. $L_{cut}=L_{ex}=5$ mm. Variant for the calculation is student's number in the group list.

Sketch of treatment	Conditions of processing					
		**V1**	**V6**	**V11**	**V16**	**V21**
	D, mm	100	90	80	70	60
	L_t, mm	120	110	100	90	80
	Turning of cylindrical surface diameter D on the length of L_t 3 passes f= 0,1 mm/rev, *V*= 60 m/min.					
		**V2**	**V7**	**V12**	**V17**	**V22**
	D, mm	140	130	120	110	100
	Turning end surface of the workpiece diameter D 2 passes. f= 0,05 mm/rev, *V*= 60 m/min.					
		**V3**	**V8**	**V13**	**V18**	**V23**
	D, mm	40	35	30	25	20
	Turning form cutter sphere of diameter D 1 pass. f= 0,1 mm/rev, **V**= 60 m/min.					
		**V4**	**V9**	**V14**	**V19**	**V24**
	D, mm	100	90	80	70	60
	d, mm	70	60	50	40	30
	Turning groove of diameter D to the diameter d. *S*= 0,05 mm/rev, *V*= 40 m/min.					
		**V5**	**V10**	**V15**	**V20**	**V25**
	D, mm	M24x 2	M22x 1,7	M20x 1,5	M18x 1,2	M16x1
	L_t, mm	120	110	100	90	80
	Turning thread on the length of L_t to diameter D 3 passes. *V*= 8 m/min.					

Operational sketch (contours of the workpiece and the instrument and direction of motion)	**Calculation T_m** $T_m = (L_{cutting} + L_{turning} + L_{exit}) I / f n$

Protokol № 2
Milling

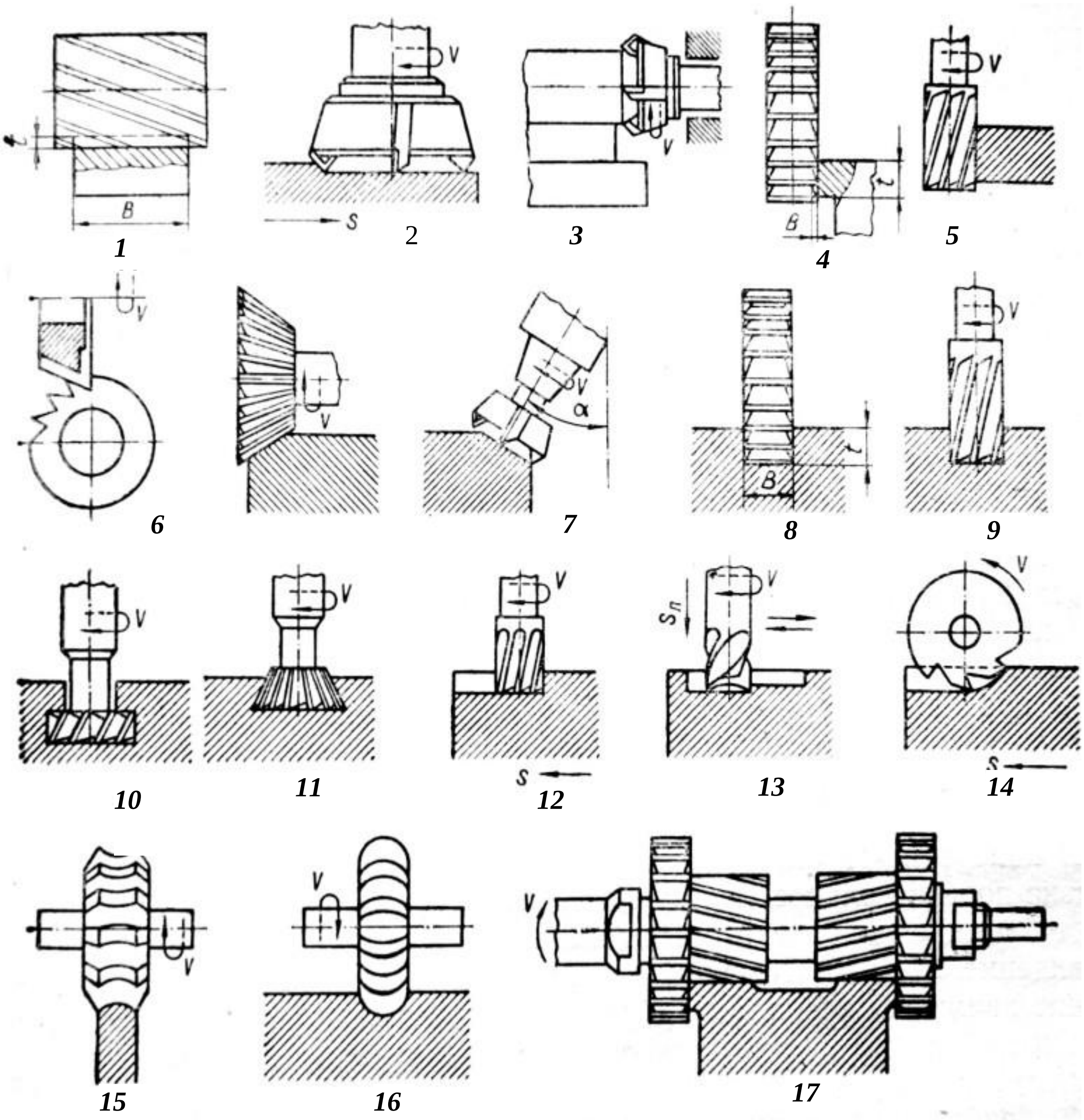


Fig.5.29. Milling machines process the various surfaces.

Horizontal plain surface (slab milling) – 1, 2
vertical plain surface (slab milling) – 3, 4, 5
inclined plain surface (face milling)– 6, 7
slot surface (slotting (slot milling)) – 8, 9
slot surface (T- like and type "swallowtail") (slotting)– 10, 11
slot surface (end milling) – 12, 13
slot surface (very thin) (slitting) – 14
form surfaces (form milling) 15, 16
complex surfaces (*straddle milling)* – 17
Horizontal column-and-knee milling machine – 1,3 4,6,8, 14, 15,16,17
Vertical column-and-knee milling machine 2, 5,7, 9, 10 (2 pass), 11 (2 pass),12, 13

Draw operational sketch and calculate Spindle speed N (tr/min), the major time of milling T_m and productivity of processing details P_m for 1 shift (8 hrs.) for given surfaces. Conventionally considered processing 1 parts equal to 1,3 T_m $\mathbf{T_d = 1.3\,T_m}$.

Variant for the calculation is student's number in the group list.

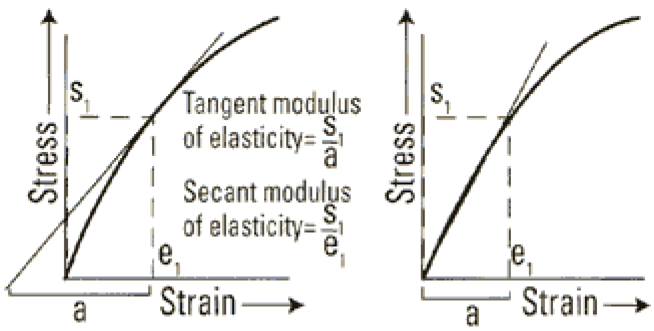
Var.	Cutting velocity, *V*, m/min.	Feed *f*f_z, mm/ tooth	Diam., *D*, mm	Number teeth, *z*	Pass *i*	Milling cutter	Milling cutter machine	Processed surface
1	15,7	0,04	110	30	2	Face	Vertical.	Plain, L=200
2	15,7	0,05	80	50	1	Disc	Horiz.	Slot, L=30, h=8
3	15,7	0,06	24	6	1	End	Vertical.	Circle, D=80
4	20,4	0,07	10	6	1	End	Vertical.	Slot, L=40, h=6
5	20,4	0,08	100	25	3	Cylindr	Horiz.	Plain, L=180
6	20,4	0,09	24	6	1	End	Vertical.	Rectangular contour 80x160
7	31,4	0,10	30	7	1	End	Vertical.	Circle, D=100
8	31,4.	0,04	100	40	3	Face	Vertical.	Plain, L=140
9	31,4	0,05	22	6	1	End	Vertical.	Semicircle, D=120
10	40,6	0,06	60	24	3	Cylindr	Horiz.	Plain, L=200
11	40,6	0,07	18	6	1	End	Vertical.	Square, a=140
12	40,6	0,08	60	27	1	Disc	Horiz.	Slot, L=20, h=6

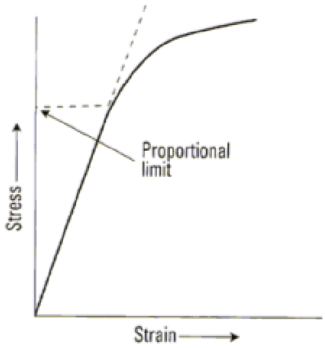
Operational sketch *(contours of the workpiece, the cutter and direction of motion)*	**Calculation N, T_m та P_m**
	$\mathbf{N = 1000V/\pi D}$ **tr/min** $\mathbf{T_m = L\,I / f_m}$, min $\mathbf{P_m = T / T_d}$

Student's signature ____________________ Teacher's signature ____________________

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

Glossary

Axial Strain	The strain in the direction that the load is applied, or on the same axis as the applied load.
Break Elongation	The elongation of the specimen to the break point.
Breaking Load	Load which causes fracture in a tensile, compression, flexure or torsion test. In tensile tests of textiles and yarns, breaking load also is called breaking strength
Breaking Strength	Tensile load or force required to rupture textiles (e.g., fibres, yarn) or leather. It is analogous to breaking load in a tension test. Ordinarily, breaking strength is reported as kN.
Coefficient of Elasticity	An alternate term for modulus of elasticity.
Compression Test	Method for determining behaviour of materials under axial loading in compression. A standard sample of material is placed under load tending to squash the material. Applied force and the resulting reduction in length are recorded, and often plotted as a load - reduction graph which can be converted to a compressive stress – strain graph for analysis. Commonly used in testing cement and concrete products.
Ductility	Extent to which a material can sustain plastic deformation without rupture. Percentage elongation and percentage reduction of area are common indices of ductility.
Elastic Limit	The greatest stress that can be applied to a material without causing permanent deformation. For metals and other materials that have a significant straight-line portion in their stress/strain diagram, elastic limit is approximately equal to the proportional limit. For materials that do not exhibit a significant proportional limit, elastic limit is an arbitrary approximation (the apparent elastic limit) found from a proof test.
Elasticity	Ability of a material to return to its original shape when the load-causing deformation is removed.
Engineering Stress	Load applied to a specimen in a tension or compression test divided by the cross-sectional area of the specimen. The change in cross-sectional area that occurs with increases and decreases in applied load, is disregarded in computing engineering stress. It is also called conventional stress.
Friction	The resistance encountered when one body slides, or tends to slide, over another body
Modulus of Elasticity	Rate of change of strain as a function of stress. The slope of the straight line portion of a stress-strain diagram. Tangent modulus of elasticity is the slope of the stress-strain diagram at any point. Secant modulus of elasticity is stress divided by strain at any given value of stress or strain. It also is called stress-strain ratio.  Moduli of elasticity in tension and compression are approximately equal and are known as Young's modulus.

Modulus of Toughness	The work done on a unit volume of material as a simple tensile force is gradually increased from zero to the value causing rupture is defined as the Modulus of Toughness. This may be calculated as the entire area under the stress-strain curve from the origin to rupture. Toughness of a material is its ability to absorb energy in the plastic range of the material.
Necking	Localised reduction of cross-sectional area of a specimen under tensile load. It is disregarded in calculating engineering stress but is taken into account in determining true stress.
Offset Yield Strength	Arbitrary approximation of elastic limit. It is the stress that corresponds to the point of intersection of a stress-strain diagram and a line parallel to the straight-line portion of the diagram. Offset refers to the distance between the origin of the stress-strain diagram, and the point of intersection of the parallel line and the 0 stress axis. Offset is expressed in terms of strain (often 0.2%). Often referred to as Proof Stress
Percent Elongation	Measure of the ductility of a material determined in a tensile test. It is the increase in gauge length (measured after rupture) divided by the original gauge length represented as a percentage. Higher elongation indicates higher ductility.
Plastic Deformation	Deformation that remains after the load causing it is removed. It is the permanent part of the deformation beyond the elastic limit of a material. It also is called plastic strain and plastic flow.
Plasticity	Tendency of a material to remain deformed, after reduction of the deforming stress, to a value equal to or less than its yield strength.
Proportional Limit	The highest stress at which stress is directly proportional to strain. It is the highest stress in a stress-strain diagram where the graph is a straight line. Proportional limit is equal to elastic limit for many metals. 
Reduction of Area	A measure of the ductility of metals obtained from a tensile test. It is the difference between the original cross sectional area of a specimen and the area of its smallest cross section after testing. It is usually expressed as % decrease in original cross section. The smallest cross section can be measured at or after fracture. For metals, it is usually measured after fracture, and for plastics and elastomers, it is measured at fracture.
Rupture Strength	Nominal stress developed in a material at rupture. It is not necessarily equal to ultimate strength. And, since necking is not taken into account in determining rupture strength, it seldom indicates true stress at rupture.
Shear Test	A method for determining the behaviour of materials under shear loading. A standard sample of material is placed between a punch and a die. The load tends to shear a section out of the material. Applied load (force) and the resulting deformation are recorded, and often plotted as a load - elongation graph which can be converted to a shear stress – strain graph for analysis. Data from this test is used to determine elastic limit, ultimate shear strength, yield strength and other shear properties.
Strain	Change per unit length in a linear dimension of a part or specimen under

	load. It is usually expressed as a percentage. Strain, as used with most mechanical tests, is based on the original gauge length of the specimen.
Strain Energy	Measure of energy absorption characteristics of a material under load up to fracture. It is equal to the area under the stress-strain curve, and is a measure of the toughness of a material.
Stress	The internal reaction within a specimen to an externally applied load. Calculated by dividing the applied load by the area through which it acts. As used with most mechanical tests, stress is based on original cross-sectional area without taking into account changes in cross sectional area due to the applied load. This is sometimes called conventional or engineering stress. True stress is equal to the load divided by the instantaneous cross-sectional area through which it acts.
Stress-Strain Diagram	Graph of stress as a function of strain. It can be constructed from data obtained in any mechanical test where load is applied to a material, and continuous measurements of stress and strain are made simultaneously. It is constructed for compression, tension and torsion tests. The applied load is converted to applied stress, and the resulting elongation is converted to strain. The two sets of figures are plotted on a graph. More useful than a load-elongation graph as it allows the direct comparison of many different materials and specimens.
Tensile Impact Test	Method for determining energy required to fracture a specimen under shock tensile loading. (Also known as Tension Impact Test)
Tensile Test	A method for determining behaviour of materials under axial loading in tension. A standard sample of material is placed under load tending to stretch the material. Applied load (force) and the resulting increase in length are recorded, and often plotted as a load - elongation graph which can be converted to a tensile stress – strain graph for analysis. Commonly used in testing metal and polymer products. Data from this test is used to determine elastic limit, elongation, modulus of elasticity, proportional limit, reduction in area, ultimate tensile strength, yield point, yield strength and other tensile properties.
Toughness	Toughness is the resistance of a material to fracture or break. It is usually measured in units of energy (Joules).
True Strain	Instantaneous % change in length of a specimen in a mechanical test. It is equal to the natural logarithm of the ratio of length at any instant to original length.
True Stress	Applied load divided by actual area of the cross section through which the load operates. It takes into account the change in cross section that occurs with changing load.
Ultimate Strength	Highest engineering stress developed in a material before rupture. Normally, changes in area due to changing load and necking are disregarded in determining ultimate strength.
Ultimate Compressive Strength	Ultimate strength of a material subjected to compressive loading. It is the maximum stress developed in a material in a compression test.
Ultimate Shear Strength	Ultimate strength of a material subjected to shear loading. It is the maximum stress developed in a material in a shear test.
Ultimate Tensile Strength	Ultimate strength of a material subjected to tensile loading. It is the maximum stress developed in a material in a tensile test.
Young's Modulus	Alternate term for modulus of elasticity in tension or compression.

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