Manufacturing

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Metal Forming

Casting

Casting is one of the oldest manufacturing processes, and even today is the first step in manufacturing most products.

"In a casting process, the liquid molten metal is poured into the mould cavity having the similar shape of the casting to be produced, & left free it to solidify and after solidification, the casting can be taken out by breaking the mould".

A **Pattern** is the replica of the part to be cast (to be produced) and is used to prepare the mould cavity. Patterns are made of either wood or metal.

An assembly of two or more metal blocks, or bonded refractory particles (sand) consisting of a primary cavity is called mould.

Advantages of Casting

1. Molten metal can flow into any small section in the mould cavity, hence any intricate shape can be produced.
2. Practically any material can be casted.
3. Tools required are very simple and inexpensive.
4. Due to same cooling rate from all directions, the uniform mechanical properties can be obtained.

Pattern Allowance - A pattern is always slightly different from the final job to be Produced. This difference in dimensions is referred as the pattern allowance.

Pattern size = casting size ± allowances

Shrinkage Allowance

1. Liquid Shrinkage
2. Solidification Shrinkage
3. Solid shrinkage

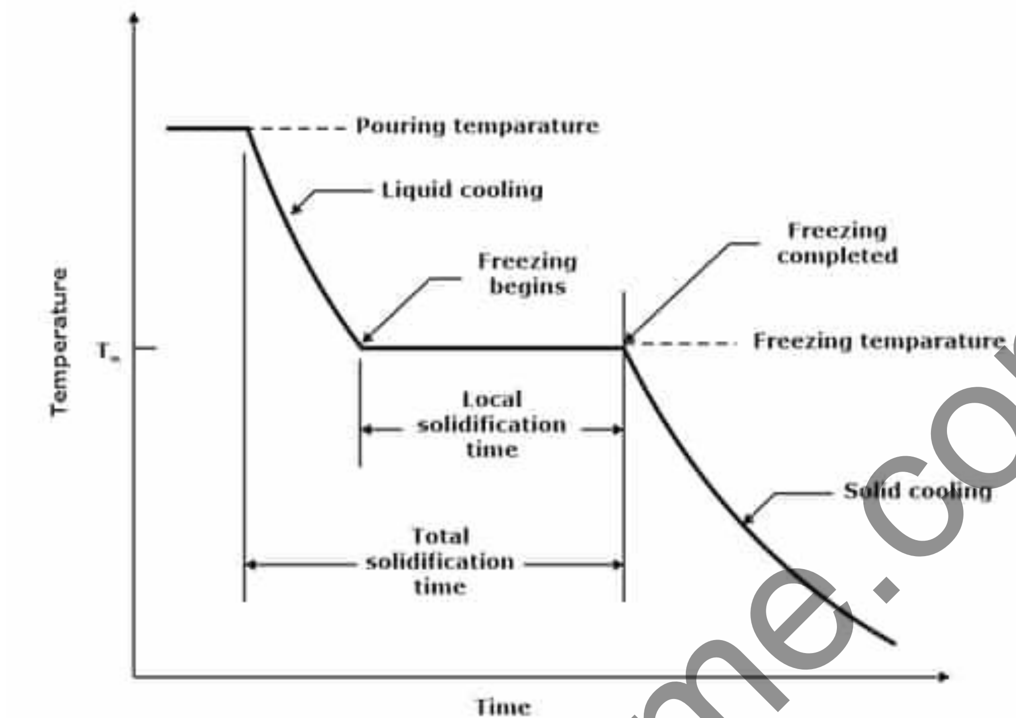


Fig.1: Cooling curve for a pure metal during casting.

Solid shrinkage,

Shrinkage allowance to be provided on pattern

$$\delta L = L\alpha\Delta T = L\alpha\left(T_F - T_o\right)$$

Where, δL=Change in dimension

L = Initial dimension of component

α = Coefficient of thermal expansion

Metals	Solid shrinkage in mm (per 1000mm)
Invar, Bismuth	0
White Metal	5
Cast iron	10
Aluminium	13
Copper	17
Steel	20
Brass	23

Machining Allowance:

The Typical machining allowances for sand castings range = 1.5 mm and 3 mm

Draft or Taper Allowance:

A draft facilitates easy withdrawal of the pattern. The value of the draft is between 0.5° and 2°.

Shake Allowance:

Allowance provided on the pattern to compensate this increase in size of the casting is known as shaking Allowance.

Distortion Allowances:

To avoid the distortion, the shape of pattern itself should be given a distortion of equal amount in the opposite direction of the likely distortion direction so that final product will come in true shape known as distortion allowance.

Types of Patterns

(i). Solid or single piece pattern:

It is the simplest pattern in which pattern is made up of single piece and it does not contain any attached part.

(ii). Split Pattern or Two-Piece Pattern

This pattern is used mainly for intricate castings.

(iii). Match plate pattern

Production efficiency and dimensional accuracy is improved by this method.

(iv). Cope and drag pawn:

The cope and drag halves of a split pattern are separately mounted on two match plates. Thus, the cope and the drag flasks are made separately and brought together (with accurate relative location) to produce the complete mould.

(v). Gated Pattern:

This is simply one or more than one loose pattern with attached gates and runners and provides a channel through which the molten metal can flow from the pouring sprue to the mould cavity.

(vi). Loose Piece Pattern:

In this pattern, the parts of the pattern will overhang such that It is not possible to remove the pattern from the sand, in any direction, even if parted.

(vii). Sweep pattern:

Sweep patten is used to generate surfaces of revolution in large castings, and to prepare moulds & it is done by sweeping the complete casting by means of a plane.

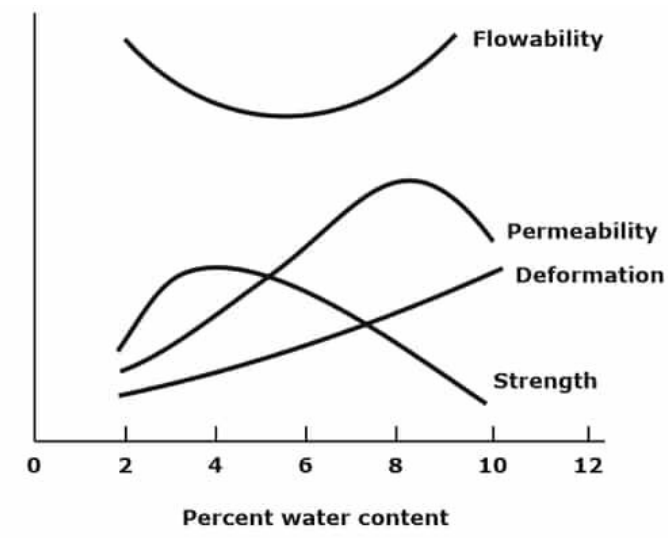
(viii). Follow board pattern:

It is used for castings where having structurally weak portions and are likely to break under the force of ramming if not supported.

(ix). Skeleton Pattern:

This type of pattern is useful generally for very large castings required in small quantities where large expense on complete wooden pattern is not justified.

Effect of moisture content on properties of moulding sand:



Properties of Moulding Sand

(i). Permeability:

It is the ability of moulding sand to allow the air to escape". It is important to remove the gases because the gases trapped inside the casting cause defects.

The permeability number is given by:

$$P_n = \frac{VH}{PAT}$$

Where,

V= volume of air in cm^3

H = height of the sand specimen in cm

P = air pressure, gm/cm^2

A = Cross section area of sand specimen in cm^2

T = time in minutes,

$$P_n = \frac{50.127}{T}$$

Where, T is in minute

(ii). Strength:

Measurement of strength of moulding sands can be carried out on the universal sand strength testing machine.

(iii). Green Strength:

The strength of the moist moulding sand is termed as green sand.

(iv). Dry Strength:

When the moisture in the moulding sand is completely removed, it is called dry sand.

(v). Hot Strength:

The strength of the sand that is required to hold the shape of the mould cavity is called hot strength.

(vi). Refractoriness:

The ability of with standing higher temperature of the molten metal so that it does not cause fusion i.e. without losing its strength and hardness is called refractoriness.

(vii). Mould Hardness:

Hardness is opposite to permeability. Higher the permeability number lower will be the hardness and vice versa.

(viii) Cohesiveness:

The ability to form bond between same material particles is called as cohesiveness.

(ix) Adhesiveness:

The ability of bond formation of sand particles with other materials is called adhesiveness.

(x) Collapsibility:

Collapsibility is the property of material due to which, it does not provide any resistance during the contraction of the solidified casting.

(xi). Flowability:

The ability of flowing of moulding sand into each and every corner of the mould is called flowability. Cavities and hollow projections, which are difficult to produce using the pattern alone, are produced with the help of core.

Core print:

- Recess provided in the mould for locating, positioning and supporting of cores is called core print.

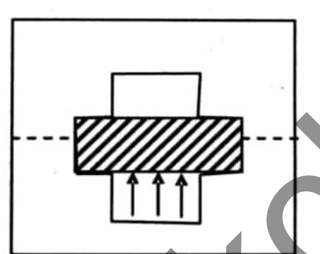


Fig.: buoyancy force on Core

Net buoyancy force acting on the core = Weight of liquid displaced due to projected portion —total weight of Core.

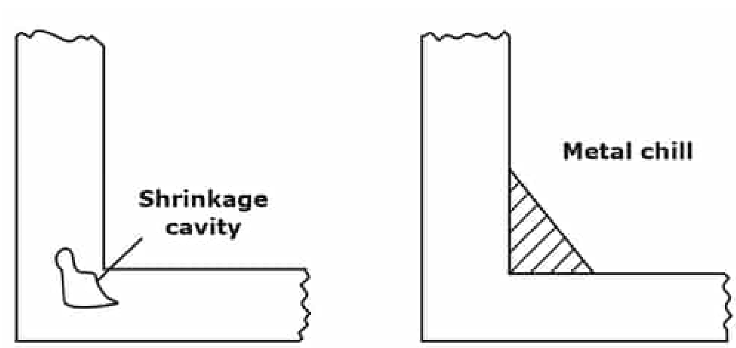
$F = Vg(\rho_m - \rho)$

Chaplets:

- Metallic supports, which are kept inside the mould cavity to support the cores, are called chaplets.
- Chaplets have the same composition as that of the pouring metal thus enough heat is present from the molten metal to completely melt them and thus fuse with it during solidification.

Chills:

Chills are metallic objects which is placed in the mould to increase the cooling rate of castings to provide uniform or desired cooling rate.



PADS OR PADDING

At the corner, due to improper ramming, there is always chances of erosion of sand When the molten metal is filled in mould cavity.

To avoid this, some objects are provided at the corner to support the mould which is known as pad & this process is known as padding.

Properties increases ↑	Effect on Fluidity
Pouring temperature	↑
Surface finish of the mould	↑
Viscosity	↓
Density	↓
Surface tension	↓
Moisture content	↓

Gating Ratio:

The gating ratio refer to the proportion of the cross-sectional areas between the sprue, runner and in-gates, and is generally denoted as sprue area, runner area, and ingate area.

Gating ratio = Ratio of (sprue area: runner area: ingate area)

Gating ratio = A_S: A_R: A_G

Casting Yield:

The casting yield is the proportion of the actual casting mass, m, to the mass of metal poured into the mould M.

$$\text{Casting yield} = \frac{m}{M} \times 100$$

Choke Area:

It is also the minimum area in whole gating system (sprue area, runner area, ingate area).

$$A = \frac{m}{C_d \rho t_f \sqrt{2gH}}$$

where H = effective metal head (sprue height), mm

Non-pressurized Gating System:

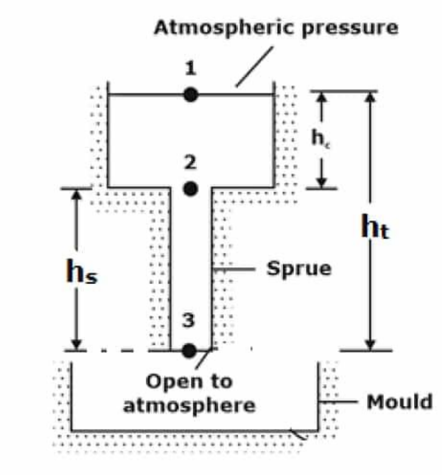
A non-pressurized gating system has choke area (minimum area) at the bottom of the sprue base and have total runner area and in-gate areas higher than the sprue area.

Pressurized Gating System:

In this system, the smallest area is the in-gate area and thus it maintains a back pressure throughout the gating system.

Top Gating System

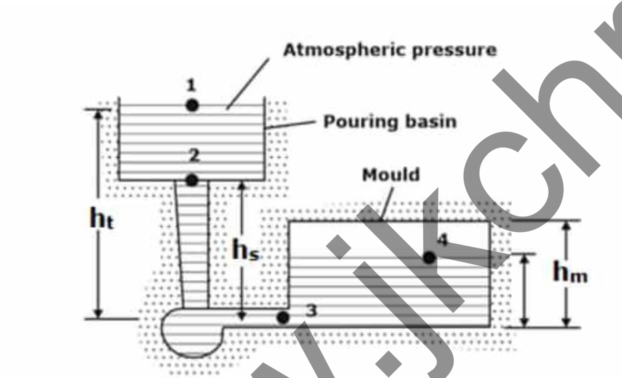
In top gating, the liquid metal is poured directly from the sprue to mould cavity with atmospheric pressure at the base.



Pouring or filling time for Top Gating:

$$t_f = \frac{A_m \times h_m}{A_g \times \sqrt{2gh_t}}$$

Bottom gating system:



$$t_f = 2\frac{A_m}{A_g}\frac{1}{\sqrt{2g}}\left[\sqrt{h_t} - \sqrt{h_t - h_m}\right]$$

where,

h_t =total height

h_m=height of the mould

Special case:

If height of the mould(h_m) is equal to total height (h_t).

$$(t_f)_{Bottom} = 2 \times (t_f)_{Top}$$

Solidification time:

"It is the time required for the casting to solidify after pouring" and this time is dependent on the size and shape of the casting.

Solidification time is given by Chvorinov's rule:

$$t_s = k\left(\frac{V}{SA}\right)^n$$

Where,

t_s = total solidification time

k = mould constant (or) solidification factor

V = volume of the casting,

SA = surface area of the casting,

Side Riser	**h = d**	$\left(\frac{A}{V}\right)=\frac{6}{d}$
Top Riser	**h =d/2**	$\left(\frac{A}{V}\right)=\frac{6}{d}$

MODULUS:

It is the ratio of volume to surface area of any casting. This formula is applicable for risers also.

$$M = \frac{V}{SA}$$

Methods of Riser Design

Caine's Method:

This method can be used to calculate the dimensions of the Riser for the simple shape of the castings.

$$\text{Freezing ratio (FR)} = \frac{\left(\frac{SA}{V}\right)_C}{\left(\frac{SA}{V}\right)_R}$$

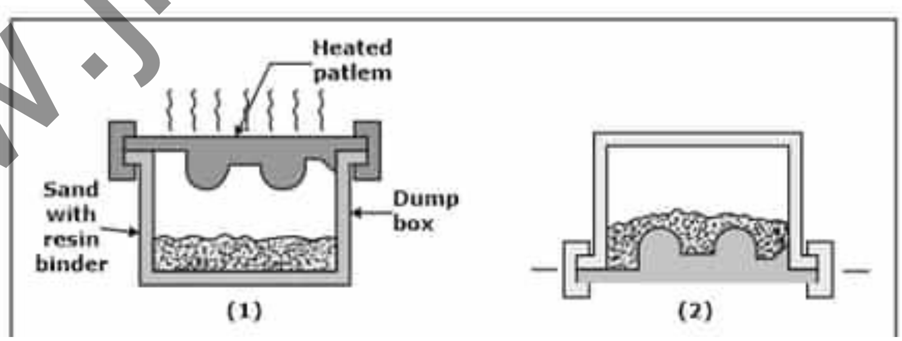
Shape factor method:

$$\text{shape factor}, (S.F.) = \frac{L + W}{t}$$

SPECIAL CASTING PROCESSES:

Shell moulding

- Shell moulding is a casting process in which the mould is a thin shell (typically 9 mm) made of sand held together by a thermosetting resin binder.
- The thickness of the shell can be determined accurately by controlling the time that the pattern is in contact with the mould.



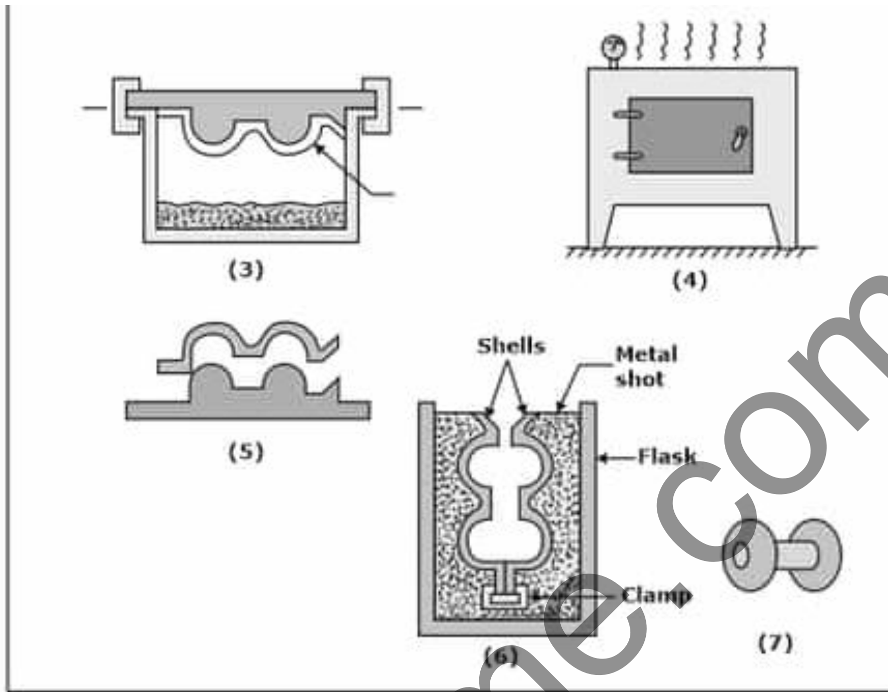


Fig.: Steps in shell-moulding

Investment casting:

(i) In investment casting, a pattern made of wax is coated with a refractory material to make the mould, after which the wax is melted away prior to pouring the molten metal.

(ii) The term Investment comes from one of the less familiar definitions of the word Invest, which is "to cover completely," this referring to the coating of the refractory material around the wax pattern.

Advantages of investment casting:

(i). parts of great complexity and intricacy can be cast

(ii). Close dimensional control—tolerances of ±0.075 mm, are possible.

(iii). Good surface finish is possible.

Applications:

(i) All types of metals. including steels, stainless steels, and other high-temperature alloys, can be investment cast.

(ii) Examples of parts include complex machinery parts, blades. and other components for turbine engines, jewellery, and dental fixtures.

Permanent-Mould Casting Processes:

In this section. permanent-mould casting is treated as the basic process in the group of casting processes that all use reusable metal moulds.

Other members of the group include die casting and centrifugal casting.

Slush casting:

Slush Casting Slush casting is a permanent mould process in which a hollow casting is formed by inverting the mould after partial freezing at the surface to drain out the liquid metal in the center.

Vacuum Permanent-Mould Casting:

The general configuration or the vacuum permanent-mould casting process is like the low-pressure casting operation. The difference is that reduced air pressure from the vacuum in the mould is used to draw the liquid metal into the cavity, rather than forcing it by positive air pressure from below.

Die casting:

Die casting is a permanent-mould casting process in which the molten metal is injected into the mould cavity under high pressure. Typical pressures are 7 to 350 MPa.

There are two main types of die-casting machines:

(i). Hot chamber die casting

(ii). Cold chamber die casting

Hot chamber die casting:

- In hot-chamber machines, the metal is melted in a container attached to the machine, and a piston is used to inject the liquid metal under high pressure into the die. Typical injection pressures are 7 to 35 MPa.

- The process is therefore limited in its applications to low-melting-point metals that do not chemically attack the plunger and other mechanical components. The metals include zinc, tin, lead, and sometimes magnesium.

Cold chamber die casting:

- In cold-chamber die-casting machines, molten metal is poured into an unheated chamber from an external melting container, and a piston is used to inject the metal under high pressure into the die cavity.

- Cold-chamber machines are **typically used for casting aluminum, brass, and magnesium alloys.** Low-melting-point alloys (zinc, tin, lead) can also be cast on cold-chamber machines, but the advantages of the hot-chamber process usually favor its use on these metals.

Advantages of die casting:

(i). high production rates possible:

(ii). economical for large production quantities

(iii). close tolerances possible, on the order of ±0.076 mm for small parts.

(iv). Good surface finish

Limitation of die casting:

- In addition to the metals cast, is the shape restriction. The part geometry must allow for removal from the die cavity.

Centrifugal casting

Centrifugal casting refers to several casting methods in which the mould is rotated at high speed so that centrifugal force distributes the molten metal to the outer regions of the die cavity. The group includes:

(i). True centrifugal casting

(ii). Semi centrifugal casting

(iii). Centrifuge casting

Centrifuge Casting

In centrifuge casting, the mould is designed with part cavities located away from the axis of rotation, so that the molten metal poured into the mould is distributed to these cavities by centrifugal force.

Casting Defects

(i). Misruns

(ii). Cold Shuts

(iii). Shrinkage cavity

(iv). Micro porosity

(v). Hot tearing

(vi). Sand blow

(vii). Pinholes

(viii). Sand wash

(ix). Scabs

(x). Penetration

(xi). Mould shift

(xii). Core shift

(xiii). Mould crac

Metal cutting & Tool Life

1. INTRODUCTION

Metal forming processes, also known as mechanical working processes, are primary shaping processes in which a mass of metal or alloy is subjected to mechanical forces. Under the action of such forces, the shape and size of metal piece undergo a change. By mechanical working processes, the given shape and size of a machine part can be achieved with great economy in material and time.

2. HOT AND COLD WORKING

Cold working may be defined as plastic deformation of metals and alloys at a temperature below the recrystallization temperature for that metal or alloy. In cold working process the strain hardening which occurs as a result of mechanical working, does not get relieved.

Hot working may be explained as plastic deformation of metals and alloys at such a temperature above recrystallization temperature at which recovery and recrystallization take place simultaneously with the strain hardening.

ADVANTAGES AND DISADVANTAGES OF COLD AND HOT WORKING PROCESSES

- As cold working is practically done at room temperature, no oxidation or tarnishing of surface takes place. No scale formation is there, hence there is no material loss where as in hot working, there is scale formation due to oxidation.
- Cold working results in better dimensional accuracy and a bright surface.

- In cold working heavy work hardening occurs which improves the strength and hardness of bars.

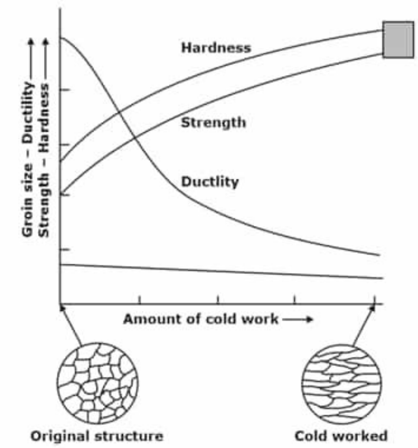


Fig.1: Variation of properties with cold working

- Due to limited ductility at room temperature, production of complex shapes is not possible by cold working processes.
- Severe internal stresses are induced in the metal during cold working.

3. FLOW STRESS

(a) TRUE STRESS

The true stress is defined as the ratio of the load to the cross-section area at any instant

$$(\sigma_T) = \frac{\text{load}}{\text{Instantaneous area}} = \sigma(1+\varepsilon)$$

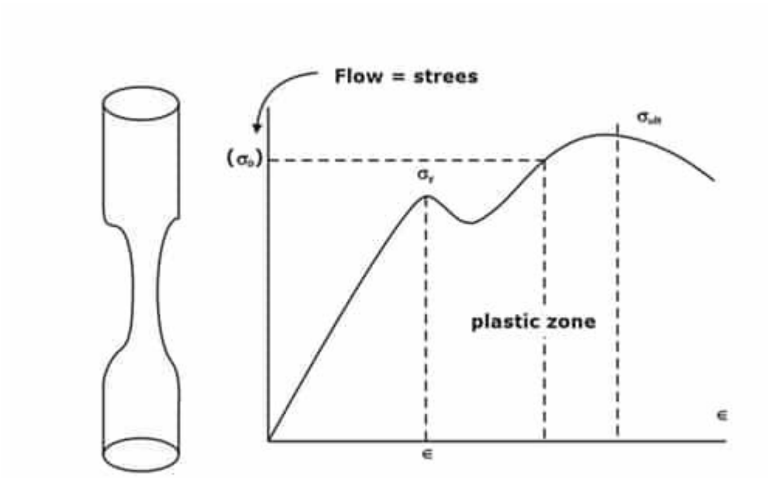
where σ and ε is the engineering stress and engineering stress and engineering strain respectively.

(b)TRUE STRAIN

$$(\varepsilon_T) = \frac{\text{Elongation}}{\text{Instantaneous lenght}} = \int_{L_0}^{L} \frac{dx}{x} = \ln\left|\frac{L}{L_0}\right| \ln(1+\varepsilon) = \ln\left|\frac{A_0}{A}\right| 2\ln\left|\frac{d_0}{d}\right|$$

4. Mean Flow stress

Mean flow stress is the stress at which material begins to flow. When a material deforms plastically strain hardening occurs.



Stress-Strain curve with work hardening

$$\sigma_0 = \frac{K\varepsilon^n}{n+1}$$

Here σ_o is flow stress.

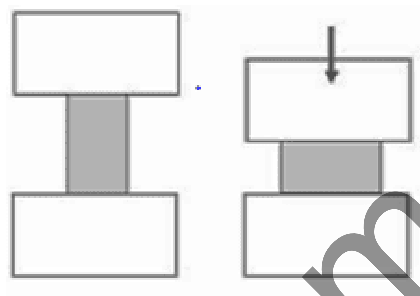
5. FORGING

- Forging is a basic process in which the work piece is shaped by compressive forces applied through various dies and tooling.
- Simple forging operations can be performed with a heavy hammer and an anvil, as has been done traditionally by blacksmiths. However, most forgings require a set of dies and such equipment as a press or a powered forging hammer.
- Forging may be carried out at room temperature (cold forging) or at elevated temperatures (warm or hot forging) depending on the homologous temperature.
- Cold forging requires higher forces (because of the higher strength of the work piece material, and the work piece material must possess sufficient ductility at room temperature to undergo the necessary deformation without cracking.

Based on the nature of material flow and constraint on flow by the die/punch, forging is classified as open die forging, impression die forging and flash less forging.

(a) OPEN DIE FORGING

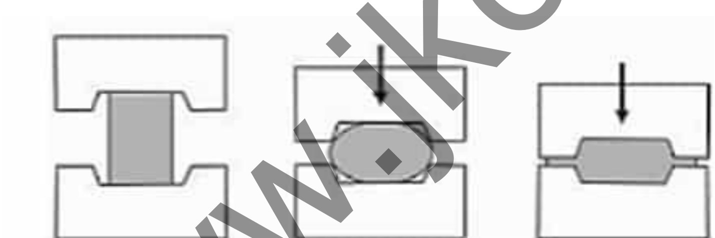
In this, the work piece is compressed between two platens. There is no constraint to material flow in lateral direction.



Open-die forging

(b) CLOSED DIE FORGING

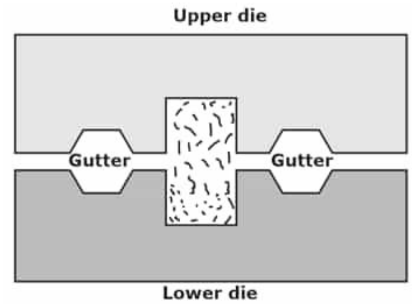
In closed die forging a calculated amount of material is kept inside the die cavity and force is applied by the punch



Closed-die forging

(c) IMPRESSION DIE FORGING

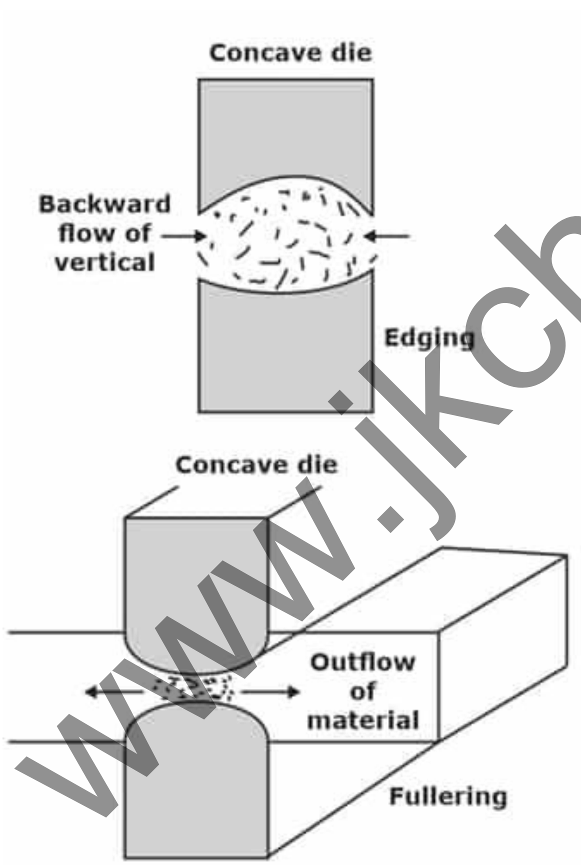
When the closed die forging is equipped with flash and gutter it is called impression die forging.



Impression die forging

(d) EDGING AND FULLERING

In edging material flow towards centre of die, the objective is to reduce length. In fullering material flow away from centre of die, objective is to increase length and decrease cross sectional area.



(e) UPSETTING

In many cases, only of portion of the job needs to be forged. A common example is the forging of the bolt head at one end of a rod. Such a localized forging operation is commonly known as upsetting.

(f) DROP FORGING

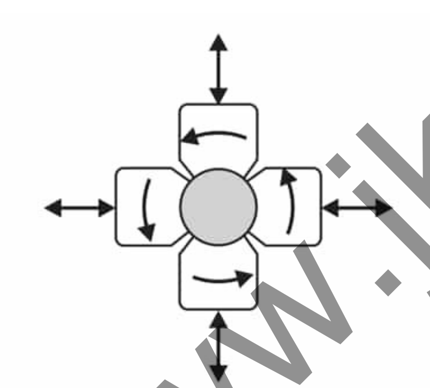
Drop forging utilizes a closed impression die to obtain the desired shape of the component. The shaping is done by the repeated hammering given to the material in the die cavity. The equipment used for delivering the blows are called drop hammers.

(g) PRESS FORGING

Press forging dies are similar to drop forging dies as also the process. In press forging the metal is shaped not by means of a series of blows as in drop forging, but by means of a single continuous squeezing action.

(h) SWAGING

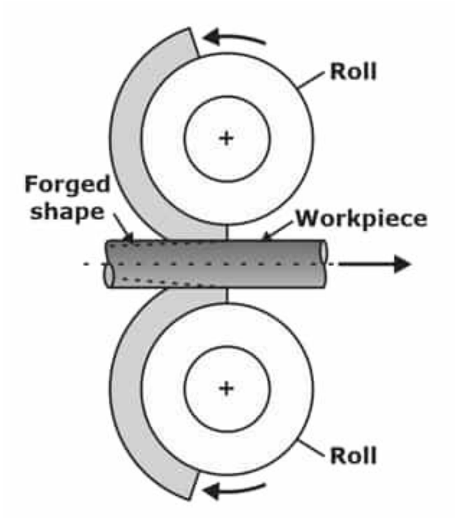
Swaging is a special variation of impact forging where the repeated blows are obtained by a radial movement of shaped dies.



Principle of rotary swaging

(i) ROLL FORGING

Roll forging is performed with two semicircular, grooved rolls held by two parallel shafts. The process is used for reducing the diameter of rods.



Principle of roll forging

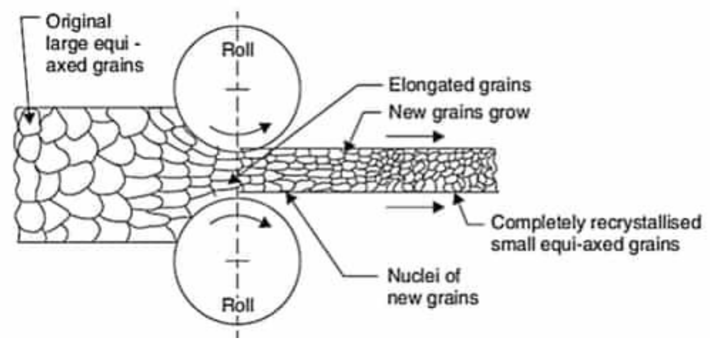
5.1 FORGING DEFECTS

- Incomplete forging—either due to less material or inadequate or improper flow of material.
- Mismatched forging due to improperly aligned die halves.
- Scale pits—due to squeezing of scales into the metal surface during hammering action.
- Internal cracks in the forging which are caused by use of heavy hammer blows and improperly heated and soaked material.

6. ROLLING

In this process, metals and alloys are plastically deformed into semi-finished or finished products by being pressed between two rolls which are rotating.

The material is subjected to high compressive force as it is squeezed (and pulled along) by the rolls. This is a process to deal with material in bulk in which the cross-section of material is reduced and its length increased.



Grain refinement by rolling

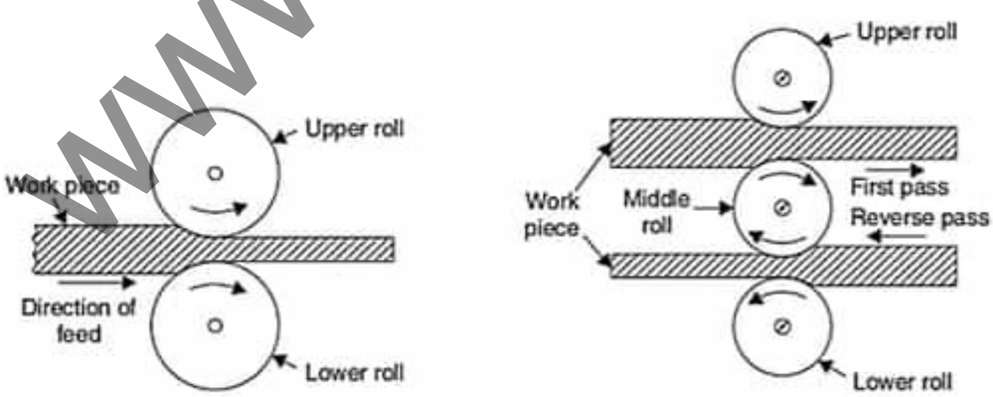
Different types of rolling mills are described below in brief:

(a) TWO HIGH MILLS

It comprises of two heavy rolls placed one over the other. The rolls rotate in opposite directions and are driven by powerful electrical motors. Usually the direction of rotation of rolls cannot be altered, thus the work has to be fed into rolls from one direction only.

(b) THREE HIGH MILLS

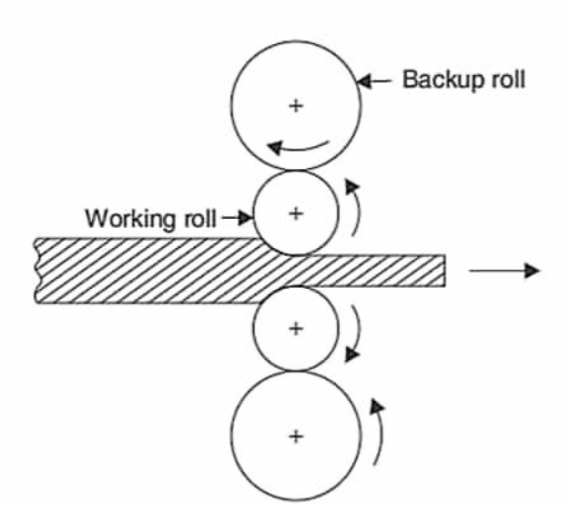
It consists of three rolls positioned directly over one another as shown below. The direction of rotation of the first and second rolls are opposite as in the case of two high mill. The direction of rotation of second and third rolls is again opposite to each other. All three rolls always rotate in their bearings in the same direction. The advantage of this mill is that the work material can be fed in one direction between the first and second roll and the return pass can be provided in between the second and third rolls.



(a) A two high mill (b) A three high rolling mill

(c) FOUR HIGH MILLS

This mill consists of four horizontal rolls, two of smaller diameter and two much larger ones. The larger rolls are called backup rolls. The smaller rolls are the working rolls, but if the backup rolls were not there, due to deflection of rolls between stands, the rolled material would be thicker in the centre and thinner at either end.



Four-high mill

6.1 DEFECTS IN ROLLING

- Several surface defects (such as scale, rust, scratches, gouges, pits, and cracks) have been identified in sheet metals. These defects may be caused by inclusions and impurities in the original cast material.
- Wavy edges on sheets are the result of roll bending. The strip is thinner along its edges than at its centre).; thus, the edges elongate more than the centre.
- The cracks are usually the result of poor material ductility at the rolling temperature.

7. EXTRUSION

Extrusion is a process in which the metal is subjected to plastic flow by enclosing the metal in a closed chamber in which the only opening provided is through a die. The material is usually treated so that it can undergo plastic deformation at a sufficiently rapid rate and may be squeezed out of the hole in the die.

Types of Extrusion Processes

Extrusion processes can be classified as followed:

(A) Hot Extrusion

(i) Forward or Direct extrusion.

(ii) Backward or Indirect extrusion.

(B) Cold Extrusion

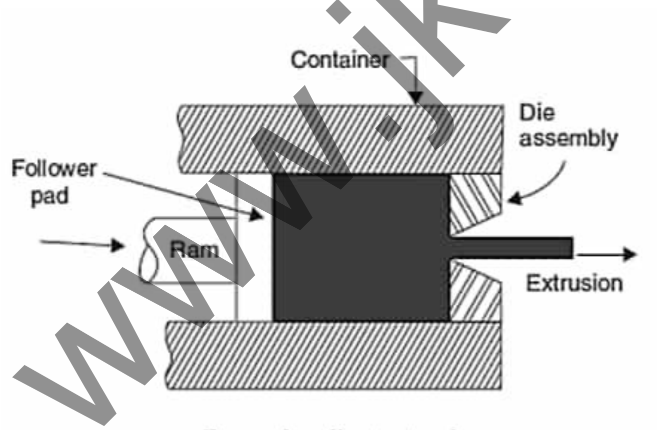
(ii) Hydrostatic extrusion.

(iii) Impact extrusion.

7.1 HOT EXTRUSION PROCESSES

(I) FORWARD OR DIRECT EXTRUSION PROCESS

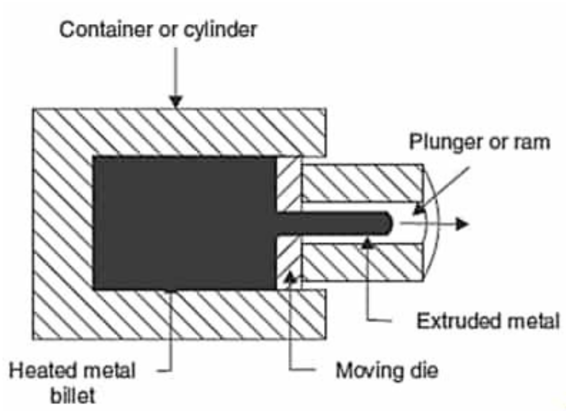
In this process, the material to be extruded is in the form of a block. In the front portion of the chamber, a die with an opening in the shape of the cross-section of the extruded product, is fitted. the heated material is forced to squeeze through the die-opening in the form of a long strip of the required cross-section.



Forward or direct extrusion

(II) BACKWARD OR INDIRECT EXTRUSION

This process is called backward extrusion process as the flow of material is in a direction Opposite to the movement of the ram. In the forward extrusion process the flow of material and ram movement were both in the same direction.

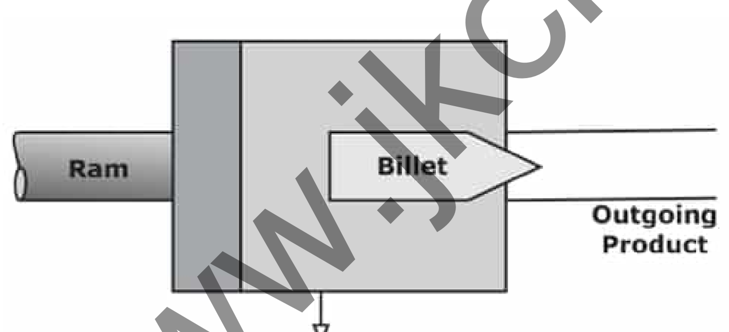


Backward extrusion

7.2 COLD EXTRUSION PROCESSES

(I) HYDROSTATIC EXTRUSION

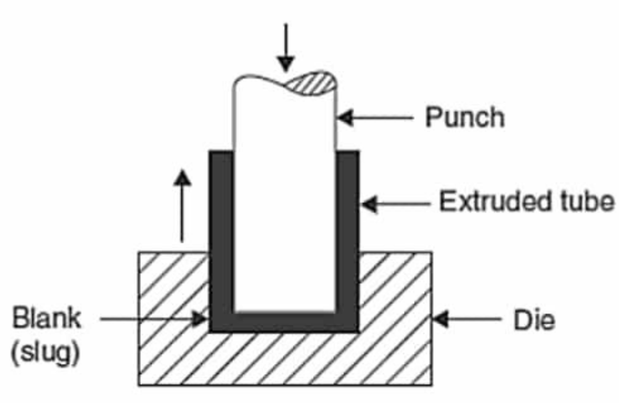
This is a direct extrusion process, but the pressure is applied to the metal blank on all sides through a fluid medium. Relatively brittle materials can also be successfully extruded by this method.



Hydrostatic Extrusion

(II) IMPACT EXTRUSION

In this process, the punch descends with high velocity and strikes in the centre of the blank which is placed in a die. The material deforms and fills up the annular space between the die and the punch flowing upwards.



Impact extrusion

7.3 EXTRUSION DEFECTS

(a) SURFACE CRACKING

Sometimes the surface of extruded metal/products develops surface cracks. If extrusion temperature, friction, or speed is too high, surface temperatures can rise significantly, which may cause surface cracking and tearing. These cracks are intergranular (i.e., along the grain boundaries. and usually are caused by hot shortness. Because of the similarity in appearance to the surface of a bamboo stem, it is known as a bamboo defect.

(b) PIPING

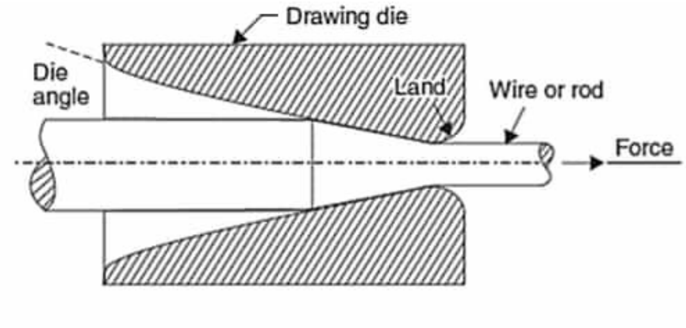
The type of metal-flow pattern in extrusion tends to draw surface oxides and impurities toward the centre of the billet-much like a funnel. This defect is known as pipe defect.

(c) INTERNAL CRACKING

The centre of the extruded product can develop cracks, called center cracking, center-burst, arrowhead fracture.

8. WIRE DRAWING

Wire drawing process is a cold working process used to produce wires from solid rods by pulling through a stationary die. In this process, rods made of steel or nonferrous metals and alloys are pulled through conical dies having a hole in the centre. As the material is pulled through the cone, it undergoes plastic deformation and it gradually undergoes a reduction in its diameter.



Wire drawing process

9. SHEET METAL OPERATIONS- A sheet is a plate with thickness less than 5 mm. Sheet metal operations are performed over metal sheet when length and width is very large compared to thickness. The basic cutting operations which come under Sheet Metal Operations are Punching Operation and Blanking Operation. For both punching and blanking operations, the punch and die combination will be used as tools.

PUNCHING OPERATION- When the force is applied by using the punch on to the sheet, the cutting or shearing action will be taking place in the sheet producing a piece/blank leaving **a hole** in the sheet.

- In punch and die working, if the hole produced in the sheet is useful, it is called Punching or Piercing operation.
- To ensure that the cutting or shearing action is taking place on the sheet, the Punch size is always less than the Die size.
- In punching operation, the punch size is made equal to hole size and clearance is provided on the die.
- Punch Size < Die Size (Basic Requirement)
- Punch Size = Hole Size (Needed)
- Clearance → Die.
- Shear → Punch.

BLANKING OPERATION- When the force is applied by using the punch on to the sheet, the cutting or shearing action will be taking place in the sheet producing a piece/blank.

- In punch and die working, if the Piece/blank produced in the sheet is useful, it is called as Blanking operation.

- In blanking Operation, the die size is made equal to blank size and clearance is provided only on the Punch.
- Die Size = blank Size.
- Clearance → Punch.

ANALYSIS OF PUNCHING AND BLANKING- Let, C is the amount of clearance per side of the die opening. The optimum clearance can be determined with the help of the following relation,

Optimum clearance, $C = 0.0032t*\text{sqrt}(\tau)$

Where, t = sheet thickness in mm, τ_u = ultimate shear stress in N/mm^2

LOAD ESTIMATION OF PUNCHING AND BLANKING OPERATION- The distance which the punch enters into the work material to cause rupture to take place is called 'penetration' and is usually given as the percentage of the stock thickness.

$F_{max} = A_s \times \tau_u$

where A_s = shearing area = p × t
τ_u = ultimate shear stress
t = thickness of plate
p = perimeter, p = πd for Circular cross-section
A_s = πdt for circular cross-section

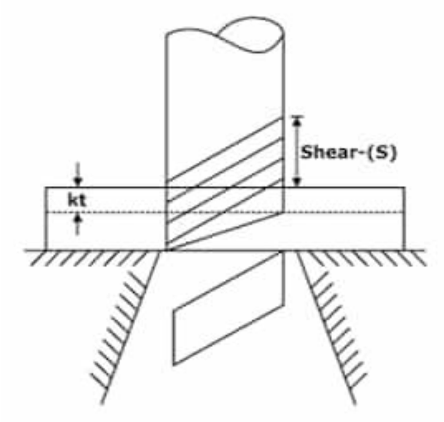
For rectangular blanks with length L and width b, it is $F_{max} = 2(L + b)t.\tau_u$

ENERGY REQUIRED OR WORK DONE IN PUNCHING / BLANKING

Work done = Force × distance = F_{max} × Kt

In general K = 0.2 to 0.6, K = % penetration required for completing the shearing action.

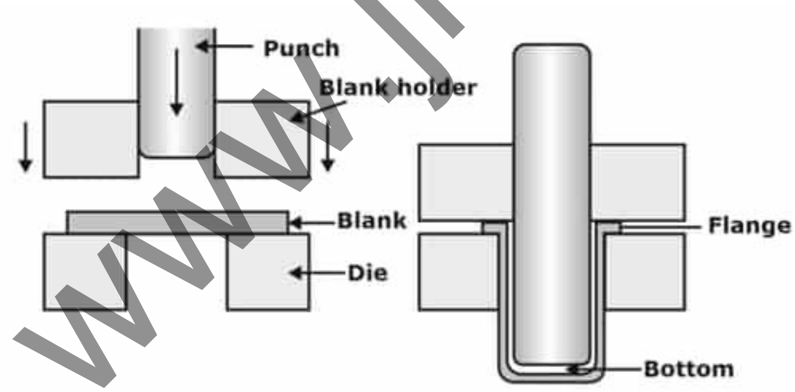
METHODS OF REDUCING PUNCH FORCE- The working faces of the punch or die are ground off so that these do not remain parallel to the horizontal plane but are inclined to it. The angle of inclination is called shear. This has the effect of reducing the sheared area at any one time and the maximum force is much less.



Spring back- Spring back is the elastic recovery leading to the increase of the included angle when the bending pressure is removed. To compensate for spring back two methods are commonly used:

- Overbending—the punch angle and radius are smaller than the final ones.
- Bottoming—squeezing the part at the end of the stroke.

Deep drawing- It is a Sheet Metal forming process in which a sheet metal blank is radially drawn into a forming die by the mechanical action of a punch. Deep drawing is mainly used for producing Cup-shaped components. Drawing is called deep drawing when the height of the cup if greater than half of the diameter of the cup, otherwise shallow drawing. Most of the utensils used in the kitchen are produced by using Deep Drawing Operation only.



Clearance- Clearance c 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 following measures are used,

- **Drawing ratio D_R** defined as **$D_R = D_b/D_p$,** Here D_b is the blank diameter and D_p is the punch diameter. D_R 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/D_b- It is desirable to be greater than 1% to avoid wrinkling.

Blank size determination- The blank diameter can be calculated by setting the initial blank volume equal to the final volume of the part and solving for diameter D_b.

DEEP DRAWING DEFECTS- As already noted, many types of deformations are involved in the deep drawing operation on sheet metals.

- An insufficient blank holder pressure causes wrinkles to develop on the flange, which may also extend to the wall of the cup.
- Too much of a blank holder pressure and friction may cause a thinning of the walls and a fracture at the flange, bottom, and the corners(if any).
- While drawing a rolled stock, ears a lobes tend to occur because of the anisotropy induced by the rolling operation.
- Due to this misplacement of the stock, unsymmetrical flanges may result. This type of defect is commonly referred to as a miss strike.
- The effect of a large grain size is to produce a dull surface (orange peel effect). This effect is also common in the bending operations.

Basic Machine Tools

1. Introduction:

A machine tool is used for holding the cutting tools which are used to remove metal from a work piece to generate the desired product of given size, configuration and finish.

2. Classification of Machine Tool

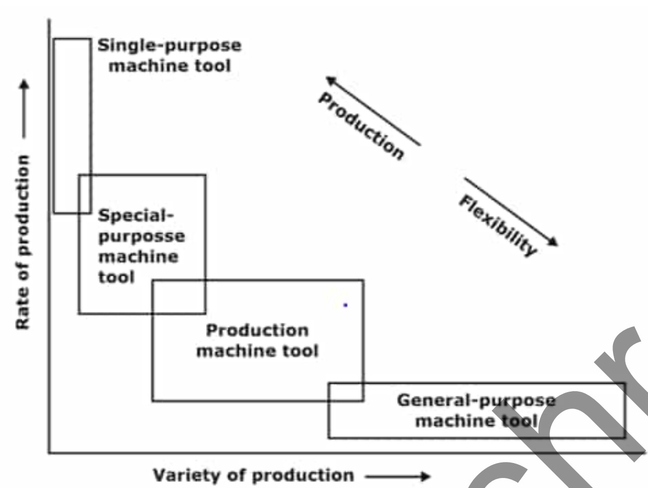
There are many ways in which the machine tools can be classified. Here, the classification shown below is based on the production capability and application:

(1) General Purpose machine tools

(2) Production machine tools

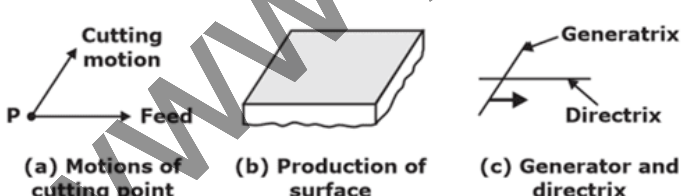
(2) Special purpose machine tools

(3) Single purpose machine tools



Application of machine tools based on capability

3. Concept of Generatrix and Directrix



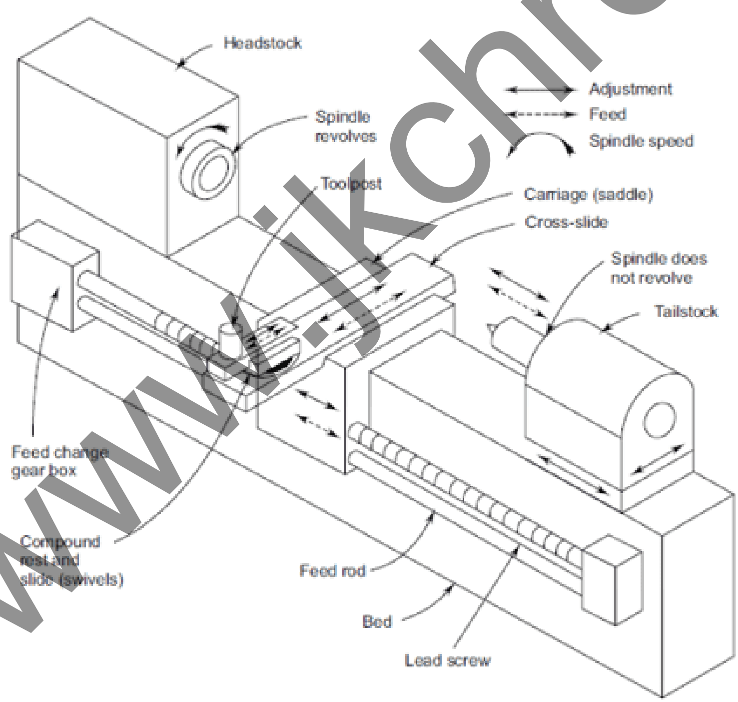
The line generated by the cutting motion is called the generatrix and the line from the feed motion is termed as the directrix. Different geometries and shapes are obtained on the basis of relative directions of the generatrix and the directrix.

3.1 Generation of various surfaces:

S. No.	Generatrix	Directrix	Process	Surface obtained
1.	Straight line	Straight line	Tracing	Plain
2.	Circular	Straight line	Tracing	cylindrical
3.	Plain curve	Circular	Tracing	Surface of revolution
4.	Circular	Straight line	Generation	Straight line (Plain surface in practice)

4. Lathe Machine and Operations

- Lathe is the oldest machine tool invented, starting with the Egyptian tree lathes.
- The principal form of surface produced in a lathe is the cylindrical surface. This is achieved by rotating the work piece while the single point cutting tool removes the material by traversing in a direction parallel to the axis of rotation.



General view of a centre lathe various mechanisms and features

4.1 Types of Lathes:

Considering the versatility, a large number of variants of lathes are used in manufacturing shops. The variations are:

(a) Centre lathe:

- The centre lathe is the most common of the lathes, which derives its name from the way a work piece is clamped by centres in a lathe, though this is not the only way in which the job is mounted.

Example: Bench Lathe

(b)Tool room lathe:

- A tool room lathe is generally a high precision lathe having a gearbox in the headstock offering an extended range of thread pitches and feeds.
- The tool room lathe is generally meant for applications of tool making, where the accuracy desired is much higher than is normally required for general production work.

(c). Special purpose lathes: These are the form of centre lathe used for special forms of application which are difficult to made by the conventional centre lathe**.**

(d). Capstan and turret lathes:

- These are automatic lathes which are used for high-rate production and thus used for very special applications.
- These have the special features to help in improving the production rate and also work unattended if necessary.

4.2. Lathe specifications:

The main basic elements specified for the capability of the lathe machine are as follows:

- Distance between centres—this specifies the maximum length of the job that can be turned in the lathe.
- Swing over the bed—this specifies the maximum diameter of the job that can be turned in the lathe machine, generally restricted to small length jobs.

- Swing over the cross slide—this specifies the maximum diameter of the job that can be turned in the lathe machine with the job across the cross slide, which is generally the case.

4.3. Aids for support and location:

(i) Chucks:

The most common form of work holding device used in a lathe is the chuck.

Three jaw Chuck:

- The main advantage of this chuck is the quick way in which the typical round job is centred.
- The jaws will be able to centre any job, whose external locating surface is cylindrical or symmetrical, like hexagonal.

Four jaws chuck:

- The independent jaw chuck has four jaws, which can be moved in their slots independent of each other, thus clamping any type of configuration.
- Since each of these jaws could move independently any irregular surface could be effectively centred.

(ii) Centers:

- Centres would be **able to locate the central axis of the work piece**, however, would not be able to transmit the motion to the work piece from the spindle.
- The centre located in the spindle is termed live centre while that in the tailstock is termed the dead centre.
- **Live centre rotates with the work piece**, and hence it remains soft. Whereas **the dead centre does not rotate**.

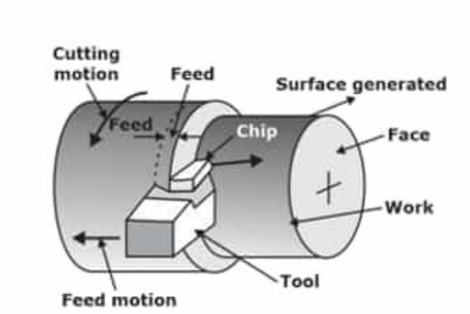
(iii) Faceplate: The face plate is used for holding jobs such as thin and irregularly shaped pieces that cannot be held between the centre and chucks.

(iv) Mandrel:

- It is used for holding and rotating hollow workpieces or those that have been drilled or bored previously.
- For **holding components with locating holes**, for the purpose of generating external surfaces, a mandrel is generally used.

5. Turning:

Here, a tool having single cutting edge is used material removal from a rotating workpiece and a cylindrical shape is generated.



Turning operation

5.1 Taper turning:

Cutting tapers on a lathe is one of the most common applications. There are various methods available for cutting tapers in a lathe. They are:

(a). Using a compound slide:

- The compound slide is an auxiliary slide underneath the tool post and above the carriage.
- It is possible to swivel the compound slide to the desired angle of the tape.
- The angle set on the compound slide is half the included angle of the taper required.

The empirical formula used for calculating the taper is

$$\tan\theta = \frac{D_1 - D_2}{2L}$$

:

Where θ is half of the included angle, D_1 and D_2 are the major and minor diameters of the workpiece and L is the length of the tapered portion.

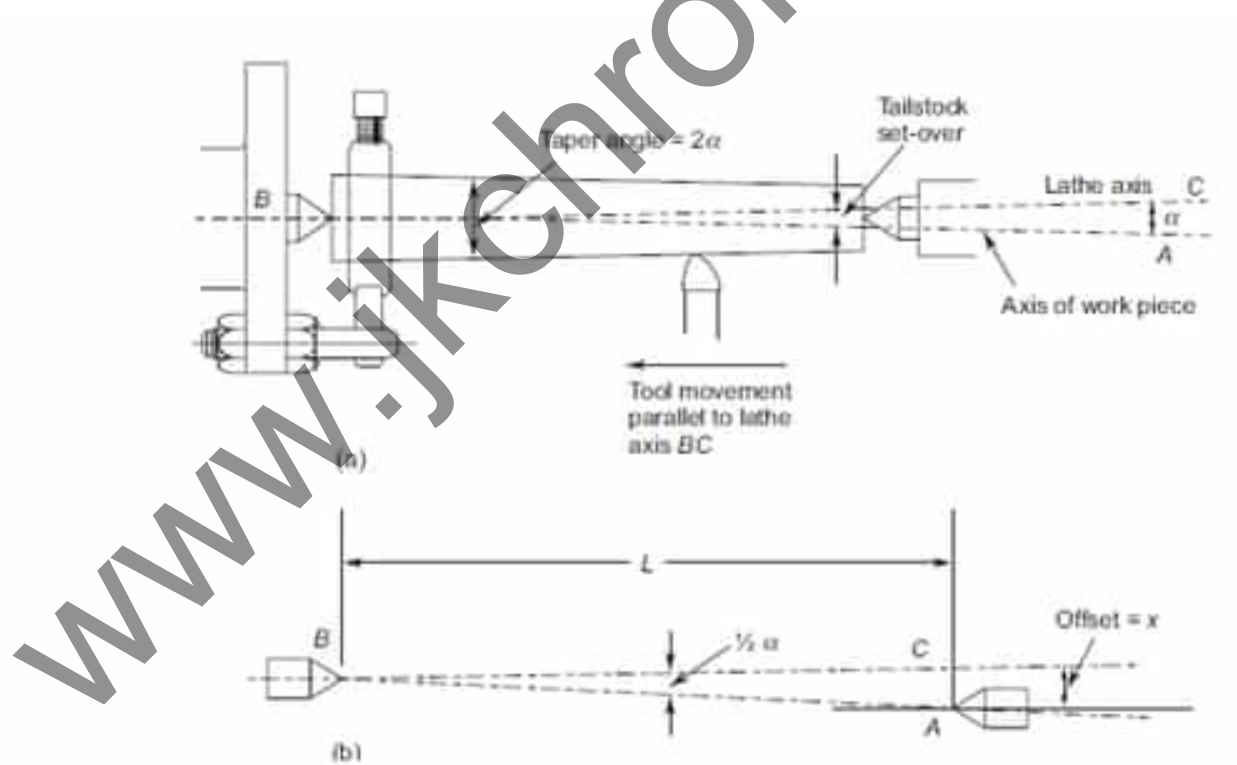
(b). Using form tools:

In this method a special form tool is sued for generating the tapers

The feed is given by plunging the tool directly into the work. Short tapers where the steepness is of no consequence, such as for chamfering, are produced by this method.

(c). Offsetting the tailstock:

- By offsetting the tailstock, the axis of rotation of the job is inclined by the half angle of taper as shown in Fig.
- The feed to the tool is given in the normal manner parallel to the guideways. Thus, the conical surface is generated.



Tailstock Offset

If α is very small, then we can approximate

$$\sin\alpha = \tan\alpha = \frac{D-d}{2L}$$

$$\therefore \text{Offset: } S = L\frac{(D-d)}{2l} = \frac{(D-d)}{2} \times \frac{\text{Total length of workpiece}}{\text{Taper length}}$$

(d). Using taper turning attachment:

- In this method, tool is guided in a straight path at an angle to the axis of rotation of the workpiece.
- The taper turning attachment is fixed on the bed lathe and the taper guide bar swivels around a pivot. The transverse feed of the carriage produces the taper.

5.2. Machining time calculation:

The cutting speed in turning is the surface speed of the work piece. Thus,

$$V = \frac{\pi DN}{1000}$$

where,

V a cutting speed (surface), m/min

D = Initial diameter of the work piece, mm

N = rotational speed of the work piece, rpm

- The machining time, t for a single pass is given by

$$t = \frac{L + L_0}{fN}$$

where L = length of the job, mm

L_0= over travel of the tool beyond the length of the job to help in the setting of the tool, mm

f = feed rate, mm/rev. It is the linear distance travelled for one revolution of the workpiece along the length of the job.

6. Shaper

- The shaper is a relatively slow machine tool with very low metal removal capability. Hence it is replaced by more versatile milling machine in many shops. This is a low-cost machine tool and hence is used for initial rough machining of the blanks. It is rarely used in production operations.

- It uses **a single point tool similar to a lathe** which is clamped to **a tool post mounted to a clapper box which in turn is mounted to a reciprocating ram.**
- The ram while undertaking the cutting stroke pushes the cutting tool through the work piece to remove the material. When the ram returns, no cutting takes place.
- In between the return and cutting strokes, the table moves in the horizontal direction perpendicular to the cutting direction, which is termed as the feed direction.

6.1 Machining time calculation

Let N be the rotational speed of the bull gear and L be the length of the stroke. The speed ratio indicates the proportion of time actual cutting is taking place and is defined as:

Let L: Stroke length of the ram

V = cutting velocity (or) velocity of ram during forward stroke

$$m = \frac{1}{\text{quick return ratio}}$$

$$m = \frac{V_c}{V_r} = \frac{T_r}{T_c} < 1$$

Since: $V_c < V_T$ thus, $T_r < T_c \Rightarrow m < 1$

W = width of workpiece

f = feed

T_c = Time taken for cutting stroke

T_r = Time taken for return stroke

V_c = Velocity during cutting stroke

V_r = Velocity during return stroke

$$\text{Time/Double Stroke (t)} = \frac{L}{V}(l + m)$$

$$\text{Number of strokes required: } n = \frac{W}{f}$$

Total machining time:

T = t × number of double strokes (n)

$$T = \frac{W}{f} \times \frac{L}{V}(1 + m)$$

7. Planning (Planer)

- Planning machine is very similar to the shaper in terms of the Surfaces that can be generated.
- Generally, planer is **used for machining large work pieces**, which cannot be held in the shaper.
- In the shaper, the cutting tool reciprocates during the cutting motion, while in the case of planer the worktable reciprocates.

7.1 Planning Time Estimation:

$$\text{Planing time: } t = \frac{W}{f}\left(\frac{l}{V_c} + \frac{l}{V_r} + a\right)$$

Where l = length of the planer stroke, m

W = width of surface to be cut, mm

f = feed rate, mm/stroke

V_c = cutting speed, m/ min

V_r = table return speed, m/ min

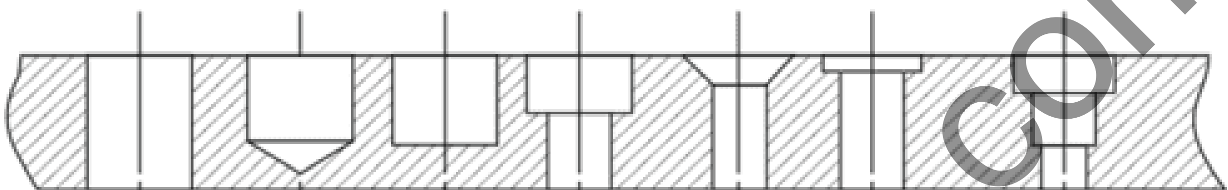
a = time for reversal of table, min which is about 0.015 to 0.040 minutes.

8. Slotting Machine (Slotter)

- Slotting machine is basically **a vertical axis shaper.**
- The **stroke of the ram is smaller in slotting machines than in shapers** to account for the type of the work that is handled in them.

9. Hole Making Operations

Machining round holes in metal stock is one of the most common operations in the manufacturing industry.



Various types of holes

9.1 Drilling:

- Drilling is used to create a round hole.
- It is accomplished by a rotating tool that typically has two cutting edges. The tool is fed in a direction parallel to its axis of rotation into the work part to form the round hole.

9.1.1 Drilling Time Estimation:

The cutting speed in drilling is the surface speed of the twist drill. Thus

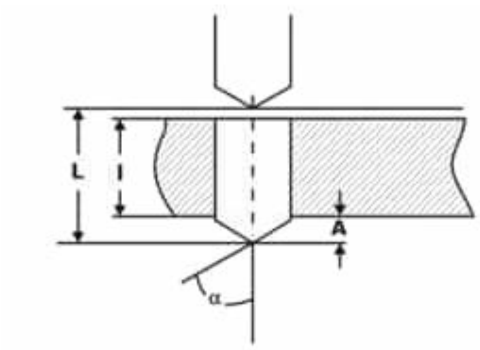
$$V = \frac{\pi D N}{1000}$$

Where, V = cutting speed (surface), m/min

D = diameter of the twist drill, mm

N - rotational speed of the drill, rev/min

- The initial approach (A_I) is generally a small value for positioning the drill above the hole. This distance, A_I can generally be taken as 2 to 3 mm.
- The traverse distance beyond the hole is often termed as the breakthrough distance and is required because of the conical shape of the twist drill.



End of the twist drill showing the breakthrough distance

Break through distance, $A = \dfrac{D}{2\tan\alpha}$

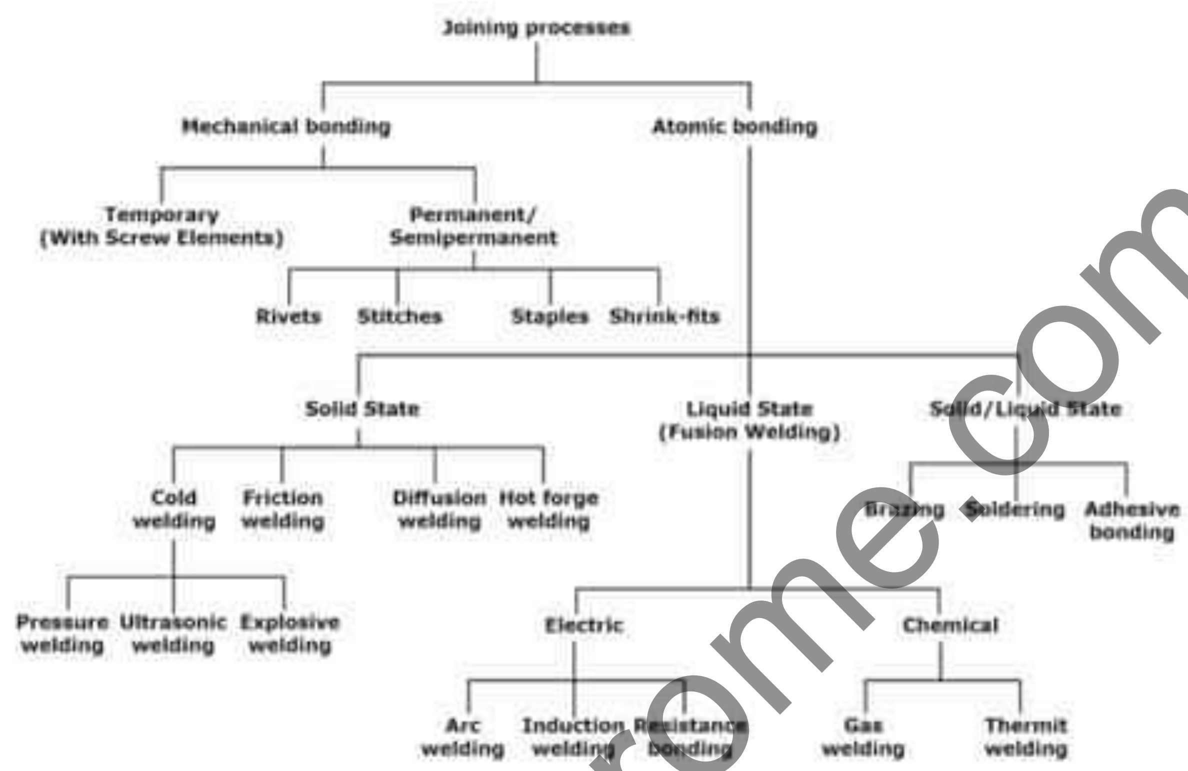
Time for drilling the hole = $\dfrac{L}{fN}$ minutes

Where f= feed rate, mm/rev

Material removal rate:

$$MRR = \frac{\pi D^2 f N}{4}$$

Welding



Welding is the process of joining together two pieces of metal with or without the application of heat or pressure or both is applied and with or without addition of filler metal for formation of metallic bond.

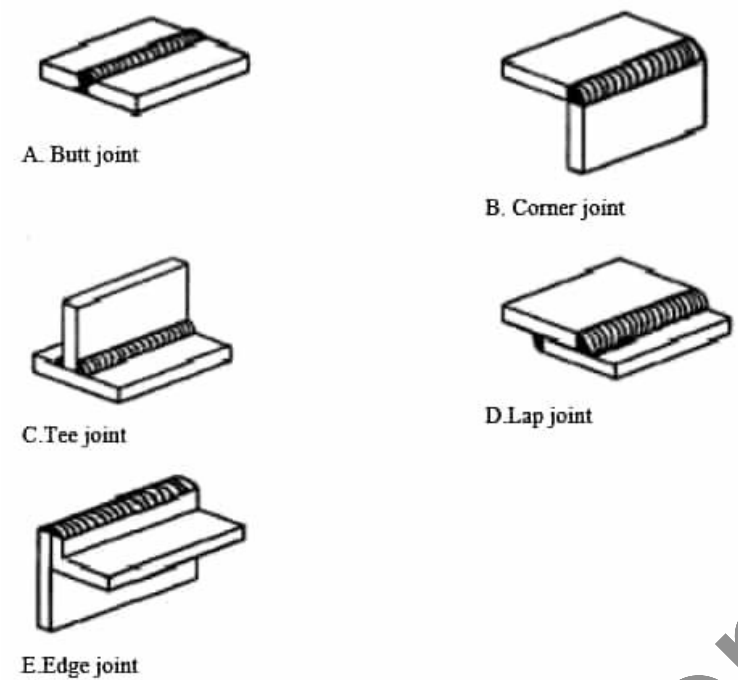
Classification of the welding processes: Welding process based on composition of filler material are as follows:

(i). Autogenous Welding: In this type, no filter material is required. All types of solid phase welding and resistance welding are the examples of this category.

(ii). Homogenous: Here, the filler material provided to the joint is the same as the parent material. Arc, gas, and thermit welding are examples of this category.

(iii). Heterogenous Welding: Here the filler material has different composition from the parent material. Soldering and brazing are two such joining processes. The insoluble materials, for example iron and silver, can be welded using the heterogeneous process.

Types of joints:



Welding Accessories

(1). Non consumable electrodes

(2). Coated consumable electrodes

(3). Welding cables

(4). Hand screen

(5). Chipping hammer

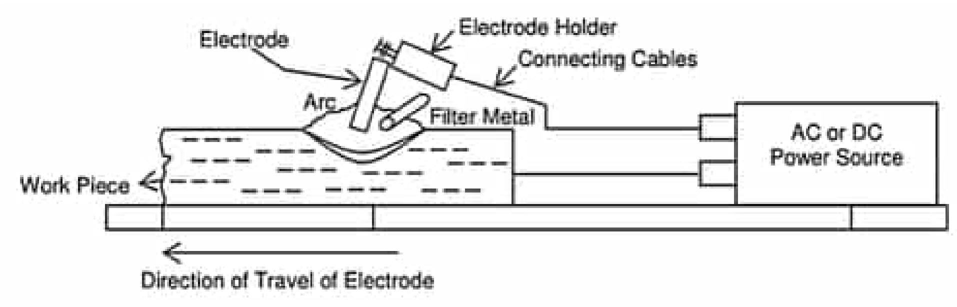
(6). Wire Brush

(7). Protective clothing

(8). Filler Metal:
(i). Coated filler metal

ii). Bare filler metal

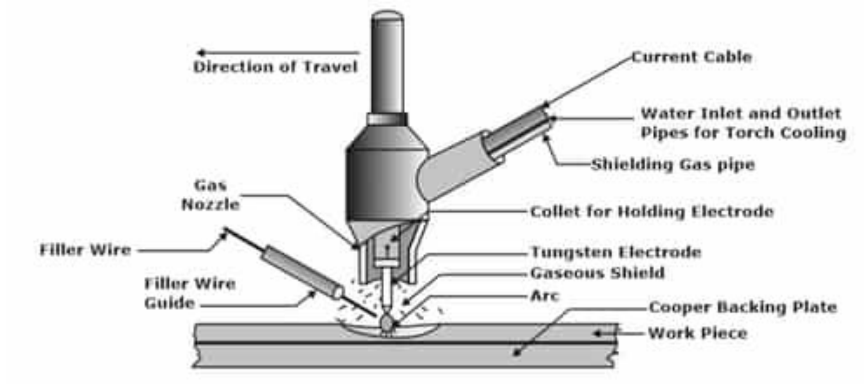
Arc welding: It is the liquid state joining process in which coalescence of the metal is achieved with the application of the heat from an electric arc generated between an electrode and workpiece.



- Electric arc is generated when electrode is brought into contact with the work and is then quickly separated by a short distance approximately 2 mm.
- The circuit operates at low voltage and high current, so arc is established in the gap due to thermionic emission from electrode (Cathode) to workpiece (Anode).
- The arc is sustained due to continuous presence of a thermally ionized column of gas. This arc produces at temperature of the order of 5500°C or higher.

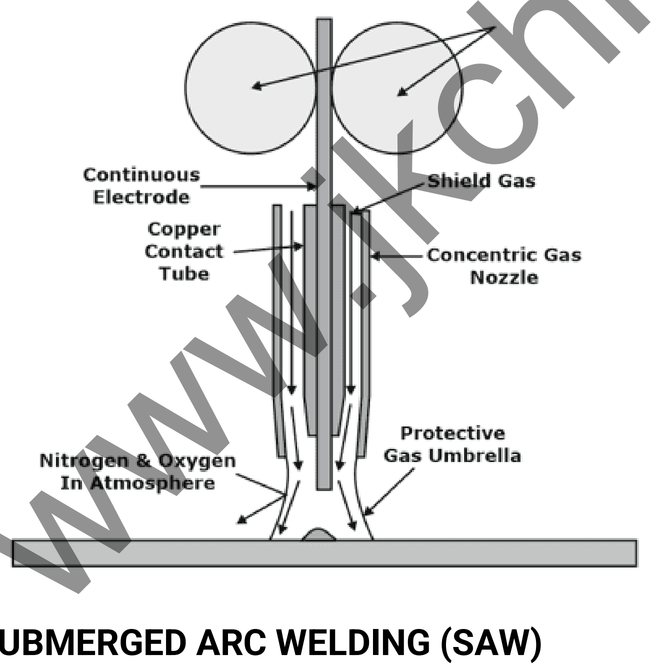
TIG Welding

- A non-consumable is used in TIG welding process and its objective is only to create an arc.
- A separate metal rod is supplied as filler material during welding.
- TIG welding is mainly used to weld Aluminum and Magnesium allloys. Aluminium is very difficult to weld because as soon as it is exposed to atmosphere it forms a layer over it. Thus, work piece is given negative polarity and electrode positive polarity to avoid this problem. With such polarity, electrons flow from workpiece to electrode and peels of oxide layer and fresh Aluminum comes in contact with the arc. This phenomenon of self-cleaning is known as cathodic cleaning.



MIG Welding

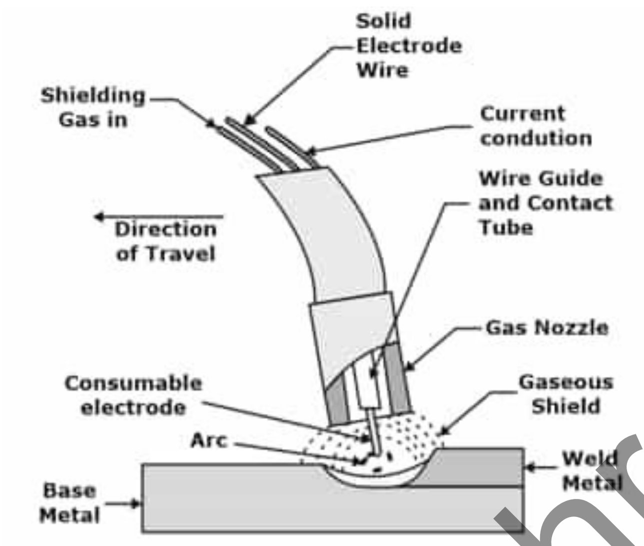
- MIG works on same principle of TIG or arc welding.
- It utilizes the heat generated due to electric arc for the welding process. The heat generated is used to melt consumable electrode and parent metal workpieces which make a strong joint together on the solidification.
- The shielded gases are used to protect the weld zone from other reactive gases. This welding results in good surface finish of the welded parts and a stronger joint.



SUBMERGED ARC WELDING (SAW)

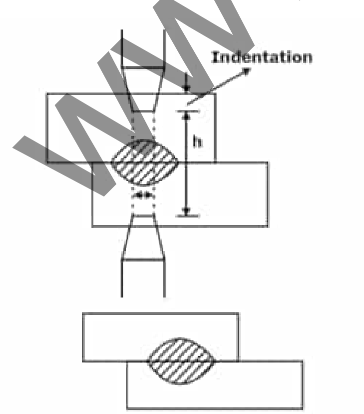
- This is semi-automatic version of SMAW process which can produce long weld runs.

- The electrode used is in the form of spool of having copper coating (to increase the conductivity of wire) and granular flux.
- The powdered flux is poured in to the welding area not only helps in maintaining the arc but also minimizes the Spatter of liquid metal and suppresses the intensity ultraviolet radiation.
- Flux is fed on weld zone by gravity through flow nozzle, a long continuous weld can be performed.
- This process is mainly suitable for down hand welding position.



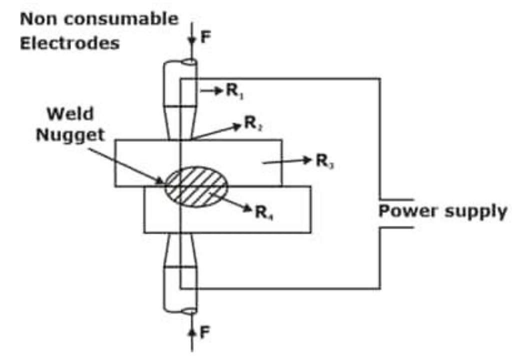
Resistance Welding

- Resistance welding is a fusion welding process that also utilizes pressure in welding operation.
- In Resistance welding whatever the heat required for melting and joining of plates is obtained due to electrical resistance circuit, so the name given as resistance welding operation.



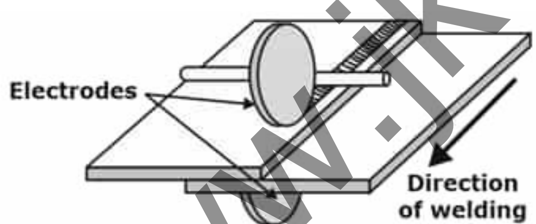
Resistance Spot Welding:

- It is a resistance welding process in which contacting metal surface are joint at different points by the heat obtained from resistance to electric current.



Seam welding:

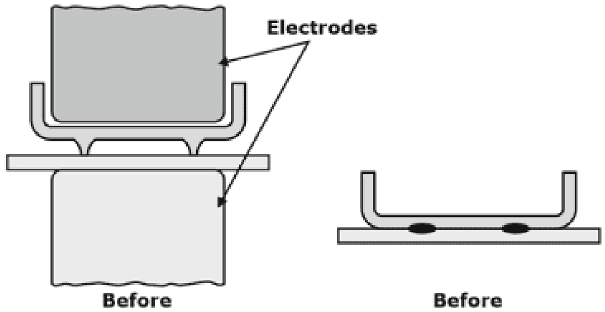
- It is resistance welding process where continuous series of spots is obtained to join the metal with the application of heat from resistance and pressure by electrodes.
- Here disc electrodes are continuously rotated and the workpiece is advanced underneath them while at the same time the pressure on the joints is maintained. The electrodes pressure is relieved after solidification of molten metal.



- This process is used for air tight joints.

Projection welding:

- The method of joining a projected component on a flat component by using resistance welding is called resistance projection welding.
- In projection welding, the shape of the electrode remains same as the shape of components to be joined.

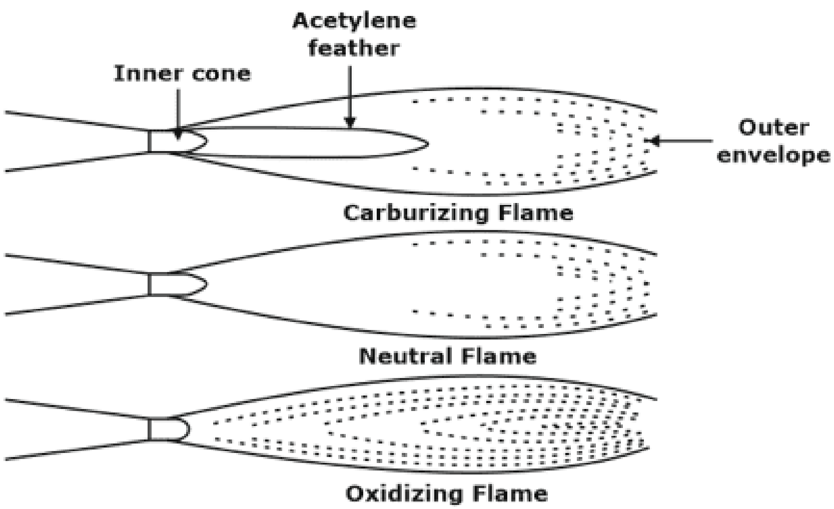


Oxyacetylene welding (Gas welding):

- It can used for welding of wide range of metals and alloys.
- In this welding, Acetylene and oxygen mixture are burnt under a controlled environment which releases a large amount of heat resulting in high temperature rise.
- Carbon dioxide is also produced which prevents the oxidation of metals being welded.
- Highest temperature obtained in this welding is 3200°C.
  The chemical reaction involved in burning of acetylene is:
- Oxygen cylinder valves are made of Brass and Acetylene cylinder valves are made by Steel. Brass valve does not corrode so easily and that is why brass valves are used in oxygen cylinder.
- Acetylene is a very dangerous gas because it can explode under its own weight. So, calcium silicate is filled in the cylinder and then acetone is poured. Acetylene is absorbed in acetone.

Flame Formation and its Types

Based on the proportion of acetylene and oxygen, flames are divided into three categories named neutral flame, carburizing flame and oxidizing flame. These are explained below:



(1). Neutral flame:

- It consists of 1:1 ratio of acetylene and oxygen by volume. It has two parts namely the inner cone and the outer envelope.
- It produces hissing sound on burning and is used for welding low Carbon steels & Aluminum.
- The temperature of neutral flame is 3200°C.

(2). Carburizing flame:

- In this flame, there is excess of volume of acetylene over oxygen and thus it is white in color due to excess acetylene.
- Its temperature generation range is 3100 °C to 3300 °C.
- It is used for the welding of metals where risk of oxidation at elevated temperature is more like aluminum, its alloys and lead and its alloys.

(3). Oxidizing Flame:

- This flame has an excess volume of the oxygen over the acetylene. It is the hottest flames and produces roaring sound.
- It consists of a very short pointed white inner cone and a shorter outer envelope. The reduction of length of the inner cone is a measure of excess oxygen.
- These flames are used to weld alloys of Copper and Zinc. In welding these metals, the oxidizing flame produces a base metal oxide layer to protect the evaporation of low point alloying elements.
- The temperature of these flames is around 3480°C.

Electron Beam Welding

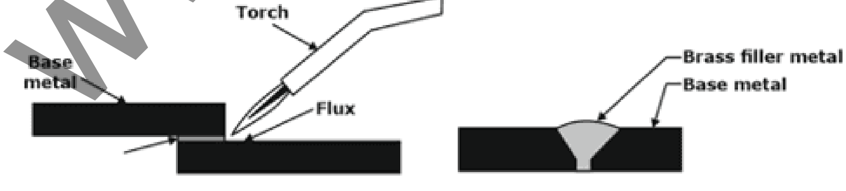
- Electron Beam Welding (EBW) is a fusion welding in which coalescence is produced by heating the work piece due to impingement of the concentrated electron beam of high kinetic energy on the work piece.
- Electron beam welding process is done under the vacuum condition.
- Molten metal fills into the gap between parts to be joined and subsequently it gets solidified and forms the weld joint.

Laser Beam Welding

- In the LBM process, the laser beam is directed by flat optical elements, such as mirrors and then focused to a small spot (for high power density) at the workpiece using either reflective focusing elements or lenses.
- Inert gas shielding is generally employed to prevent oxidation of the molten puddle and filler metals may be occasionally used.
- The Lasers which are predominantly being used for industrial material processing and welding tasks are the Nd-YAG laser and 1.06 μm wavelength CO_2 laser, with the active elements most commonly employed in these two varieties of lasers being the neodymium (Nd) ion and the CO_2 molecules respectively.

Brazing

- In this welding, the coalescence of a joint is obtained using the filler metal whose liquidus temperature is above 450°C and is below the solidus temperature of the base metal.
- In brazing, the base metal is not melted. Dissimilar metals can be joined by brazing. Except for aluminum and magnesium, brazing can join almost all metals.

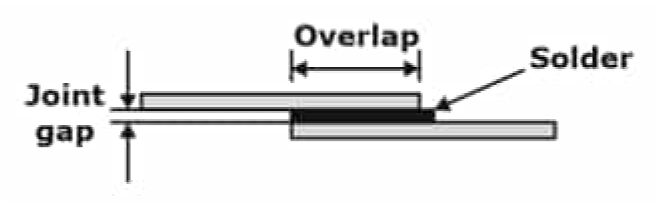


- Here the filler metal in the joint, is filled by capillary action. Thus, it is necessary to control the clearance between two parts.

- Since too much clearance doesn't allow the capillary force to draw the filler metal into the joint and also insufficient clearance may be too small to allow the filler metal to give rise to an effective strength.

Soldering

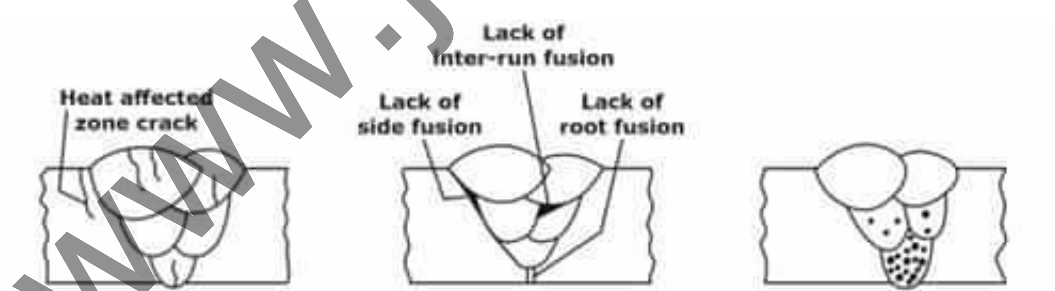
- It is used tp join similar or dissimilar metals by means of a filler metal whose liquidus temperature is below 450°C.

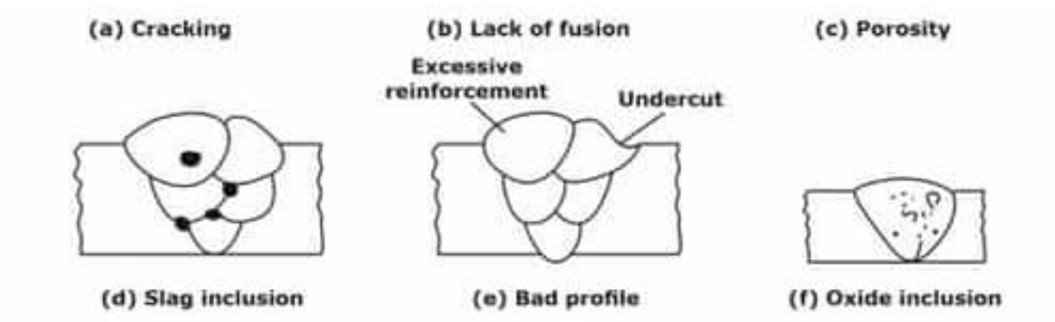


- The joint design used for soldering is similar to that of brazing as in both cases filler metals enter the joint by capillary action.
- Like brazing, soldering also needs solvent cleaning, acid pickling and mechanical cleaning of the joint surface. In order to remove the oxides from the joint surface for avoiding filler metal from oxidizing, fluxes are generally used in soldering.

Weld Defects and Testing

The ideal weld should be such that adequate fusion exists between the filler metal and edge preparation together with good penetration. The major discontinuities are





- In welding, the defects often found infusing due to lack of fusion, lack of penetration, the inclusion of slag or oxide, presence of cracks, porosity and uncut and excessive penetration.
- These are the defects generally shown in butt welds.
- The defects like cracking, lack of fusion, porosity, slag inclusion, bad profile, and oxide inclusion alter the static strength of the welded joint under ductile conditions but have serious consequences if the joint is subjected to fatigue loading.
- The presence of crack enhances the probability of brittle fracture. Similarly, a lack of fusion causes a lack of discontinuity and hence diminishes the fatigue strength.

Metrology and Inspection

Introduction

It is the measurement science which includes various aspects like design, manufacture, testing and applications of various measuring instruments, devices and techniques. Thus, it facilitates the proper application of the scientific principles in the accurate dimensional control of manufactured components.

Interchangeability: This principle generally used for the mass production of identical parts within the suggested limits of sizes.

Types of Interchangeability:

Depending on these factors three types of interchangeabilities can be obtained on the finished components:

(i) Full or Universal interchangeability

(ii) Selective assembly

(iii) Matched fits.

Limit System

NOMINAL SIZE:

- It is the size of a part by which it is designated as a matter of convenience.
  For example: when we say a 25 mm pipe we actually mean a pipe having a 25 mm diameter bore.

BASIC SIZE:

It is the theoretical size that is common to both the parts of a mating pair, usually a hole and a shaft.

ACTUAL SIZE

It is the measure of the actual dimension a part has attained after it has been finished.

ALLOWANCE:

(i) It is the difference between the upper limit of the shaft and the lower limit of the hole.

(ii) In other words, it is the minimum clearance or maximum interference.

(iii) It is the intentional difference between the basic dimensions of the mating parts. The allowance may be positive or negative.

Tolerance

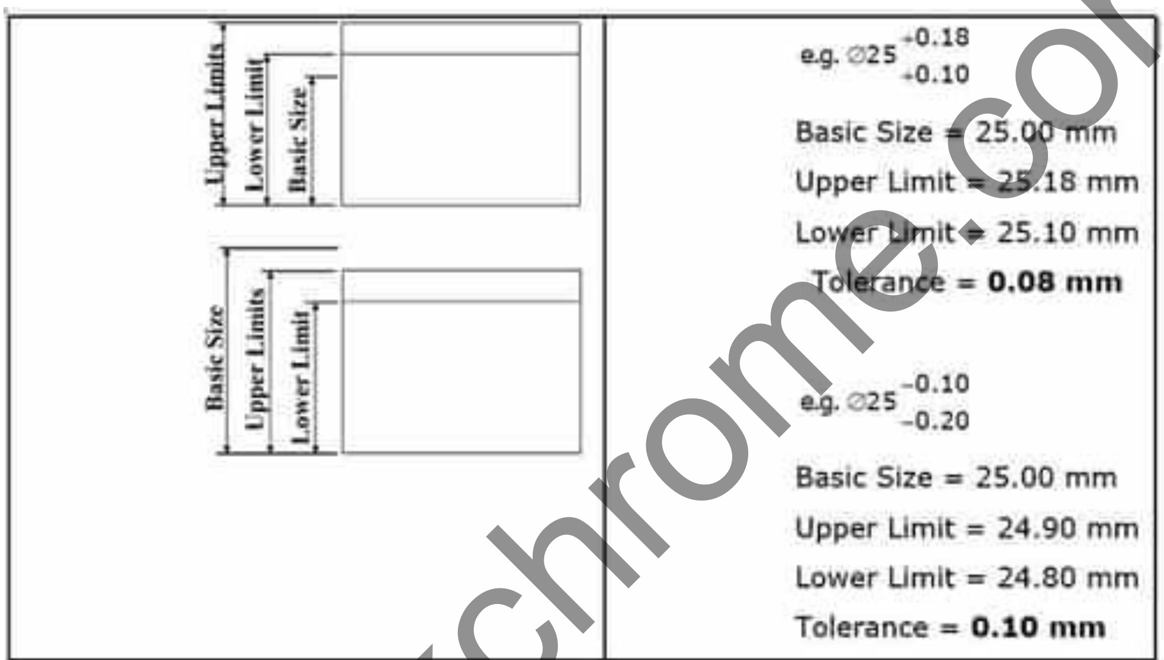
(i). It is the difference between the lower limit and the upper limit of an assembly.

(ii). It is the maximum permissible variation in a dimension.

(iii). The tolerance may be unilateral or bilateral.

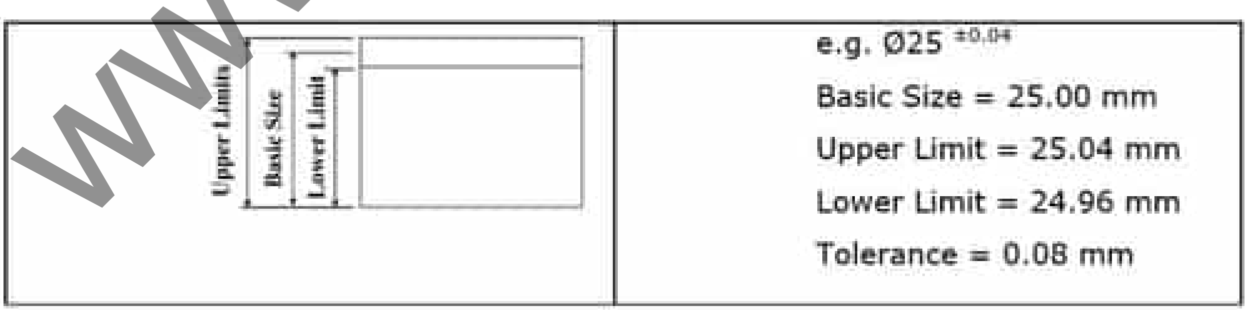
Unilateral Limits:

When variation in size is permitted on only one side, it is called unilateral limit system.



Bilateral Limits:

When the variation in size is permitted on both sides, it is called bilateral limit system.



DEVIATION

Zero Line: It is the straight line that corresponds to the basic size and from this line, all the deviations are measured.

Deviation: It is the algebraic difference of a any size and the corresponding basic size.

Actual deviation: The algebraic difference of the basic size and actual size is referred as actual deviation.

Upper deviation: The algebraic difference of the maximum size and the basic size is the upper deviation.

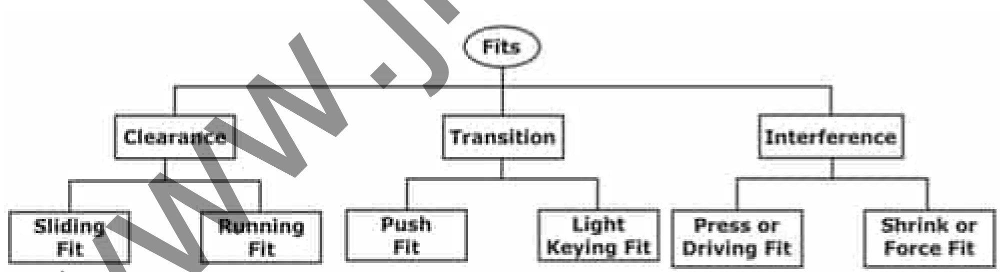
Lower deviation: The algebraic difference of the minimum size and the basic size is referred as Lower deviation.

Mean deviation: The arithmetical mean of lower and upper deviations is known as mean deviation.

Fundamental deviation: Either the upper or the lower deviation, which is the nearest one to zero line for either a hole or shaft is the fundamental deviation.

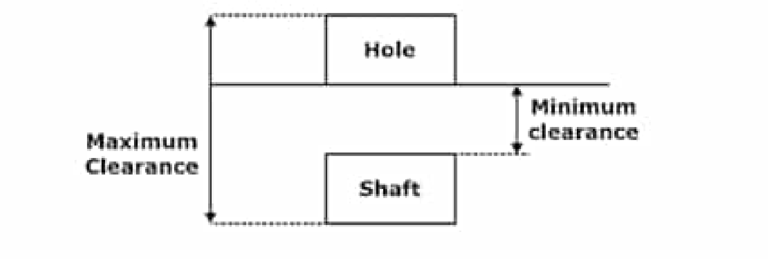
FITS

The condition which denotes the relationship between two mating parts with respect to the degree of clearance or interference appearing on the assembly is known as fit.

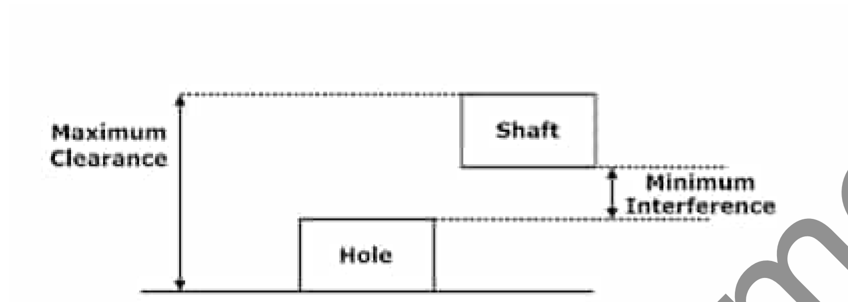


HOLE BASIS SYSTEM

CLEARANCE FIT: When lower limit of hole is greater than upper limit of shaft.



INTERFERENCE FIT: When lower limit of shaft is greater than upper limit of hole.



TRANSITION FIT: When a part is selected randomly from hole lot and randomly from shaft lot, some of the assembly have clearance fit, some are having interference fit.

INDIAN STANDARD SYSTEM:

The magnitudes of standard tolerances corresponding to grades IT01, IT0 and IT1 are as follows:

IT01 = 0.3 + 0.008D

IT0 = 0.5 + 0.012D

IT1 0.8 + 0.020D

Fundamental tolerance unit i,

$$i\ (\text{microns}) = 0.45\sqrt[3]{D} + 0.001\ D$$

D being the size or geometric mean diameter in mm. The two limits for calculating D are taken from below table.

Above (mm)		Upto and including (mm)
-	-	3
3	-	6
6	-	10
10	-	18
18	-	30
30	-	50
50	-	80
80	-	120
120	-	180
180	-	250
250	-	315
315	-	400
400	-	500

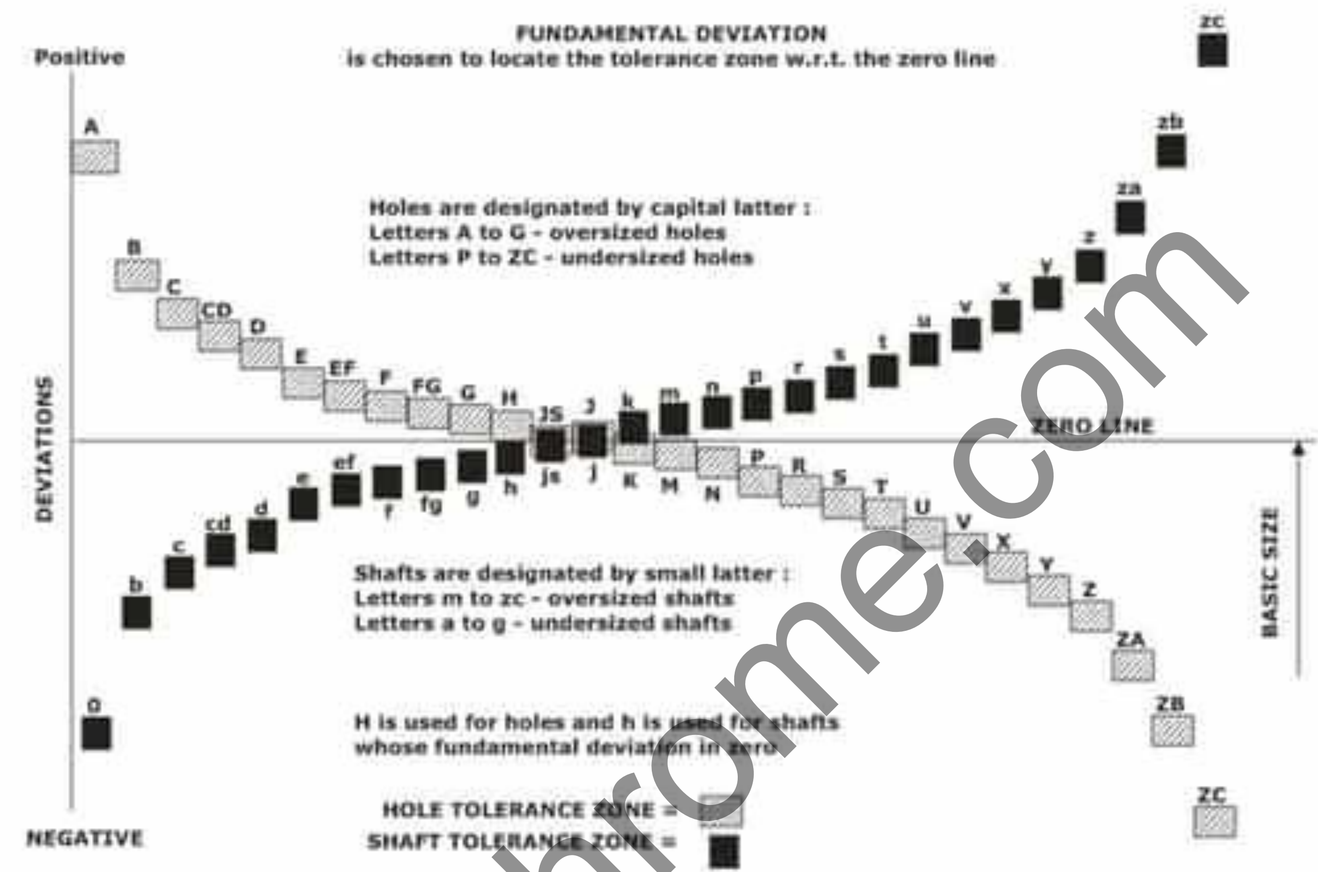


Fig.: Hole and Shaft Tolerance Zones

LIMIT GAUGES:

Gauges are scaleless inspection tools that serves to check the dimension of the manufactured part.

The main forms of these gauges are:

PLUG GAUGE:

The GO plug gauge has the size of the lower limit of the hole while the NO GO plug gauge corresponds to the high limit of the hole.

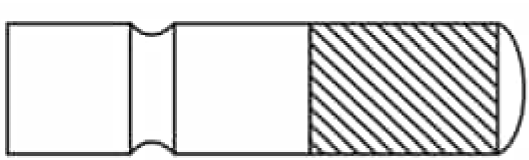


Fig.: Plug gauge

RING GAUGE:

It is used for testing the accuracy of the external features of a component such as the external diameter of a shaft.

Snap, Gap or Ring gauge are used for gauging the shaft and male components.

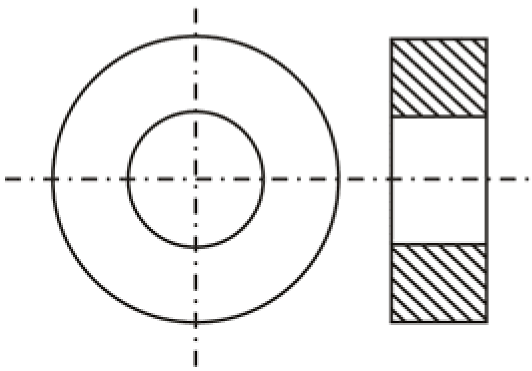


Fig.: Ring gauge

SLIP GAUGES

(i)They are in the form of rectangular prisms, very accurately made in varying lengths.

(ii)They are made of hardened steel having flat parallel surfaces.

Slip-gauge size of range, mm	Increment, mm	Number of pieces
1.005	-	1
1.001 to 1.009	0.001	9
1.010 to 1.490	0.010	49
0.500 to 9.500	0.500	19
10 to 100	10.000	10

LINEAR MEASUREMENTS:

- Rules

- Vernier
- Micrometre
- Height gauge
- Bore gauge
- Dial indicator
- Slip gauges or gauge blocks

ANGULAR MEASUREMENTS:

The angular measurement is sued to measure the angles of tapers and similar surfaces. The tools used for angular measurement are as follows:

- Bevel protractor
- Sine bar

BEVEL PROTRACTOR

- Is part of the machinist's combination square.
- The flat base of the protractor helps in setting it properly on the workpiece and then by rotation of the rule, it is possible to measure the angle. It generally has a discrimination of one degree.

The distance between centres of the plugs is fixed for a particular sine bar and the same is always written over the bar.

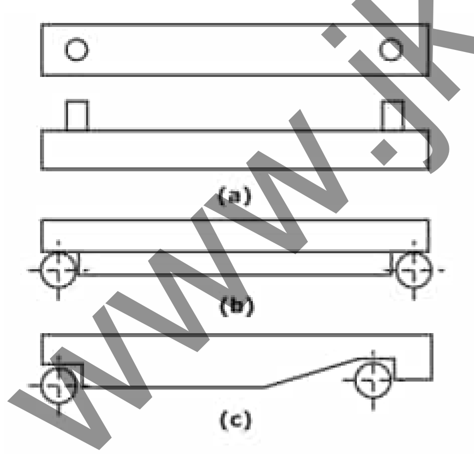


Fig.: Different forms of sine bar

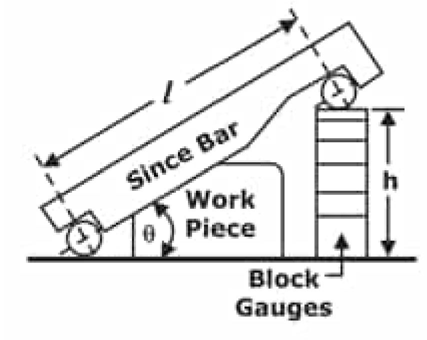


Fig.: Use of sine bar

Now, if 'θ' be the angle subtended by the lower face of the sine bar with the datum surface (i.e., top of the surface plate), then:

$$\theta = \sin^{-1}\frac{h}{l}$$

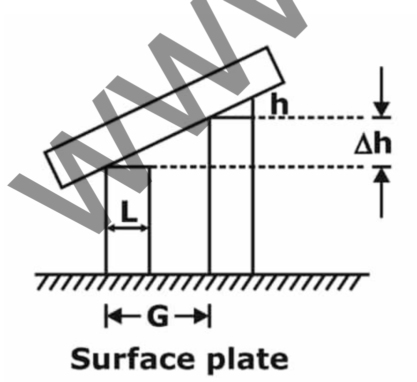
Best wire diameter,

$$d = \frac{p}{2}\sec\left(\frac{\theta}{2}\right)$$

OPTICAL FLAT AS COMPARATOR:

Using optical flat difference is the size of slip gauge can be calculated from a master reference. Suppose the difference Δh has to be calculated:

From the similar triangles,



$$\Rightarrow \Delta h = \left(\frac{h\lambda}{2}\right)\left(\frac{G}{L}\right)$$

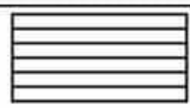
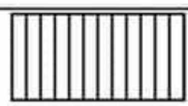
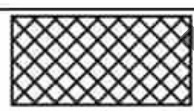
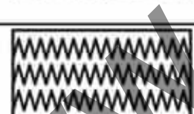
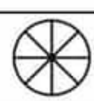
SURFACE FINISH:

It is a well-known fact that the actual surface after machining may look smooth but in reality it is not.

Most of the surfaces have some kind of roughness and inaccuracy up to a certain degree. The surface of a part seem a series of jagged peaks and valleys on magnification.

Lay direction:

The predominant surface pattern produced on the workpiece by the tool marks show the lay directions. The different types of lay directions produced are shown below:

Symbol	Diagram	Description
=		**Parallel lay:** Surface is produced
⊥		**Perpendicular lay :** Surface is produced by shaping and planning
X		**Crossed lay :** Such surface can be produced by knurling operation
M		**Multidirectional lay :** Such surfaces are produced by grinding operation
C		**Circular lay :** The surfaces are produced by facing operation
R		Radial lay

EVALUATION OF SURFACE ROUGHNESS:

ARITHMETICAL AVERAGE OR CENTER LINE AVERAGE VALUE (CLA, R_A):

$$R_a = \frac{1}{L}\int_0^L |y(x)|\,dx \cong \frac{1}{N}\sum |y_i|$$

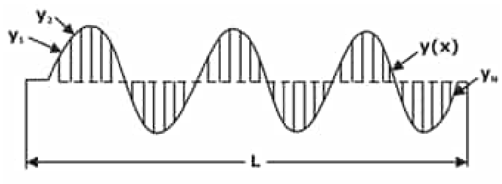


Fig.: Surface roughness parameters

Root mean square value: The root-mean-square value of the deviation is used sometimes in place of the arithmetic average, R_{rms}. This in expression form is written as:

$$R_{rms} \cong \sqrt{\frac{1}{N}\sum y_i^2}$$

PEAK TO VALLEY HEIGHT (R_T OR R_{MAX}):

It is the difference between highest peak and deepest valley.

The approximate value of R_a is,

$$R_a = \frac{H_{max}}{4}$$

Maximum height of unevenness can also be expressed as,

$$H_{max} = \frac{f^2}{8R}$$

If complete tool signature is given, the peak to valley height can also be calculated as,

$$H_{max} = \frac{f}{\tan\psi + \cot\psi_1}$$

Where,

f= feed rate

ψ =side cutting edge angle

ψ_1 =end cutting edge angle

Non-conventional Machining Process

The nontraditional processes are mostly classified as per the form of energy used to cause material removal. They are:

1. **Mechanical:** The work material is eroded by a high-velocity stream of abrasives or fluid (or both). It is a typical form of mechanical action in these processes which enables the removal of excess material.

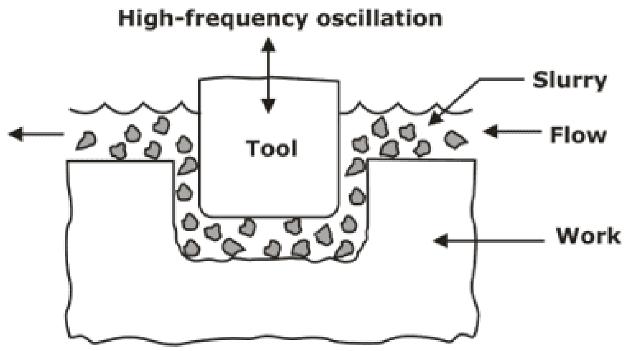
2. **Electrical**: The use of electrochemical energy is done in these non-traditional processes to remove material; the mechanism is the reverse of electroplating.

3. **Thermal**: The use of thermal energy is done to cut or shape the workpiece. The thermal energy is usually applied to a tiny portion of the work surface, which causes that portion to be removed by fusion and/or vaporization. Conversion of electrical energy takes place for the generation of thermal energy.

4. **Chemical**: Most materials (particularly metals) are prone to chemical attack by certain acids or other etchants. Chemicals selectively remove material from areas of the workpiece in chemical machining, while other portions of the surface stay protected by a mask.

Mechanical Energy Processes

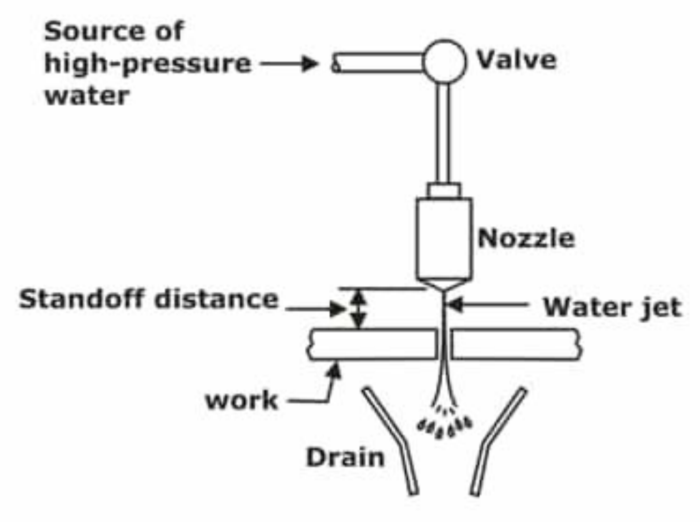
Ultrasonic Machining- Ultrasonic machining (USM) is a nontraditional machining process where abrasives present in the slurry are driven at high velocity against the work by a tool vibrating at high frequency and low amplitude. The amplitudes are approximately around 0.075 mm, and the frequencies are approximately 20,000 Hz.



- The tool vibrates in the direction perpendicular to the work surface, and is fed slowly into the work, so that the tool's shape is formed in the part. The cutting is performed by the action of the abrasives, impacting against the work surface.
- Soft steel and stainless steel are the mostly used tool materials in USM. When the tool is made hollow, the internal contour should be parallel to the external one for ensuring uniform wear.
- Boron nitride, boron carbide, aluminum oxide, silicon carbide, and diamond are some of the abrasive materials used in USM. Grain size ranges between 100 and 2000.
- Abrasive concentration in water ranges from 20% to 60% in the mixture of abrasives and water, in the slurry used in USM.
- Material removal rate is an important performance variable in ultrasonic machining in addition to the surface finish.

Jet Machining- High-velocity stream of water (Water Jet Cutting) or water mixed with abrasive materials (Abrasive Water Jet Cutting) is directed to the workpiece to be cut in Jet Machining. When a mixture of gas and abrasive particles is used, process is known as Abrasive Jet Machining and it is used not for cutting the work but for finishing operations like deburring, cleaning, polishing.

Water Jet Cutting (WJC) makes use of a fine, high-pressure, high velocity stream of water accelerated at the work surface for the purpose of cutting the work, as illustrated in the figure below.

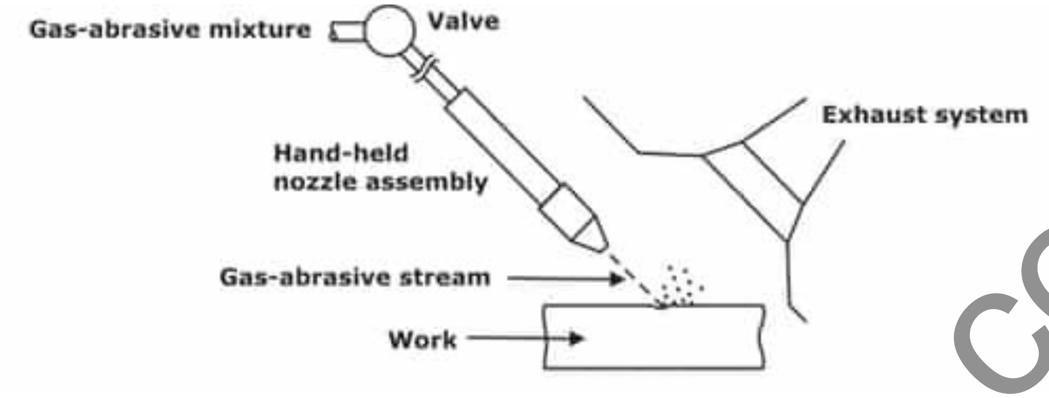


- For the improvement of fluid characteristics additives such as alcohols, oil products and glycerol is added to water, which is the most common type of fluid.
- Pressurization of the fluid is done at 150-1000 MPa to generate jet velocities of **540-1400 m/s**. The flow rate of fluid is usually from 0.5 to 2.5 l/min.
- Some of the work materials include soft metals, paper, cloth, wood, leather, rubber, plastics, and frozen food.

A narrow, focused, water jet mixed with abrasive particles is focused in **Abrasive Water Jet Cutting (AWJC)**. This jet is sprayed with high pressures developing high velocities which cut through all materials.

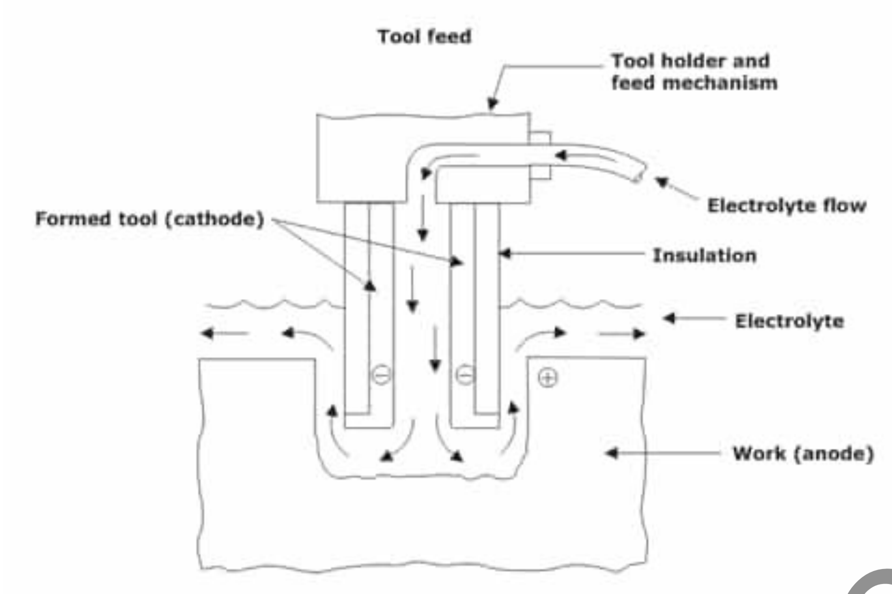
- The abrasive particles which are present in the water jet induces cutting forces and enables cutting of thick and hard materials (steel plates over 80-mm thick can be cut).
- Velocity of the stream up to 90 m/s is attained, approximately 2.5 times the speed of sound.
- Abrasive Water Jet Cutting process was developed to cut materials that cannot bear high temperatures causing stress distortion or some other metallurgical reasons such as wood and composites, and other traditionally difficult-to-cut materials, e.g. ceramics, glass, stones, titanium alloys.
- Quartz sand, silicon carbide, and corundum (Al_2O_3) are some of the common type of abrasive materials. The grit size ranges from 60 and 120.

In **Abrasive Jet Machining (AJM)** tiny abrasive particles (typically ~0.025mm) are directed and accelerated in a gas stream (usually air) towards the surface that has to be machined.



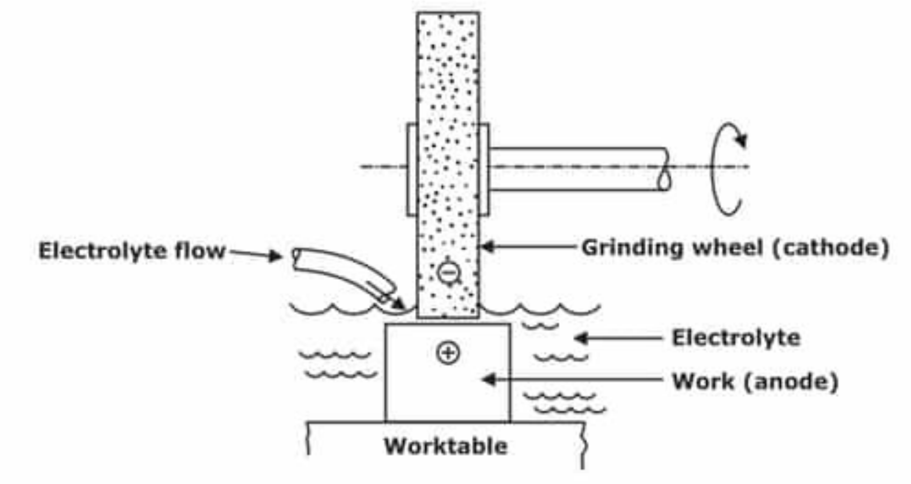
- As the particles make an impact in the work surface, small fractures are generated, and the gas stream carries both the abrasive and the fractured (wear) particles away.
- The jet velocity ranges from 150-300 m/s and pressure is from 2-10 times of atmospheric pressure.
- Aluminum oxide (corundum) and silicon carbide of small grit sizes are the preferred abrasive materials. Sharp edges should be there in the grain and they should not be reused as the sharp edges could be worn down and smaller particles can clog the nozzle.
- Deburring, etching, and cleaning of hard and brittle metals, alloys, and nonmetallic materials (e.g., germanium, silicon, glass, ceramics, and mica) are some of the applications of Abrasive Jet Machining.

Electrochemical machining: ECM uses principle of electrolysis to remove metal from the work piece. Electrolysis is based on faradays laws of electrolysis which is stated as "weight of substance produced during electrolysis is proportional to current passing, length of time the process used and the deposition of equivalent weight of material ".



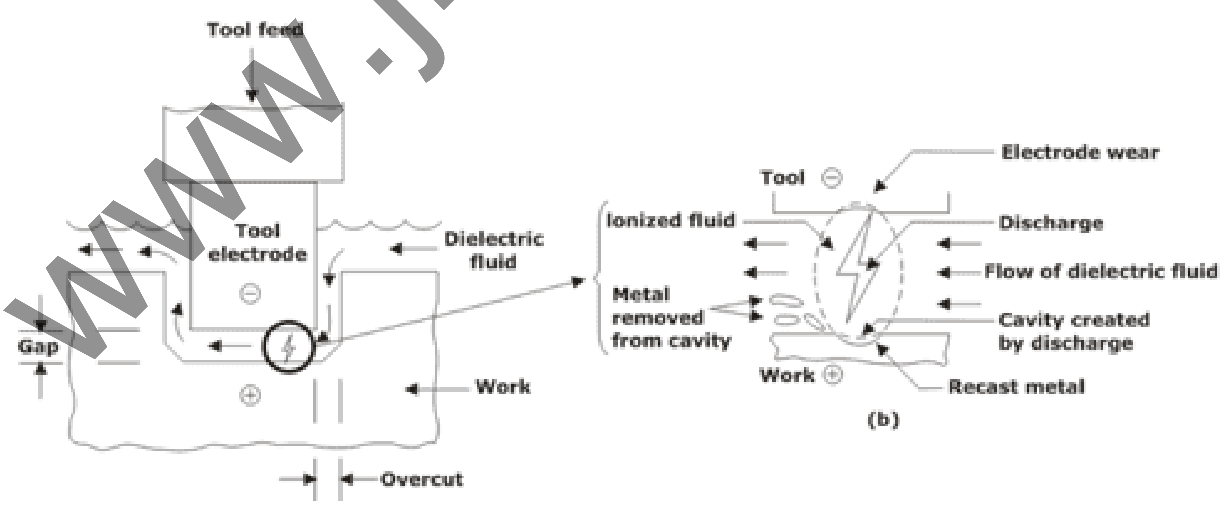
- Reverse of electroplating (anode loses metal to cathode) is ECM. So, in ECM work is made anode and tool is made cathode. So, work loses metal, but before depositing it on to tool, it is carried away be electrolyte.
- In ECM constant feed motion is provided to the tool and pumping of electrolyte occurs at a high pressure through the tool and the small gap between tool and work piece.
- The current of the order of few thousand amperes is used and voltage of 8-20 volts and gap is of the order of 0.2mm. Practically no tool wears in ECM.

Electrochemical Grinding (ECG)- In this process, a rotating grinding wheel having a conductive bond material is used to cause the anodic dissolution of the metal work part surface, as illustrated in Figure. This process is called electrochemical grinding (ECG), which is a special form of ECM.



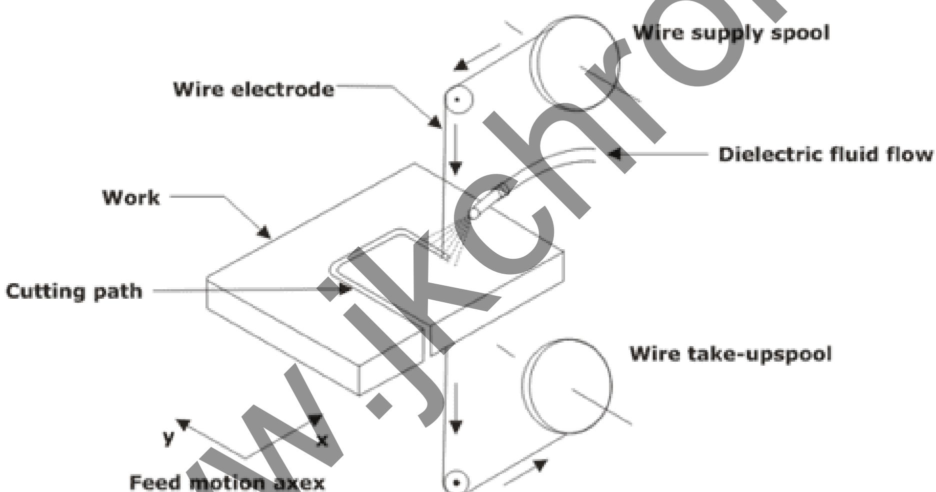
- Aluminum oxide and diamond are the abrasives used in ECG. For having an electrically conductive bond, the bond is usually metallic or resin bond impregnated by metal powders for the sake of making it conductive.
- Sharpening of cemented carbide tools and grinding of surgical needles, other thin wall tubes, and fragile parts are some of the applications of ECG.

Electric Discharge Machining- In electric discharge processes, The work material is removal of work material by a series of sparks causing localized melting and evaporation of the material on the work surface takes place in electric discharge machining. Electrically conducting work materials are the only materials upon which these processes could be used.



- Final shape of the finished work is developed by a formed electrode tool. The sparks take place across a small gap between work surface and tool.
- Dielectric fluid must be present for EDM to take place as it creates a path for each discharge as the fluid becomes ionized in the gap. Eg a kerosene-based oil.
- Typical electrode materials include Copper, tungsten, and graphite are some of the materials which are used as electrodes. Machining of these materials are relatively easy and therefore complex shapes can be given to them.
- Since the process is based on melting temperature, not hardness, therefore some extremely hard materials can be machined this way

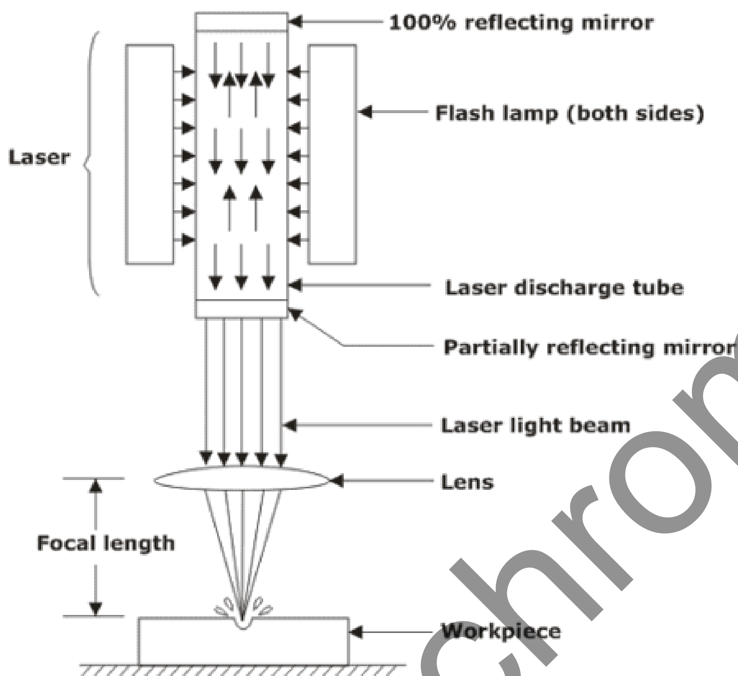
Electric Discharge Wire Machining- Wire Electric Discharge Machining (Wire EDM) is a special form of EDM process which makes use of a small diameter wire as the electrode to cut a narrow work. Wire EDM is illustrated in the figure.



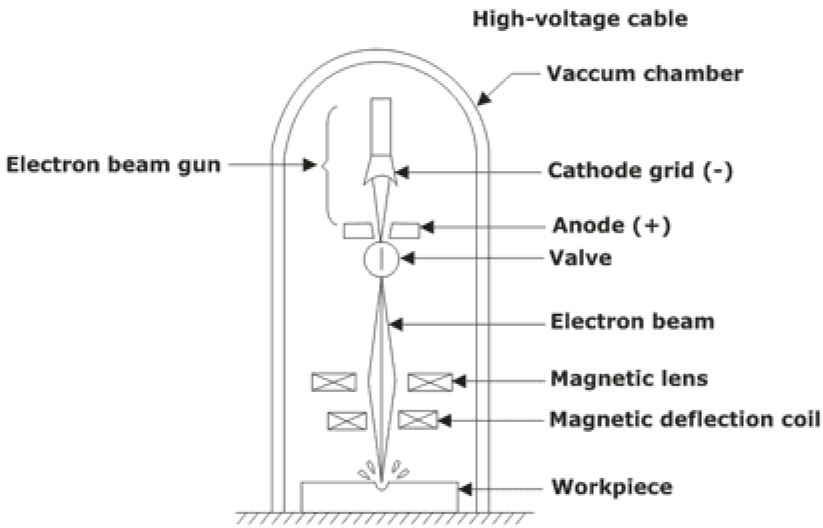
- Continuous feeding of the work piece is done slowly past the wire for achieving the desired cutting path. For controlling the work-part motions during cutting, numerical control is used.
- The wire is continuously advanced between a supply spool and a take-up spool to present a fresh electrode of constant diameter to the work during the cutting duration.
- Presence of dielectric is must in wire EDM as well just like usual EDM.

- Materials used for the wire include **brass, copper, tungsten, and molybdenum** are the materials used for the wires and the diameter of wire ranges from 0.08 mm to 0.3 mm.

Laser Beam Machining (LBM)- Using of light energy from a laser to remove material by vaporization takes place in Laser Beam Machining (LBM). An illustration of LBM setup is shown below :



- Carbon dioxide (CO_2) gas lasers are mostly used in LBM. Production of monochromatic light with constant wavelength occurs by LASER.
- The a normal white light has significantly more power than LASER, but LASER can be highly focused, thus delivering a significantly higher light intensity and temperature in a very localized area.
- Heat treatment, welding, and measurement, number of cutting operations such as drilling, slitting, slotting, and marking operations are few applications of LASER. **Electron Beam Machining (EBM)-** High-velocity stream of electrons focused on the workpiece surface to remove material by melting and vaporization takes place in EBM. A schematic of the setup of an EBM equipment is shown below:



- A continuous stream of electrons focused through an electromagnetic lens on the work surface is done by an electron beam gun. Acceleration voltages of approximately 150,000 V are used to generate a velocity of over 200,000 km/s.

- A reduction of the area of the beam to a diameter as small as 0.025 mm is possible by the lens. Upon impingement to the surface, the kinetic energy of the electrons is converted into thermal energy of high density, which causes vaporization of the material in a very localized area.

- A vacuum chamber must be used to eliminate the collision of the electrons with gas molecules.

- Thin parts in the range of 0.2 to 6 mm thick are used in EBM.

- Extremely small diameter holes, down to 0.05 mm diameter can be drilled, holes with very high depth-to-diameter ratios can also be drilled, more than 100:1, and cutting of slots that are only about 0.025 mm are few of the applications of EBM.

Computer Integrated Manufacturing

Introduction to Computer Integrated Manufacturing

Computer Integrated Manufacturing is the manufacturing approach of using computers to control the entire production process. Individual processes exchange information with each other and initiate actions with the help of this integration. Factory floor functions such as materials handling and management, providing direct control and monitoring of all the operations are linked with functional areas such as design, analysis, planning, purchasing, cost accounting, inventory control, and distribution in a CIM system.

PROCESSES INVOLVED- A list of different processes involved is given below:

- Computer-Aided Design
- Prototype manufacturing
- Determination of the efficient method for manufacturing by calculation of the costs and considering the production methods, volume of products, storage and distribution
- Giving order of the necessary materials required for the production process
- Computer-aided manufacturing of the products with the help computer numerical controllers
- Quality controls at each of the development.
- Product assembly with the help robots
- Quality check and automated storage
- Distribution of products to awaiting lorries/trucks from the storage areas automatically
- Updating of logs, financial data and bills in the computer system automatically.

WHY CIM?

- **ERROR REDUCTION-** Elimination of human error in many assignment and reporting functions on factory floor operation drastically reduces the error rate.

- **SPEED-** Quicker flow of product to customers and increased capacity, reduction in the time taken to perform manufacturing, fabrication and assembly is possible in a CIM environment.

- **FLEXIBILITY**- With CIM companies quickly react to market conditions and then return to previous setting when market condition change.

- **INTEGRATION-** A degree of introduction of integration of flexibility, speed and error reduction is offered by a CIM which is required to compete and lead markets. Integration of factory floor operations with enterprise software enables employees to do higher value functions for their companies.

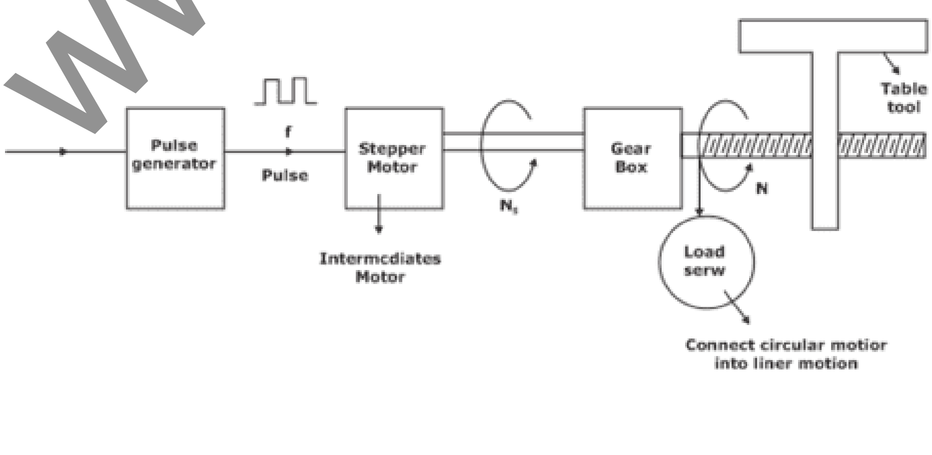
USAGES OF CIM

1. Industrial and Production Engineering
2. Mechanical Engineering
3. Electronic Design Automation
    - Printed Circuit Board design
    - Integrated Circuit design

MACHINE- Conversion of one form of energy into another is possible by a machine. Machine which performs multiple operation is known as machine centre. Tool Magazine is used to store the tool for machine centre.

NC (Numeric control) (Open loop control) - The directions of tool motions are controlled by alphabets and using number is known as Numeric Control. It is a programmable automation in which the program is installed in the form of presence and absence of holes on the punch card. Punch cards are prepared by using paper or plastic tapes.

- Tape reader is used to read the punch card and generate the electric pulses using pulse generator.
- Stepper motor rotor at a speed of N_s (steps per resolution) offer receiving the electronic signal form the pulse generator. Stepper motor is connected with the lead screw with the help of a gear box to provide the desired speed.
- Lead screw converts rotation into livers motion.



Limitation of NC

- There is no feedback loop control.
- Legibility to modify the program is zero.
- Lengthy topes are used and it very laborious and time taken.

STEPPER MOTORS- These are used for precise positioning of objects or machines slide out using a feedback control system. Stepper motor is driven by an electrical pulse train operated by the machine control unit. Rotation of the motor shaft is proportional to number of pulses it receives, and its angular velocity is proportional to the frequency of pulses. A stepper motor rotates a precise angular distance, i.e., one step for each pulse it receives. Each pulse turns the shaft by a fraction of one revolution, called the step angle.

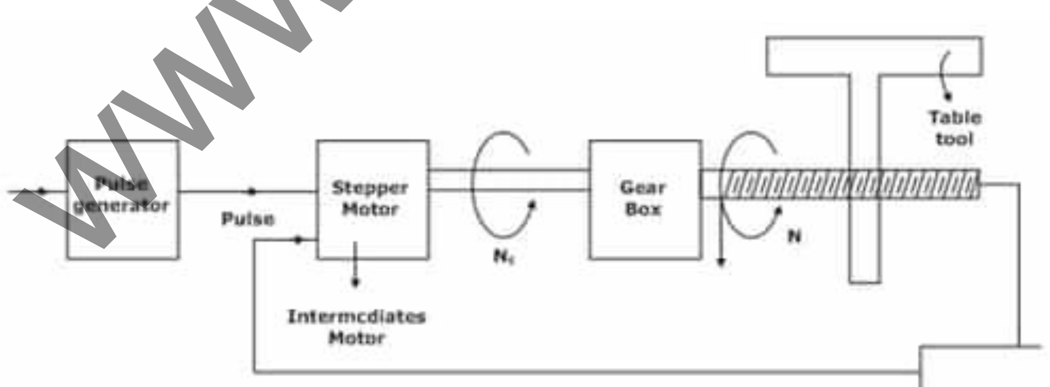
Basic Length Unit (BLU)- It is the distance travelled by the table for one step or pulse of stepping motor. where

$$BLU = \frac{\text{Lead screw pitch(mm)}}{\text{Steps per revolution of stepper motor}}$$

Also, linear velocity of stepper motor, V is given by the expression

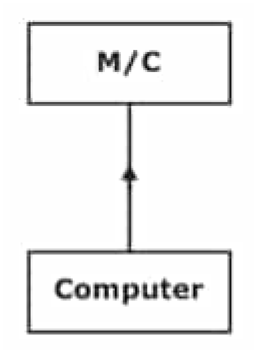
V = pulse frequency x BLU x 60 mm/min

CNC (Computer Numeric control) (Closed loop CNC)- It is a programmable automation in which program is installed in microprocessor. Programs are written using NC programming as before. The feedback signal from the table tool movement. Comparator compare the single from encode and from the pulse generator.

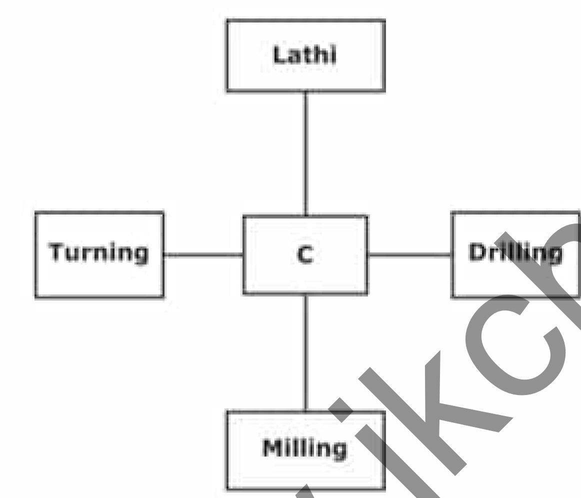


Closed loop Control

DIRECT NUMERICAL CONTROL (DNC)- In 70's the size of hardware was quite big. External computes were used to store the complex programs which is directly comely commented to the machine.



DISTRIBUTED NUMERIC CONTROL (DNC)- It is used to control multiple machines at different location using single computer.



FLEXIBLE MACHINING SYSTEM (FMS)- Automating the entire manufacturing system with negligible manual intervention. A group of machines interconnected together using automated material handling and storage system controlled by integrated computer system is contained by a FMS.

AUTOMATED GUIDED VEHICLES (AGV)- They are used to transfer the work material from one machine to the work station to the another.

PREPARATORY FUNCTIONS- This is denoted by 'G'. Movement of machine axes and the associated geometry, these functions are associated with this pre-set function. As discussed, it has two digits, e.g. G01, G42 and G90, as per ISO specifications. However, some of the current-day controllers accept up to

3 or 4 digits. In this we will only discuss some of the regular functions. A number of preparatory functions, also popularly called G codes have been standardized by the ISO. The standardized codes are shown below:

CODE	FUNCTION
G00	Point-to point positioning, rapid traverse
G01	Line interpolation
G02	Circular interpolation, clockwise (WC)
G03	Circular interpolation, anticlockwise (CCW)
G04	Dwell
G05	Hold/Delay
G20	Circular interpolation, CW for "long dimensions"
G21	Circular interpolation, CW for "short dimensions"
G80	Canned cycle cancelled
G81-G89	Canned drilling and boring cycles
G90	Specifies absolute input dimensions
G91	Specifies incremental input dimensions

MISCELLANEOUS FUNCTIONS, M- These functions operate few controls on the machine tool and hence may affect the running of the machine. The ISO standard M codes are shown below:

CODE	FUNCTION
M00	Program stop, spindle and coolant off
M02	End of program–often interchangeable with M30
M03	Spindle on, CW
M04	Spindle on, CCW
M05	Spindle stop
M06	Tool change
M07	Coolant supply 1 on
M08	Coolant supply 2 on

M09	Coolant off

INTERPOLATOR- In a number of machining situations, tool has to move along continuous curves. The problem in generating these curves with NC is that trajectory is continuous while NC is digital. So the tool cannot trace exactly the desired path. The NC controller has to calculate large number of closely spaced points on the cutter path. These points are connected by very small straight lines to form the trajectory. If these points are very closely spaced, the actual path traced becomes approximately same as the desired tool path. The minimum distance between two points that the machine can differentiate is called control **resolution**. The accuracy of the machine depends on the control resolution. The process of calculating the points on the trajectory is called interpolation. A number of interpolation algorithm have been developed to generate smooth continuous tool trajectory with contouring type NC system.

- **LINEAR INTERPOLATOR-** It is a program /algorithm which can calculate closely spaced points between the given end points of line.
- **CIRCULAR INTERPOLATOR-** This is an algorithm that generates closely spaced points on the arc or circular profile which when connected by straight lines approximates a circle. The moves from point to point in order to machine a circular cut.
- **HELICAL INTERPOLATOR-** It is an algorithm that contains the logic of circular interpolation and linear interpolation perpendicular to the plane of circle to form a helical path.
- **PARABOLIC INTERPOLATOR-** It is less common in use. It can make use of the parabolic equation to generate points on parabolic curve.