Manufacturing Engineering

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1 THEORY OF METAL CUTTING

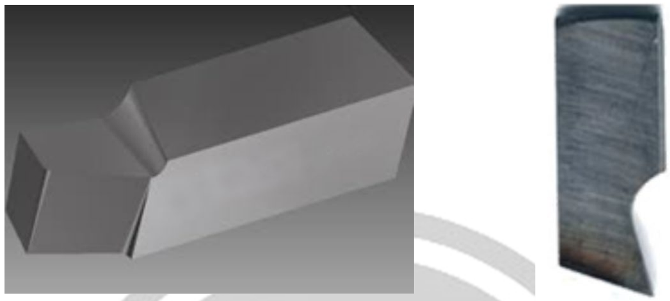


Fig. 1.1 Single point cutting tool

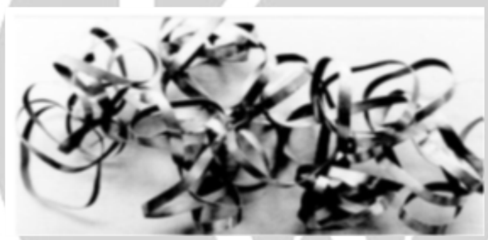


Fig. 1.2 Continues Chip

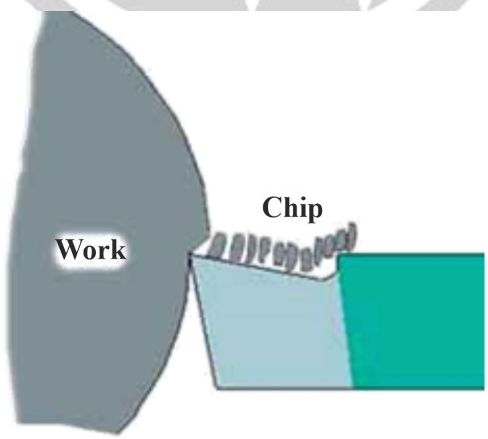


Fig. 1.3 Discontinues Chip

1.1 Machining

Machining is an essential process of finishing by which jobs are produced to

(a) The desired dimensions and

(b) Surface finish

1.2 Orthogonal Machining

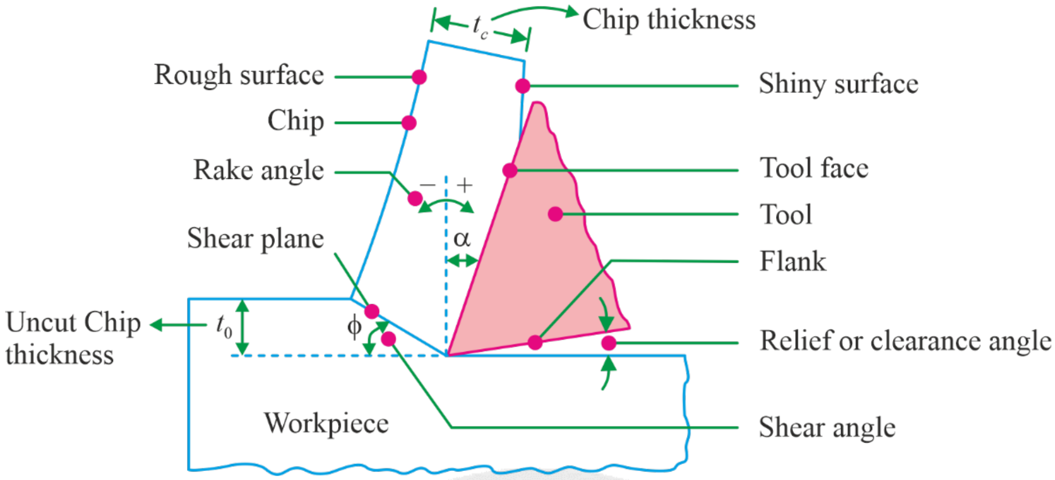
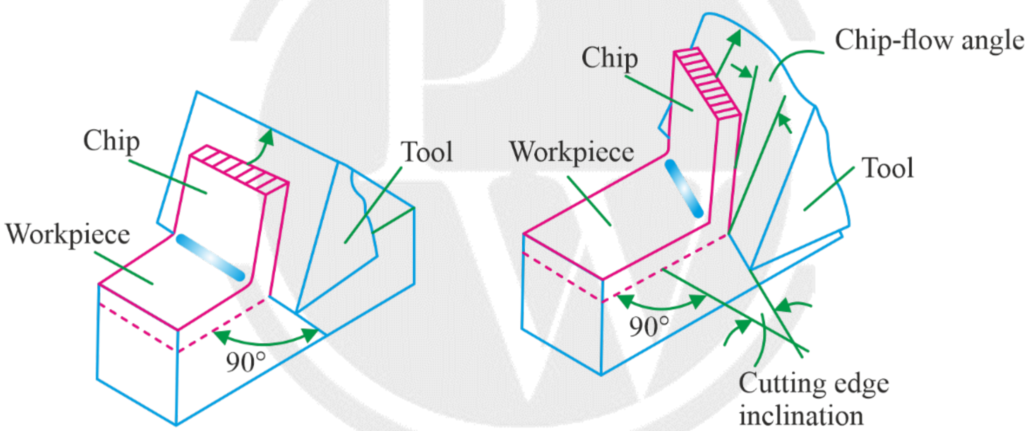


Fig. 1.4. Machining

1.3 Types of Machining



(a) Orthogonal Cutting **(b) Oblique Cutting**

Fig. 1.5 Different types of Cutting Process

1.4 Orthogonal Cutting

1. Cutting edge of the tool is perpendicular to the direction of cutting velocity.
2. The cutting edge is wider than the workpiece width and extends beyond the workpiece on either side. Also, the width of the workpiece is much greater than the depth of cut.
3. The chip generated flows on the rake face of the tool with chip velocity perpendicular to the cutting edge
4. The cutting forces act along two directions only.

1.5 Geometry of single point turning tool

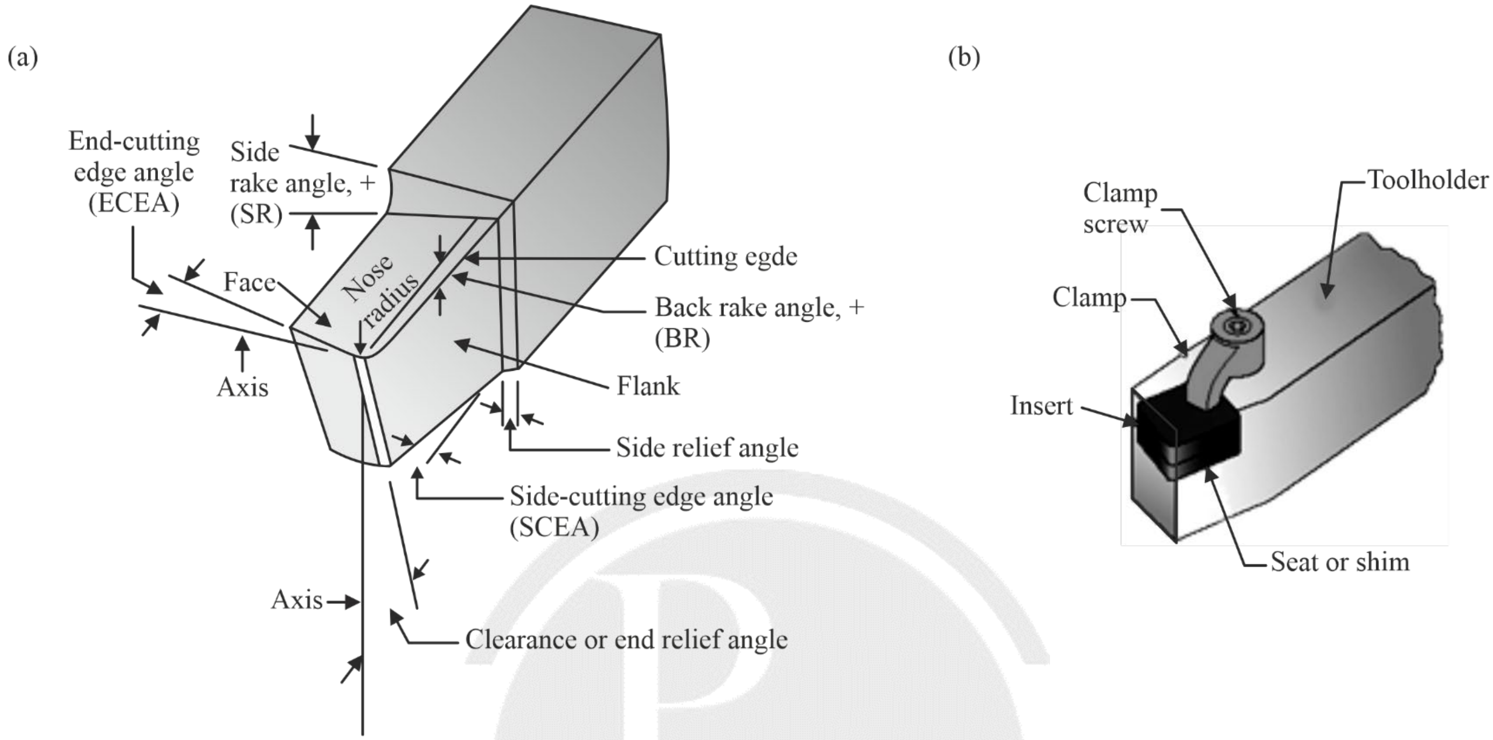


Fig. 1.6 Single point cutting tool

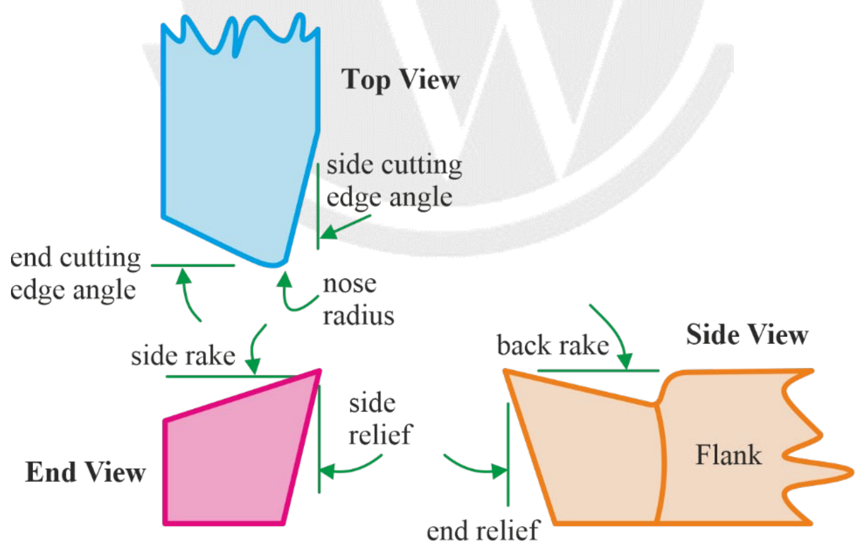


Fig. 1.7 Different type of views

1.6 Tool designation (ANSI) or ASA

1.6.1 To remember easily follow the rule

Rake (α_b α_s), relief (γ_e γ_s), cutting edge (C_e C_s)

Side will come last finish with nose radius (inch)

$$\alpha_b - \alpha_s - \gamma_e - \gamma_s - C_e - C_s - R$$

1.6.2 Orthogonal Rake System (ORS)

$$i - \alpha - \gamma - \gamma_1 - C_e - \lambda - R$$

- Inclination angle (i)
- Orthogonal rake angle (α)
- Side relief angle (γ)
- End relief angle (γ_1)
- End cutting edge angle (C_e)
- Principal cutting edge angle or Approach angle ($\lambda = 90 - C_s$)
- Nose radius (R) (mm)
- For Orthogonal cutting, i = 0
- For Oblique cutting, $i \neq 0$

1.6.3 Inter conversion between ASA & ORS

$$\tan\alpha = \tan\alpha_s \sin\lambda + \tan\alpha_b \cos\lambda$$

$$\tan\alpha_b = \cos\lambda \tan\alpha + \sin\lambda \tan i$$

$$\tan\alpha_s = \sin\lambda \tan\alpha - \cos\lambda \tan i$$

$$\tan i = -\tan\alpha_s \cos\lambda + \tan\alpha_b \sin\lambda$$

1.7 Shear angle (ϕ)

1.7.1 Chip Thickness Ratio

$$r = \frac{t_0}{t_c} = \frac{l_c}{l} = \frac{V_c}{V} = \frac{\sin\phi}{\cos(\phi - \alpha)} = \frac{1}{h}$$

and $$\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha}$$

Where

r = chip thickness ratio or cutting ratio; $r < 1$

$h = 1/r$ = Inverse of chip ratio or chip reduction factor or chip compression ratio; $h > 1$

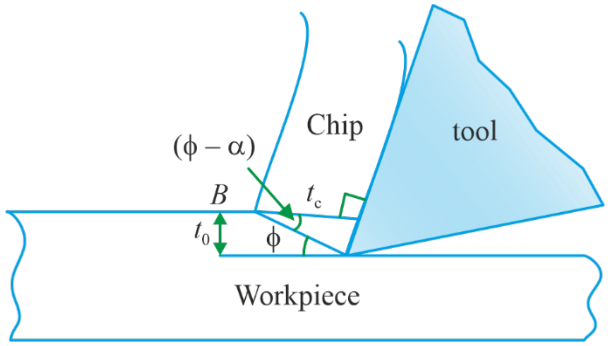


Fig. 1.8

As $\sin\phi = \frac{t_0}{AB}$ and $\cos(\phi - \alpha) = \frac{t_c}{AB}$

$$\text{Chip thickness ratio (r)} = \frac{t_0}{t_c} = \frac{\sin\phi}{\cos(\phi-\alpha)}$$

1.7.2 Cutting shear strain (ϵ) i.e cutting strain

The magnitude of strain, that develops along the shear plane due to machining action, is called cutting strain (shear). The relationship of this cutting strain, ϵ

$$\varepsilon = \cot\phi + \tan(\phi - \alpha)$$

1.8 Velocity diagram of cutting zone

Need velocities to obtain power estimates

$$V_{\frac{\text{Material}}{\text{Tool}}} + V_{\frac{\text{Chip}}{\text{Material}}} = V_{\frac{\text{Chip}}{\text{Tool}}}$$

$$V_{\frac{\text{Material}}{\text{Tool}}} = \text{Cutting velocity} = V$$

$$V_{\frac{\text{Chip}}{\text{Material}}} = \text{Shear velocity} = V_s$$

$$V_{\frac{\text{Chip}}{\text{Tool}}} = \text{Chip velocity} = V_c$$

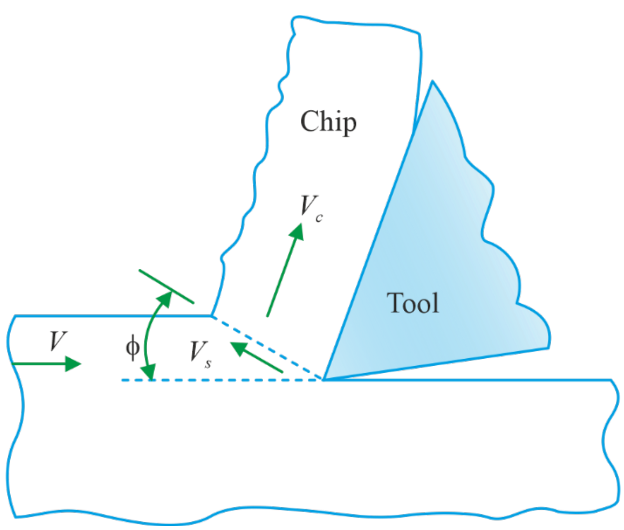


Fig. 1.9

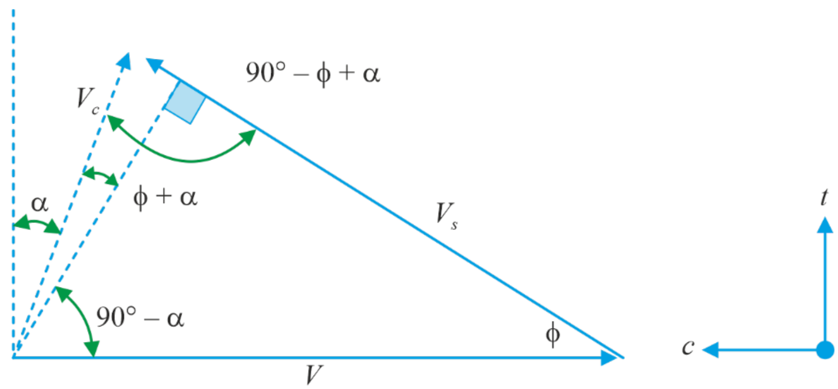


Fig. 1.10 Velocity Triangle

Apply sin rule

$$\frac{v}{\sin\left(\frac{\pi}{2}-\phi+\alpha\right)} = \frac{v_s}{\sin\left(\frac{\pi}{2}-\phi\right)} = \frac{v_c}{\sin(\phi)}$$

$$\frac{v}{\cos(\phi-\alpha)} = \frac{v_s}{\cos(\phi)} = \frac{v_c}{\sin(\phi)}$$

1.9 Shear Strain Rate

$$\dot{\varepsilon} = \frac{d\varepsilon}{dt} = \frac{V_s}{\text{thickness of shear zone}(t_s)}$$

t_s =1/10th or (10%) of shear plane length and its maximum value is 25 microns.

1.10 Determination of Un-deformed chip thickness in Turning:

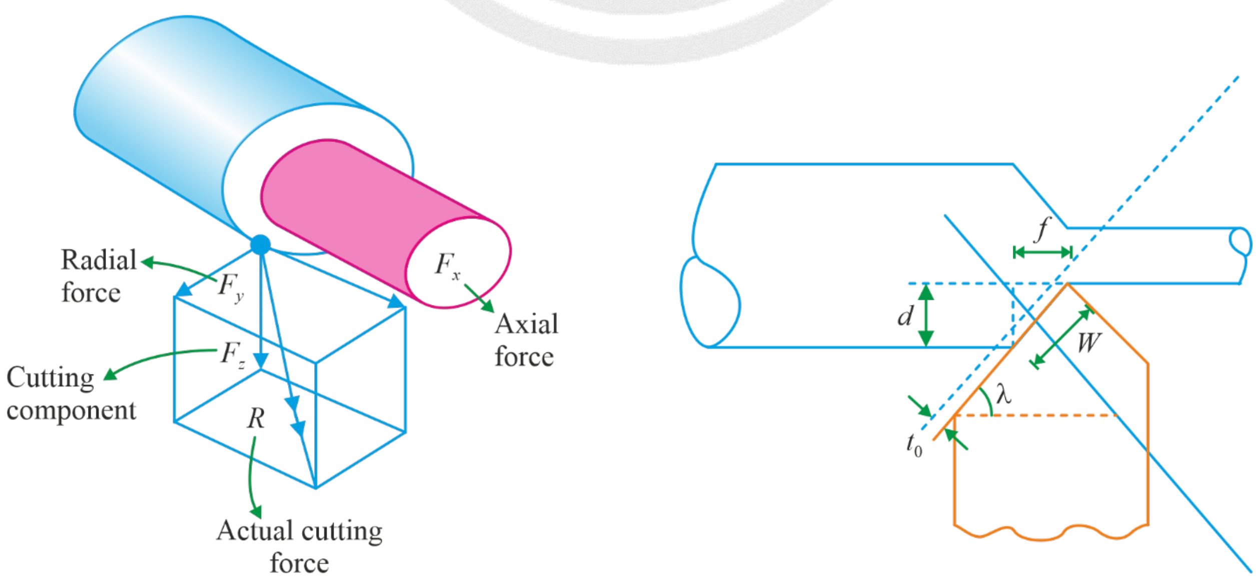


Fig. 1.11 Turning process

$$t_0 = f\sin\lambda,$$

$$w = \frac{d}{\sin\lambda}$$

where

f = feed (mm/rev)

d = depth of cut (mm)

t_0 = uncut chip thickness

W = width of chip

λ = Approach angle

(1) Turning is 3-D cutting $\Rightarrow$ three force comes in picture

(2) Turning is not Orthogonal cutting(2-D)

(3) **t_0 = fsin λ**

(4) **w = d/sin λ**

For orthogonal cutting t_0 = d

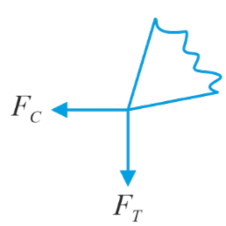
Width of chip = width of cut(w)

1.11 Types of Chip

- Continuous chip
- Discontinuous chip
- Continuous chip with BUE

1.12 Force & Power in Metal Cutting

F_c and F_t



The two orthogonal components (horizontal and vertical) Fc and Ft of the resultant force R can be measured by using a **dynamometer**.

Merchant Force Circle Diagram (MCD)

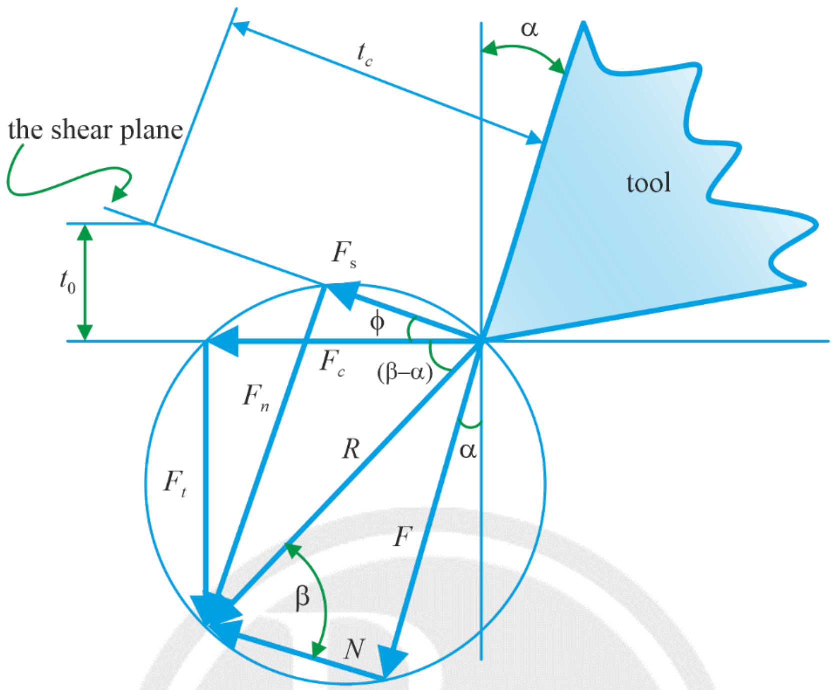


Fig. 1.12 Merchant Circle Diagram

where

- f_s = Shear force
- F_n = Normal to shear force
- F_c = Cutting component
- F_t = Thrust component
- F = Friction force
- N = Normal to friction
- β = Friction angle
- R = Actual cutting force

For orthogonal cutting only

The force relations

$$F = F_c \sin\alpha + F_t \cos\alpha$$

$$N = F_c \cos\alpha - F_t \sin\alpha$$

$$F_n = F_c \sin\phi + F_t \cos\phi$$

$$F_s = F_c \cos\phi - F_t \sin\phi$$

(a) From Merchant Analysis

$$\phi = \frac{\pi}{4} + \frac{\alpha}{2} - \frac{\beta}{2}$$

(b) Lee and Shaffer

$$\phi = \frac{\pi}{4} + \alpha - \beta$$

(c) Stabler

$$\phi = \frac{\pi}{4} + \frac{\alpha}{2} - \beta$$

1.13 Metal Removal Rate (MRR)

Metal removal rate (MRR) = $A_c.v = wt_0v$(orthogonal cutting) = fdv(turning)

Where

A_c = cross-section area of uncut chip (mm^2)

v = cutting speed = πDN, mm / min

f = feed (mm/rev)

d = depth of cut (mm)

w = width of cut

t_0 = uncut chip thickness

1.14 Heat Distribution in Metal Cutting

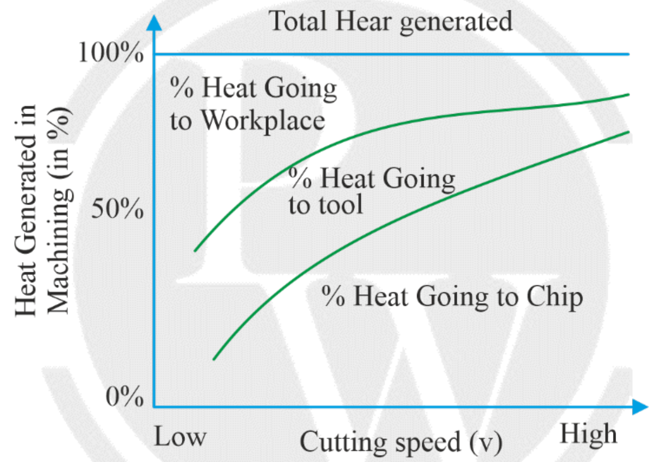


Fig. 1.13 Heat distribution

1.15 Specific cutting pressure

The cutting force, Fc, divided by the cross-section area of the undeformed chip gives the nominal cutting stress or the specific cutting pressure,

$$P_c = \frac{F_c}{bt} = \frac{F_c}{fd}$$

1.16 Tool Wear, Tool Life

1.16.1 Tool Wear

(i) Flank Wear, At low speed → **Slow Death**

(ii) Crater Wear, At high speed → **Slow Death**

(iii) Chipping off of the cutting-edge → **Sudden Death**

1.16.2 Flank Wear: (Wear land)

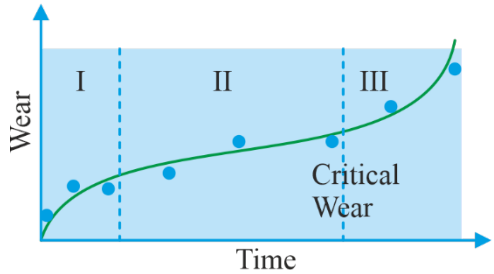


Fig. 1.14 Tool Wear

I = Primary wear zone
II = Secondary wear zone
III = Tertiary wear zone

Note:
(i) In Primary wear zone wear rate is constant.
(ii) Wear gradually increases in tertiary wear zone.

1.17 Tool Life

Taylor's Tool Life Equation

Causes

Sliding of the tool along the machined surface

Temperature rise $VT^n = C$

Where,

V = cutting speed (m/min)
T = Time (min)
n = exponent depends on tool material
C = constant based on tool and work material and cutting condition.

1.18 Extended or Modified Taylor's equation

$VT^n f^a d^b = C$

Where:

d = depth of cut
f = feed rate

$\frac{a}{n} = \frac{1}{n_1}$

$\frac{b}{n} = \frac{1}{n_2}$

or
$$T = \frac{C^{1/n}}{V^{1/n}.f^{1.n_1}.d^{1/n_2}}$$

$$\frac{1}{n} > \frac{1}{n_1} > \frac{1}{n_2}$$

i.e Cutting speed has the greater effect followed by feed and depth of cut respectively.

1.19 Economics of metal cutting

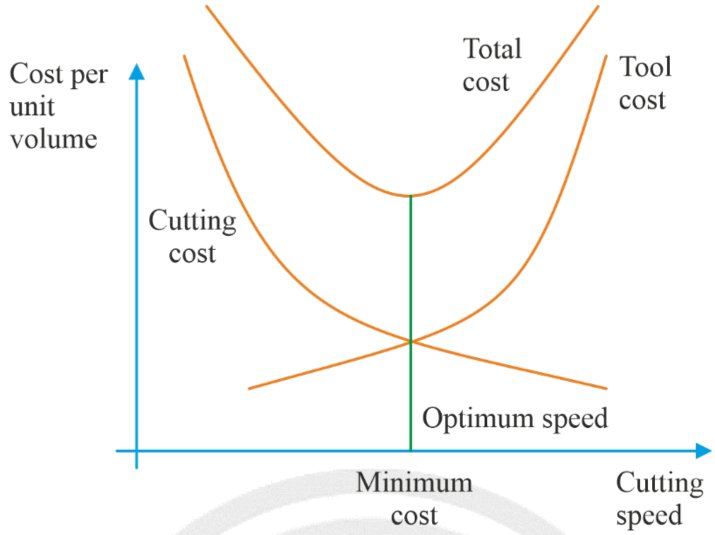


Fig. 1.15 Economics of Metal Cutting

Formula

$$V_0 T_0^n = C$$

(a) Optimum tool life for minimum cost

$$T_o = \left(T_c + \frac{C_t}{C_m}\right)\left(\frac{1-n}{n}\right) \quad \text{if } T_c, C_t \,\&\, C_m \text{ given}$$

$$= \frac{C_t}{C_m}\left(\frac{1-n}{n}\right) \quad \text{if } C_t \,\&\, C_m \text{ given}$$

(b) Optimum tool life for Maximum Productivity

(Minimum production time)

$$T_o = T_c\left(\frac{1-n}{n}\right)$$

Units: T_c – min (Tool changing time)

C_t – Rs./ servicing or replacement (Tooling cost)

C_m – Rs/min (Machining cost)

V – m/min (Cutting speed)

Tooling cost (C_t) = tool regrind cost + tool depreciation per service/ replacement

Machining cost (C_m) = labour cost + overhead cost per min

1.20 Surface Roughness

1.20.1 Ideal Surface (Zero nose radius)

Peak to valley roughness (h) = $\dfrac{f}{\tan C_s + \cot C_e}$

and (Ra) = $\dfrac{h}{4} = \dfrac{f}{4(\tan C_s + \cot C_e)}$

1.20.2 Practical Surface (with nose radius = R)

$$h = \frac{f^2}{8R}$$

and $R_a = \dfrac{f^2}{18\sqrt{3}R}$

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2 NTMM (NON-TRADITIONAL MACHINING METHOD)

2.1 Electro Chemical Machining (ECM)

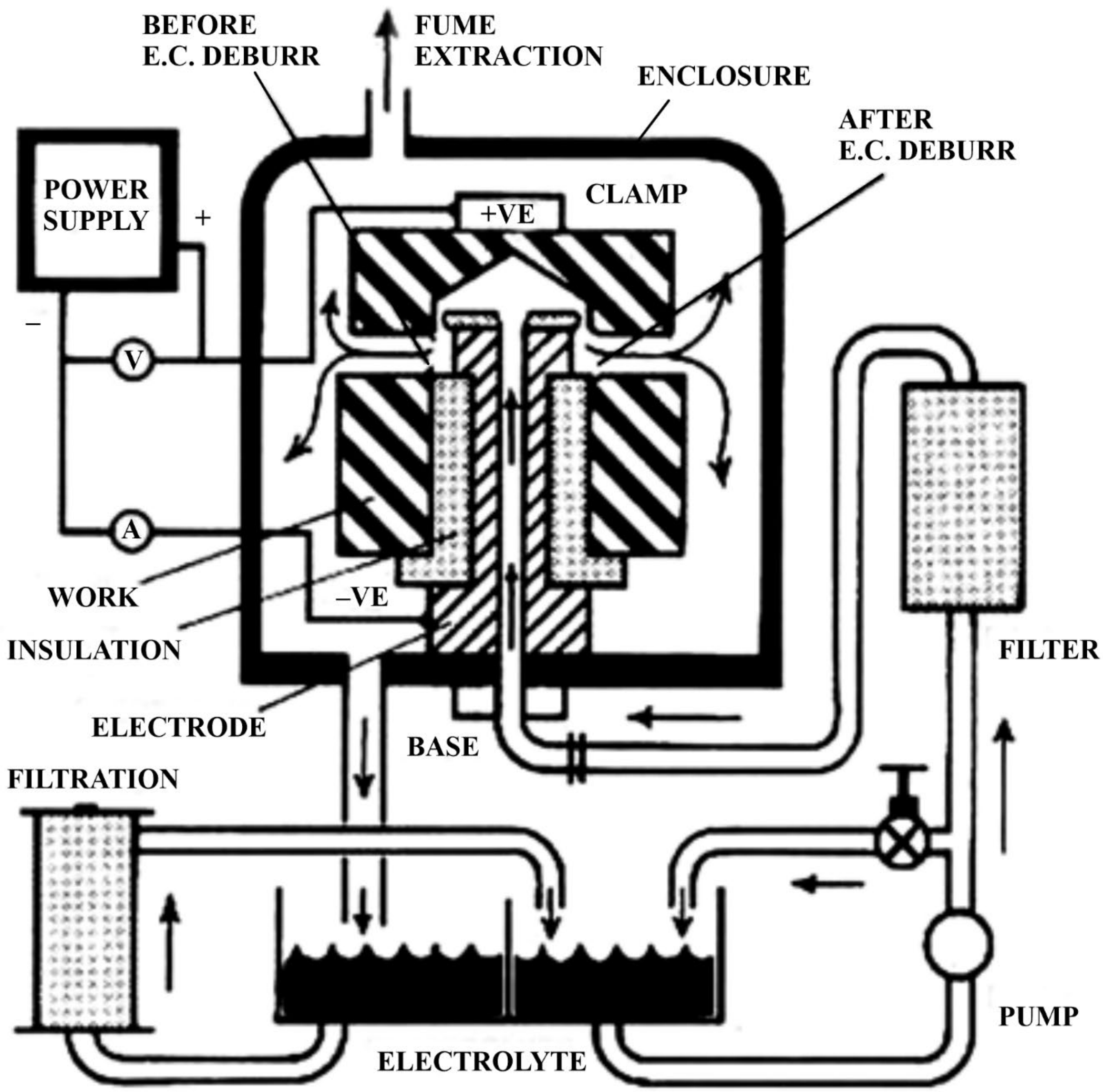

Fig. 2.1 Electro Chemical Machining

2.1.1 Electrochemical Machining

- Electrochemical machining is the *reverse of electro plating*
- The work-piece is made the anode, which is placed in close proximity to an electrode (cathode), and a high-amperage direct current is passed between them through an electrolyte, such as salt water, flowing in the anode-cathode gap.
- **MRR in ECM depends on atomic weight of work material**
- Commercial ECM is carried out at a combination of **low voltage high current**
- ECM has the highest metal removal rate, among the NTMM.

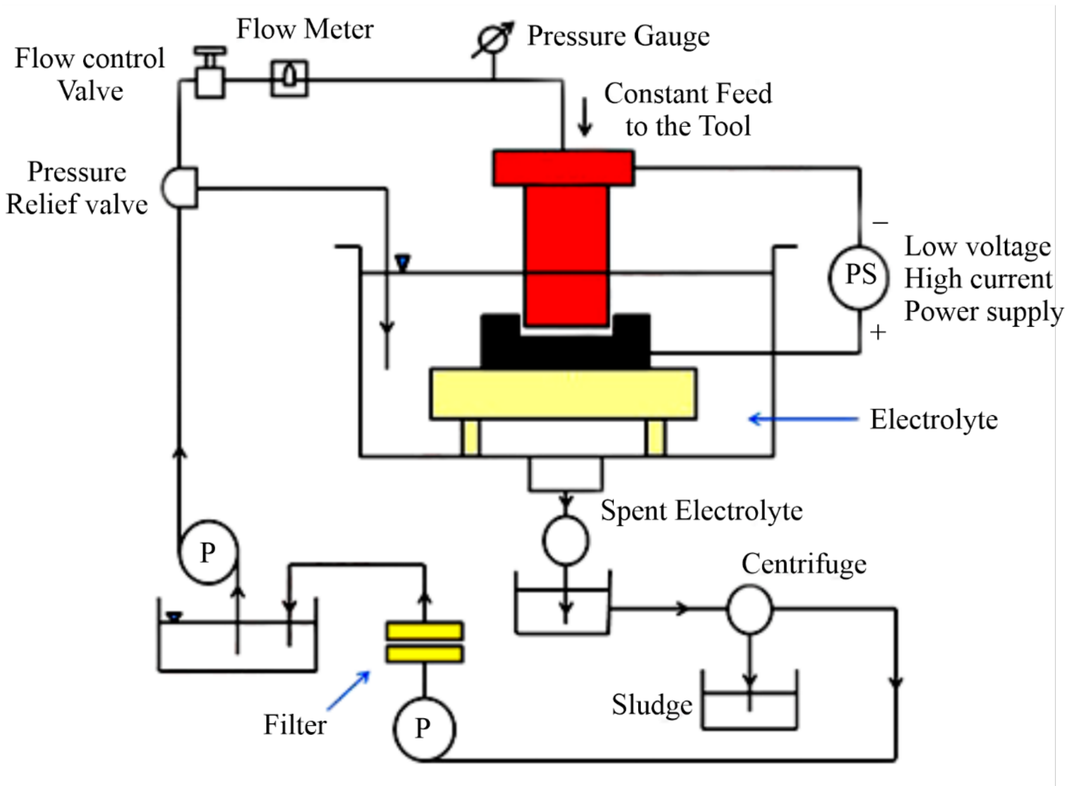

Fig. 2.2 ECM

ECM Formula

$$E = \frac{\text{Atomic Weight}}{\text{Valancty}}$$

Faraday's laws state that,

$$m = \frac{\text{It E}}{\text{F}}$$

Where m = weight (gm) of a material

l = current (A)

t = time (sec)

E = gram equivalent weight of the material

F = constant of proportionality – Faraday (96,500 coulombs)

ECM Calculations

- MRR for pure metal

$$\frac{AI}{\rho vF}\left(\frac{cm^3}{sec}\right)=\frac{EI}{\rho F}\left(\frac{cm^3}{sec}\right)$$

where,
A = Atomic weight
v = Valency

- MRR for Alloy

$$\frac{E_{eq}I}{\rho_{eq}F}\left(\frac{cm^3}{sec}\right)$$

$$\frac{100}{\rho_{eq}F}=\sum_i\left(\frac{x_i}{\rho_i}\right) \quad \text{and} \quad \frac{100}{E_{eq}}=\sum_i\left(\frac{x_i v_i}{A_i}\right)$$

- If the total over voltage at the anode and the cathode is ΔV and the applied voltage is V, the current l is given by,

$$I=\frac{V-\Delta V}{R}$$

$$JS=\frac{(V-\Delta V)}{Y}$$

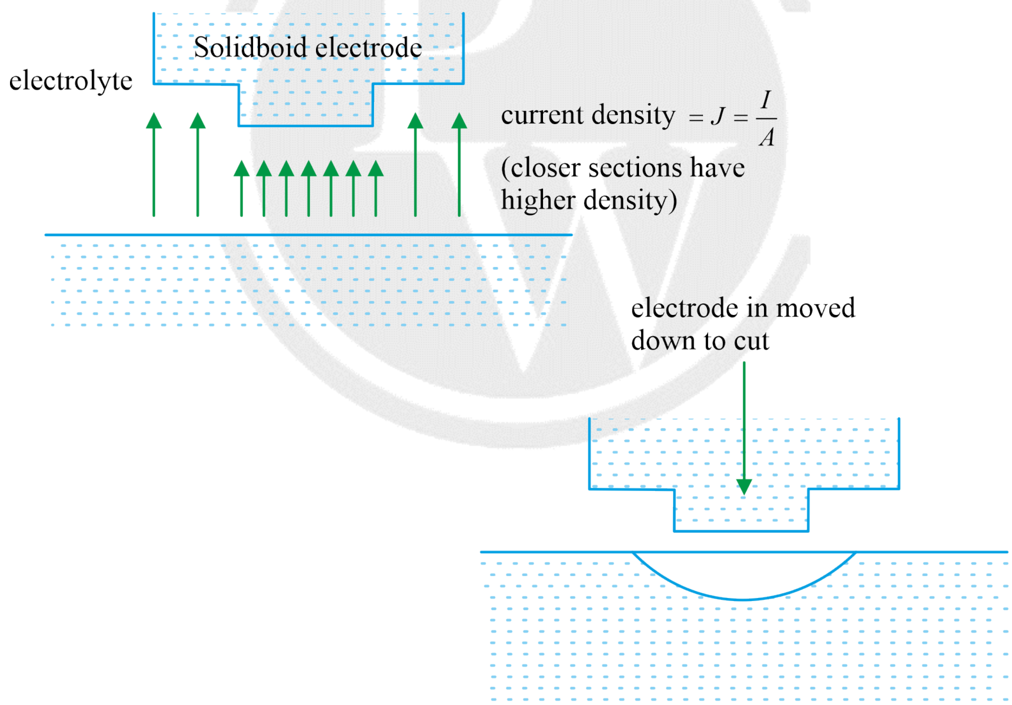

Fig. 2.3 ECM Principal

J = current density $= \frac{I}{A}$

S = specific resistance of electrolyte

I = applied of current

A = Cross sectional area of electrode

Flow analysis

- To calculate the fluid flow, required, match the heat generated to the heat absorbed by the electrolyte.
  The heat generated in the gap, H is given by
  $$H = I^2 \times R$$
  where, I = Current
  R = Resistance of electrolyte in the gap
  Heat absorbed by the electrolyte, H_e is
  $$H_e = q\, \rho_e\, c_e\, (T_f - T_i)$$
- Electing all the heat losses
  $$I^2R = q\, \rho_e\, c_e\, (T_f - T_i)$$
  where, q= Flow rate of electrolyte
  ρ_e = Density of electrolyte
  c_e= Specific heat of electrolyte
  T_i = Initial temperature
  T_f = Final temperature

2.2 Electrochemical Grinding (ECG)

- In ECG:
  The tool electrode is a rotating, metal bonded, diamond grit grinding wheel.
- As the electric current flows between the workpiece and the wheel, through the electrolyte.
  a.The surface metal is changed to a metal oxide,
  b.Which is ground away by the abrasives.
- ECG is a low-voltage high-current electrical process.
- The abrasive particles are act as an insulating spacer.

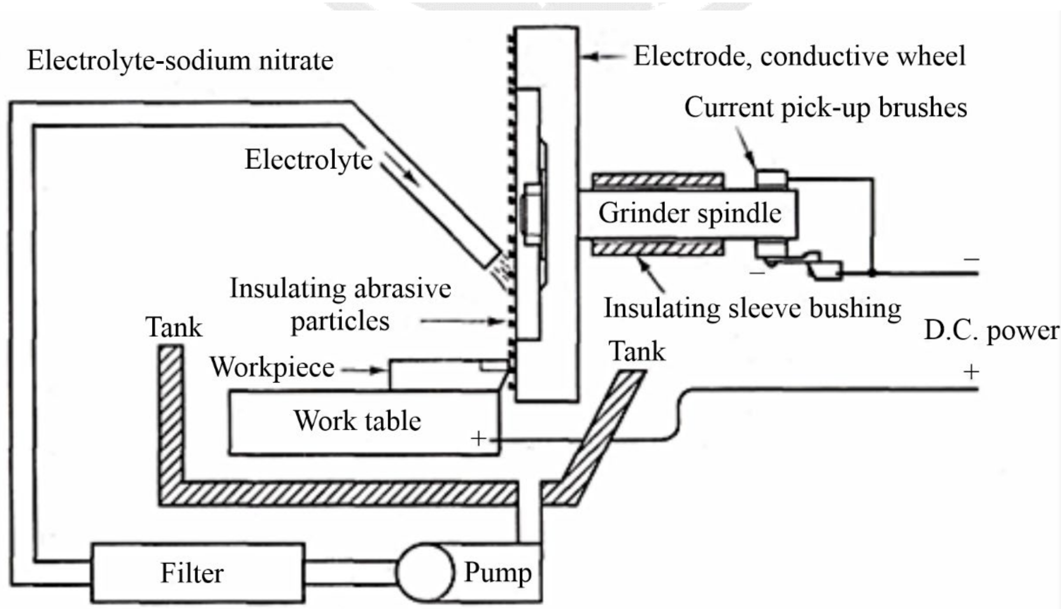

Fig. 2.4 Equipment setup and electrical circuit for electrochemical grinding.

2.3 Electro Discharge Machining (EDM)

Wear Ratio

Tool wear is given in terms of wear ratio which is defined as,

$$Wear\ ratio = \frac{\text{Volume of metal removed work}}{\text{Volume of metal removed tool}}$$

Relaxation circuit

Fig-Relaxation circuit used for generating the pulses in EDM process

$$V_c = V_0\left(1 - e^{\frac{1}{RC}}\right)$$

The time constant, τ of the circuit is given by

$$T = R_c \times C$$

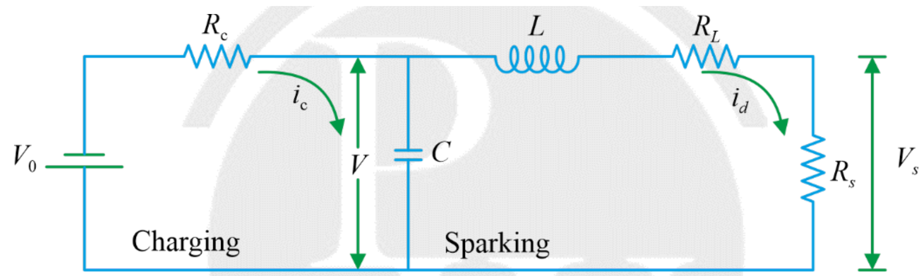

Fig. 2.5

Charging current can then be specified by

$$i_c = \frac{V_0}{R_c}e^{\frac{1}{\tau}}$$

For maximum power

$$V_c = 0.72 \times V_0$$

$$V_c = V_0\left\{1 - e^{-\left(\frac{t}{RC}\right)}\right\}$$

V_0 = Open circuit voltage

R = Charging resistance

C = Capacitance

V_c = Instantaneous capacitor voltage during charging

t = voltage at any time

Spark energy

$$E_s = \frac{1}{2}C(V_c)^2 \text{ J/cycle}$$

2.4 Ultrasonic Machining (USM)

Tool of desired shape vibrates at an ultrasonic frequency (19 ~ 25 kHz) with an amplitude of around 15 – 50 μm The tool is pressed downward with a feed force, F.

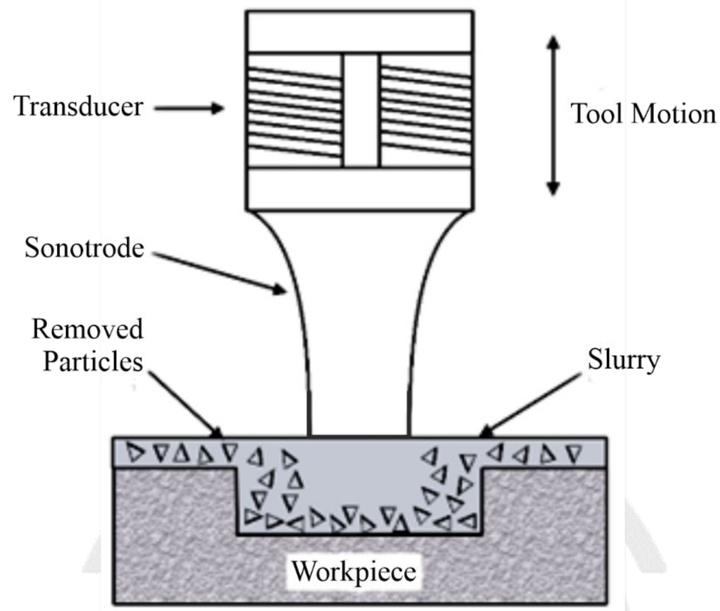

Fig. 2.6 Ultrasonic Machining

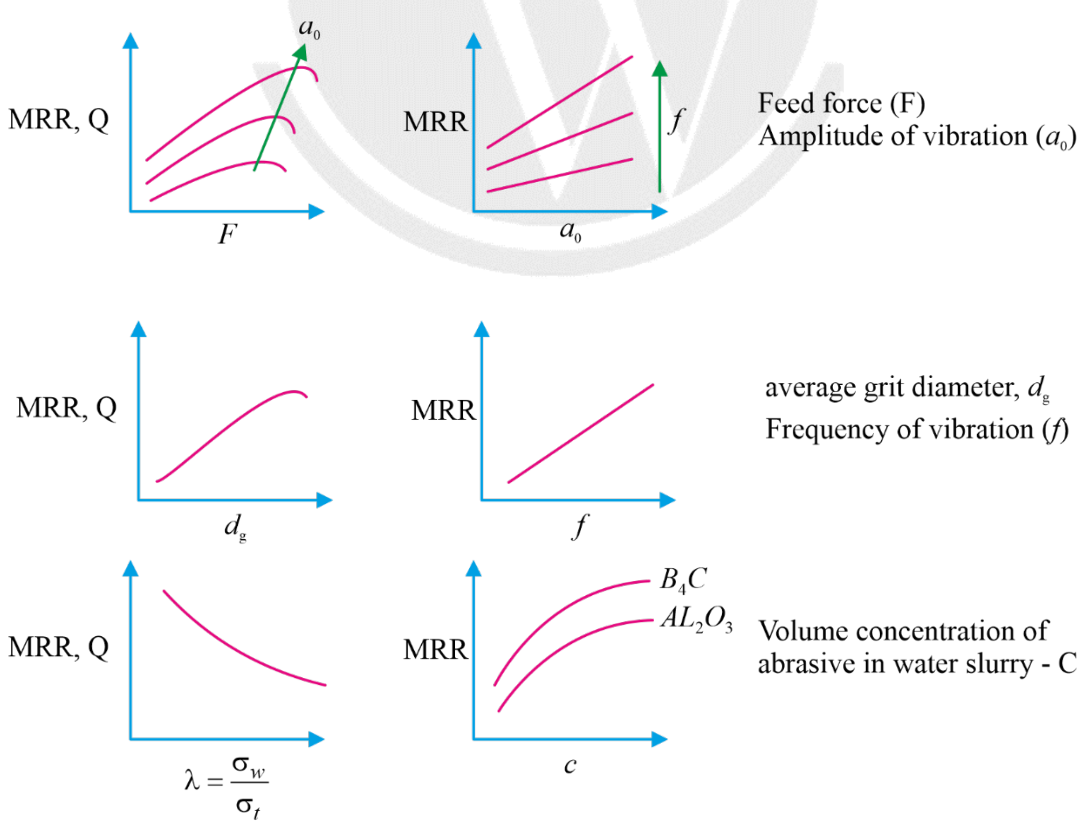

Fig. 2.7 Variation of MRR w.r.t. different Parameters

2.5 Water Jet Machining (WJM)

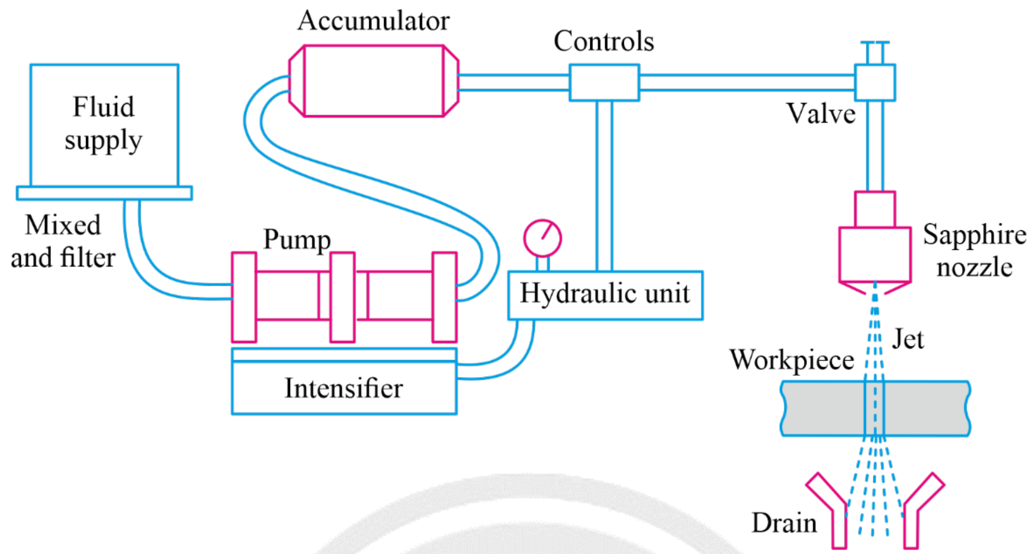

Fig. 2.8 Water Jet Machining

Narrow jet of water directed, at high pressure and velocity, against surface of workpiece

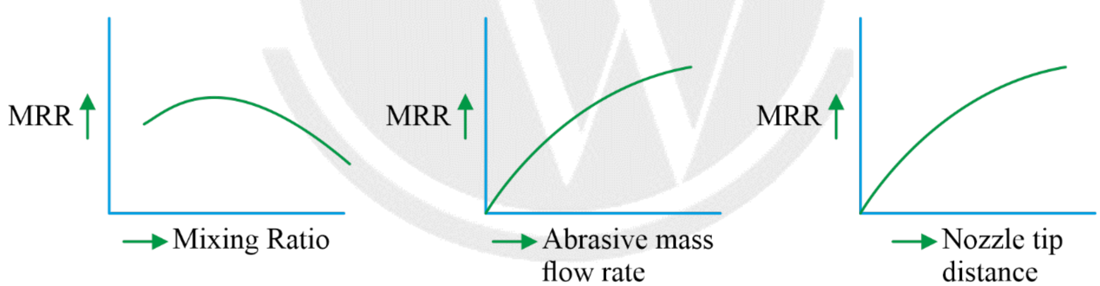

Fig. 2.9 Variation of MRR w.r.t. different Parameters

2.6 Abrasive Jet Machining (AJM)

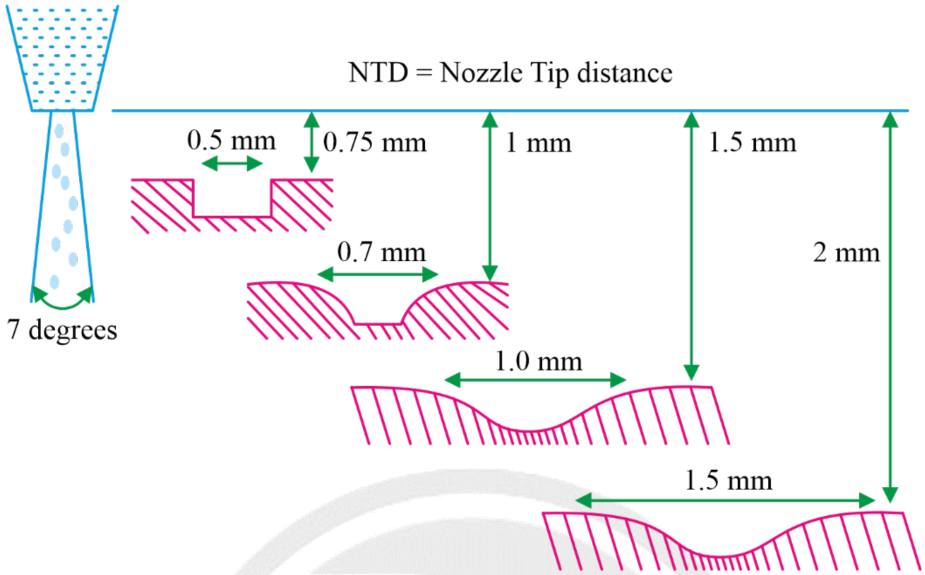

Fig. 2.10 Abrasive jet machining

$MRR \propto QD^3$

Q = flow rate abrasives

D = mean diameter of abrasives

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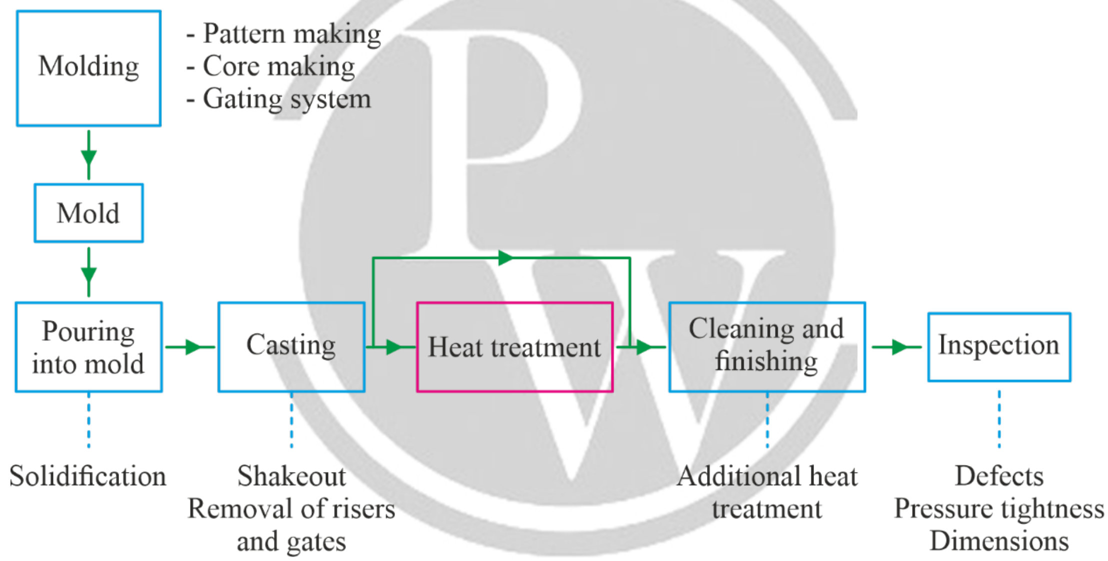
3 CASTING

3.1 Casting

Process in which molten metal flows by gravity or other force into a mold where it solidifies in the shape of the mold cavity

3.2 Steps in Sand Casting



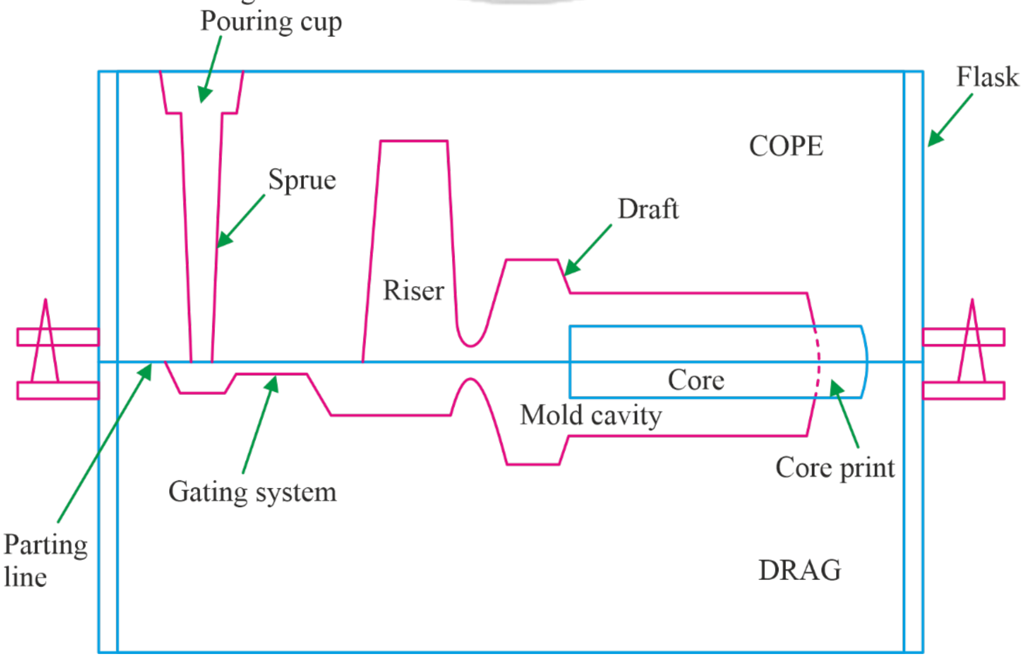


Fig. 3.1 Sand Casting

3.3 Casting Terms

Flask: Flasks have box-like structure made of rectangular walls (sometimes circular also) and without any bottom or top

Cover: These are mostly made of cast iron although wood is also used sometimes

Drag: Lower moulding flask.

Cope: Upper moulding flask.

Cheek: Intermediate moulding flask used in three-piece moulding.

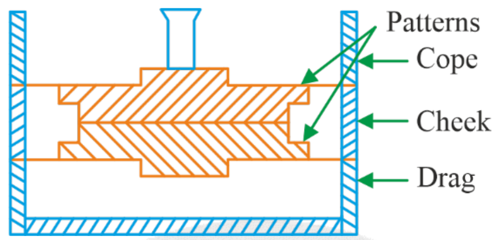


Fig. 3.2 Mould Box

Pattern: Pattern is a replica of the final object to be made with some modifications.

Parting line: This is the dividing line between the two moulding flasks that makes up the sand mould.

Bottom board: This is a board normally made of wood, which is used at the start of the mould making.

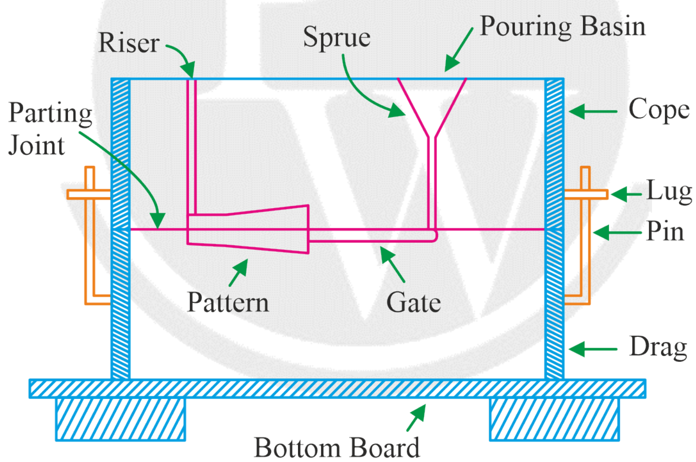


Fig. 3.3 Casting Terms

Moulding Sand: The freshly prepared refractory material used for making the mould cavity. Typical mix: 90% sand, 3% water, and 7% clay

Backing Sand: This is made up of used and burnt sand.

Core: Used for making hollow cavities in castings.

Pouring basin: A small funnel-shaped cavity at the top of the mould into which the molten metal is poured.

Sprue: The passage through which the molten metal from the pouring basin reaches the mould cavity.

Runner: The passage ways in the parting plane through which molten metal flow is regulated before they reach the mould cavity.

Gate: The actual entry point through which molten metal enters the mould cavity in a controlled rate

Chaplet: Chaplets are used to support cores inside the mould cavity.

Chill: Chills are metallic objects, which are placed in the mould to increase the cooling rate of castings.

Riser: It is a reservoir of molten metal provided in the casting so that hot metal can flow back into the mould cavity when there is a reduction in volume of metal due to solidification.

3.4 Pattern

A pattern is a replica of the object to be made by the casting process, with some modifications.

The main modifications are

3.4.1 Pattern Allowances

(1) Shrinkage or contraction allowance
(2) Draft or taper allowance
(3) Machining or finish allowance
(4) Distortion or camber allowance
(5) Rapping allowance/shaken allowance / Negative allowance

3.4.2 Shrinkage allowance

Invar and Bismuth → shrinkage is Negligible.

This is because of the inter-atomic vibrations which are amplified by an increase in temperature.

3.4.3 Liquid shrinkage and solid shrinkage

Liquid shrinkage refers to the reduction in volume when the metal changes from liquid to solid state at the solidus temperature. To account for this, risers are provided in the moulds.

Solid shrinkage is the reduction in volume caused, when a metal loses temperature in the solid state. The shrinkage allowance is provided to take care of this reduction.

3.4.4 Pattern Materials

Wood: patterns are relatively **easy to make**. Wood is not very dimensionally stable. Commonly used teak, white pine and mahogany wood.

Metal: patterns are more expensive but are more dimensionally stable and more durable. Commonly used CI, Brass, aluminium and white metal.

Investment casting uses wax patterns.

3.5 Types of Pattern

- **Single Piece Pattern:** These are inexpensive and the simplest type of patterns.
- **Gated Pattern: Gating and runner system are integral with the pattern**. This would eliminate the hand cutting of the runners and gates and help in improving the productivity of a moulding.
- **Split Pattern or Two-Piece Pattern**

  Pattern for intricate castings.

  When the contour of the casting makes its withdrawal from the mould difficult,
- **Cope and Drag Pattern**

  In addition to splitting the pattern, the cope and drag halves of the pattern along with the gating and riser systems are attached separately to the metal or wooden plates along with the alignment pins.
- **Match Plate Pattern**

  The cope and drag patterns along with the gating and the rise ring are mounted on a single matching metal or wooden plate on either side.
- **Loose Piece Pattern**

  This type of pattern is also used when the contour of the part is such that withdrawing the pattern from the mould is not possible.
- **Follow Board Pattern**

  This type of pattern is adopted for those castings where there are some portions, which are structurally weak and if not supported properly are likely to break under the force of ramming.
- **Sweep Pattern**

  These are used for generating large shapes, which are axi-symmetrical or prismatic in nature such as bell-shaped or cylindrical.
- **Skeleton Pattern**

  A skeleton of the pattern made of strips of wood is used for building the final pattern by packing sand around the skeleton

3.6 Cooling curve

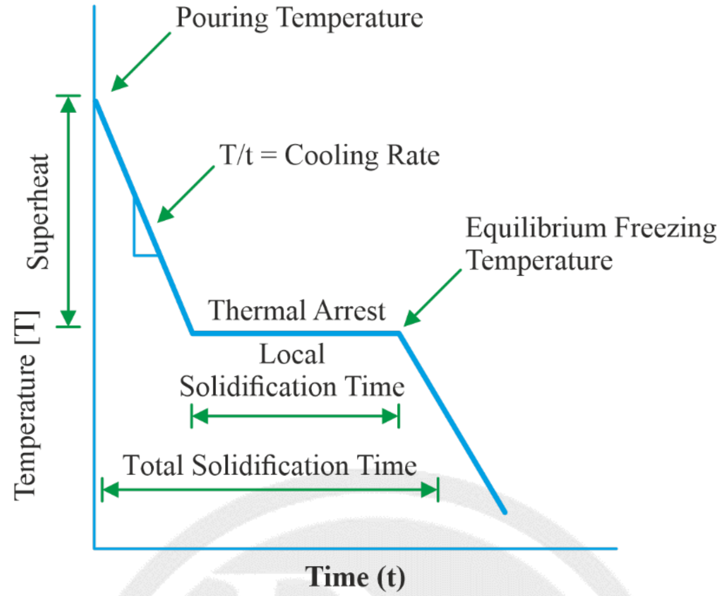


Fig. 3.4 Cooling Curve

3.7 Core

- Used for making cavities and hollow projections.
- Core sand should be of higher strength than the moulding sand.
- **Used clay free silica sand.**
- Binders used are **linseed oil**, core oil, resins, dextrin, molasses, etc.
- The general composition of a core sand mixture could be core oil (1%) and water (2.5 to 6%)

Net Buoyancy Force = Weight of Liquid Metal Displaced – Weight of Core

$$P = Vg\rho_m - Vg\rho_c$$

$$P = Vg(\rho_m - \rho_c)$$

V = Volume of core

ρ_m = Density of molten liquid metal

ρ_c = Density of core material

3.8 Permeability

Gases evolving from the molten metal and generated from the mould may have to go through the core to escape out of the mould. Hence cores are required to have higher permeability.

$$R = \frac{VH}{pAT}$$

R = Permeability Number

V = volume of air = 2000 cm^3

H = height of the sand specimen = 5.08 cm

p = air pressure, g/cm^2 = 10 g/cm^2 (standard)

A = cross sectional area of sand specimen = 20.268 cm^2

T = time in minutes for the complete air to pass through

$$R = \frac{501.28}{p.T}$$

3.9 Grain size number

ASTM (American Society for Testing and Materials) grain size number, defined as

$N = 2^{n-1}$

Low ASTM numbers mean a few massive grains; high numbers refer to many small grains.

3.10 Gate (Ingate) Design

3.10.1 Top Gate

The velocity is more than time taking to fill the mould is minimum that's why the temperature gradient is minimum.

$$t_{top} = \frac{AH}{A_g\sqrt{2gh_t}} \qquad [h_t = h_s + h_c]$$

h_c = Cup height

h_s = Sprue height

h_t = Manometric height

t_{top} = filling time in top gate

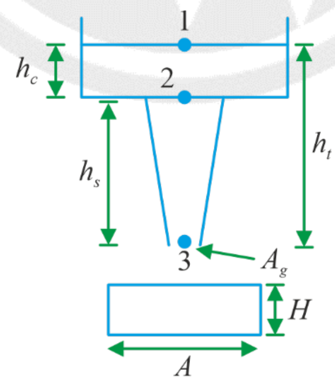


Fig. 3.5 Top Gate

3.10.2 Bottom Gate

$$t_{bottom} = \frac{2A}{A_g}\frac{1}{\sqrt{2g}}(\sqrt{h_t} - \sqrt{h_t - H})$$

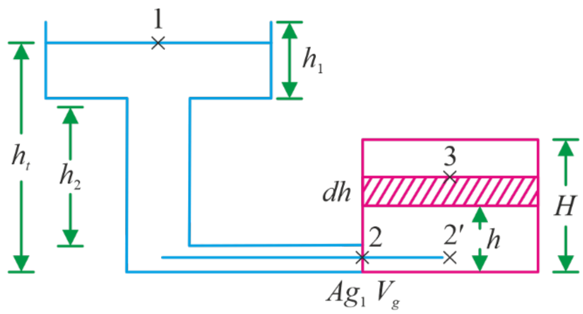


Fig. 3.6 Bottom Gate

Important result

If h_t = H in bottom Gate

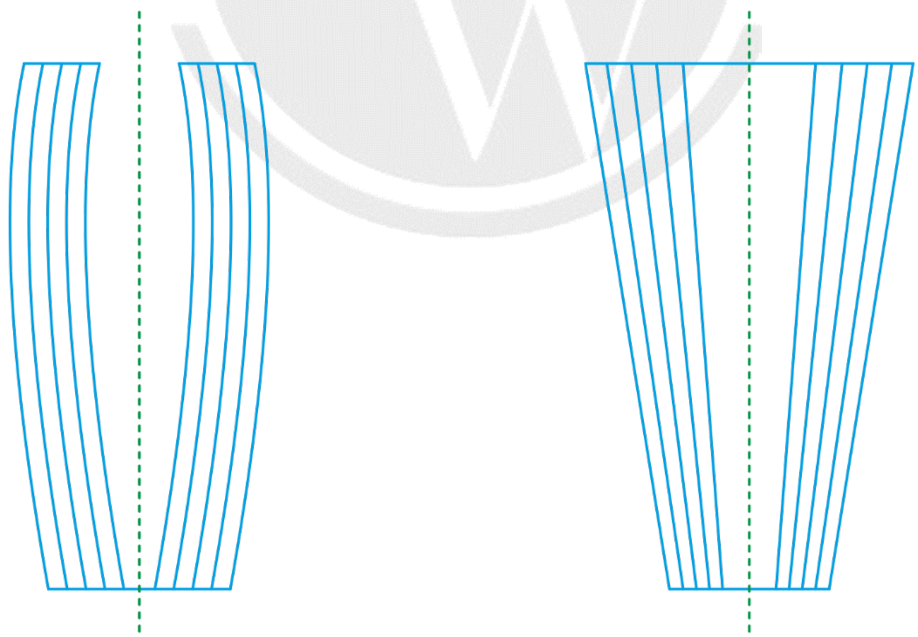
$t_{\text{bottom}} = 2t_{\text{top}}$

3.10.3 Gating ratio

- Gating ratio is defined as: Sprue area: Runner area: Ingate area.

3.10.4 Sprue Design

- **Sprue**: Sprue is the channel through which the molten metal is brought into the parting plane where it enters the runners and gates to ultimately reach the mould cavity.
- To eliminate this problem of air aspiration, the sprue is tapered to gradually reduce the cross section as it moves away from the top of the cope as shown in Figure below(b).



(a) Straight sprue **(b) Tapered**

Fig. 3.7 Design of Sprue

3.11 Risers and Riser Design

Risers are added reservoirs designed to feed liquid metal to the solidifying casting as a means of compensating for solidification shrinkage.

To perform this function, the risers must solidify after the casting.

According to Chvorinov's rule, a good shape for a riser would be one that has a long freezing time (i.e., a small surface area per unit volume).

Chvorinov's rule

- Total solidification time (t_s) = $B\left(\frac{V}{A}\right)^n$

Where n = 1.5 to 2.0

[Where, B = mould constant and is a function of mould material, casting material, and condition of casting]

n = 2 and $t_{riser} = 1.25\ t_{casting}$.

OR

$$\left(\frac{V}{A}\right)^2_{riser} = 1.25\left(\frac{V}{A}\right)^2_{casting}$$

3.11.1 Important Result

- Compare the solidification times for castings of three different shapes of same volume:

  (i) Cubic (T_{cu})

  (ii) Cylindrical (with height equal to its diameter) (T_{cy})

  (iii) Spherical (T_{sp})

  $\boldsymbol{T_{sp} : T_{cy} : T_{cu} = 1 : 0.763 : 0.649}$

3.11.2 Method of Riser Design

(a) Modulus Method

- It has been empirically established that if the modulus of the riser exceeds the modulus of the casting by a factor of 1.2, the feeding during solidification would be satisfactory.

  MR = 1.2 Mc
- Modulus = Volume/Surface area

(b) Modulus of casting shape

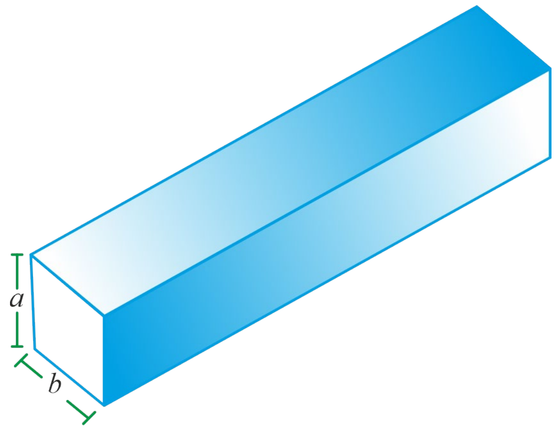
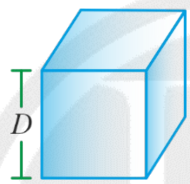
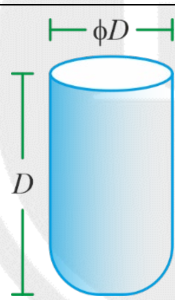
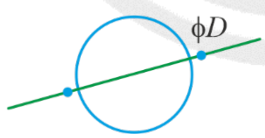
Shape	Figure	Modulus of Casting
Long bar		$\frac{ab}{2(a+b)}$
Cube		$\frac{D}{6}$
Cylinder		$\frac{D}{6}$
Sphere		$\frac{D}{6}$

Fig. 3.8 Modulus of different casting shapes

(c) Caine's Method

Freezing ratio = ratio of cooling characteristics of casting to the riser.

$$X = \frac{\left(A/V\right)_{Casting}}{\left(A/V\right)_{Riser}}$$

The riser should solidify last so $x > 1$

According to Caine $\quad x = \frac{a}{Y-b} + c$

$$Y = \frac{V_{riser}}{V_{casting}}$$ and a, b, c are constant.

(d) Naval research laboratory method (shape factor)

This method, which is essentially a simplification of Caine's method, defines a shape factor to replace the freezing ratio. The shape factor is defined as,

$$\mathbf{SF} = \frac{\textbf{Length + width}}{\textbf{thickness}}$$

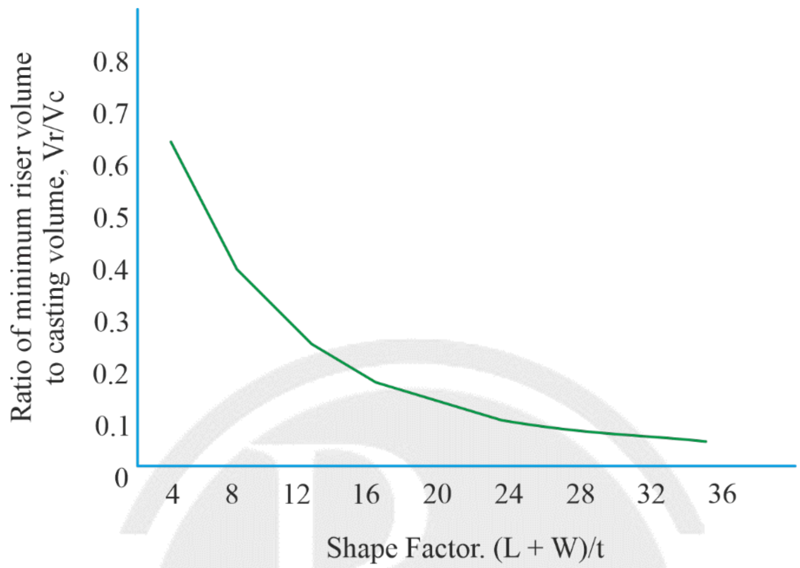


Fig. 3.9 Shape Factor

3.12 Chills

- External chills are masses of high-heat-capacity, high-thermal-conductivity **material that are placed in the mould (adjacent to the casting)** to accelerate the cooling of various regions.

  Chills can effectively promote directional solidification or increase the effective feeding distance of a riser.

- **Internal chills** are **pieces of metal** that are placed within the mould cavity to absorb heat and promote more rapid solidification. Since some of this metal will melt during the operation, it will absorb not only the heat-capacity energy, but also some heat of fusion. Since they ultimately become part of the final casting, internal chills must be made from the same alloy as that being cast.

3.13 Casting Defects

The following are the major defects, which are likely to occur in sand castings:

3.13.1 Gas Defects

- A condition existing in a casting caused by the trapping of gas in the molten metal or by mold gases evolved during the pouring of the casting.
- The defects in this category can be classified into **blowholes** and **pinhole porosity**.

3.13.2 Shrinkage Cavities

- These are caused by liquid shrinkage occurring during the solidification of the casting.
- To compensate for this, proper feeding of liquid metal is required. For this reason, risers are placed at the appropriate places in the mold.

3.13.3 Molding material defects

(i) Cut and washes

- These appear as rough spots and areas of excess metal, and are caused by erosion of molding sand by the flowing metal.
- This is caused by the: (a) Molding sand not having enough strength and (b) The molten metal flowing at high velocity.

(ii) Scab

- This defect occurs when a portion of the face of a mould lifts or breaks down and the recess thus made is filled by metal.
- When the metal is poured into the cavity, gas may be disengaged with such violence as to break up the sand, which is then washed away and the resulting cavity filled with metal.

(iii) Metal Penetration

- When molten metal enters into the gaps between sand grains, the result is a rough casting surface.

(iv) Fusion

- This is caused by the fusion of the sand grains with the molten metal, giving a brittle, glassy appearance on the casting surface.

(v) Swell

- Under the influence of met allostatic forces, the mold wall may move back causing a swell in the dimension of the casting.

(vi) Inclusions

- Particles of slag, refractory materials sand or deoxidation products are trapped in the casting during pouring solidification.

3.13.4 Pouring metal defects

(i) Mis-run

- A mis-run is caused when the metal is unable to fill the mold cavity completely and thus leaves unfilled cavities.

(ii) Cold shut

- A cold shut is caused when two streams while meeting in the mold cavity, do not fuse together properly thus forming a discontinuity in the casting.

3.13.5 Mold Shift

- The mold shift defect occurs when cope and drag or molding boxes have not been properly aligned.

3.14 Special Casting

3.14.1 Shell Casting

- The sand is mixed with a thermosetting resin is allowed to come in contact with a heated metal pattern (2000C).
- A skin (shell) of about 3.5 mm of sand and plastic mixture adhere to the pattern.
- Then the shell is removed from the pattern.
- The cope and drag shells are kept in a flask with necessary backup material and the molten metal is poured into the mold.

Advantages

- Dimensional accuracy.
- Smoother surface finish. (Due to finer size grain used)
- Very thin sections can be cast.
- Very small amount of sand is needed.
- Process is EASY

Limitations

- Expensive pattern
- Small size casting only.
- Highly complicated shapes cannot be obtained.
- More sophisticated equipment is needed for handling the shell moldings.

3.14.2 Investment Casting

Investment casting refers to the ceramics formed around the wax patterns to create a casing for molten metal to be poured. Once the wax patterns are created, they are melted onto a gate system, dipped into slurry and sand to form a layered casing, then replaced with the melted metals such as stainless steel, aluminum, and much more

Advantages

- Exceptional surface polish
- High dimensional precision
- Even the most complicated elements can be cast.
- Casting is possible with almost any metal.

Limitations

- Costly patterns and moulds
- Labour costs can be high
- Limited size

3.14.3 Hot Chamber Die Casting

- Die casting alloy is melted in a furnace located within the equipment
- Casting cycles are significantly shorter, thus has a higher production capacity
- Suitable for low melting point alloys
- Offers longer tool life
- Requires minimum safety measures
- Commonly used metal alloys include Zinc, lead and etc.

3.14.4 Cold Chamber Die Casting

- Dies casting alloy is melted in a separate furnace located outside the equipment.
- Has longer casting cycles; thus, the product capacity is less
- Suitable for high melting point alloys
- Has shorter tool life
- Requires more safety measures
- Commonly used metal alloys include Aluminum, Copper, Brass Magnesium, etc.

3.14.5 Centrifugal Casting

(i) True centrifugal casting

- **Process:** Molten metal is introduced into a rotating sand, metal, or graphite mould, and held against the mould wall by centrifugal force until it is solidified
- A mold is set up and rotated along a vertical (rpm is reasonable), or horizontal (200-1000 rpm is reasonable) axis.
- The mold is coated with a refractory coating.
- During cooling lower density impurities will tend to rise towards the center of rotation.
- ***Important result*:**
  - Mechanical properties of centrifugally cast jobs are better compared to other processes
  - **No cores** are required for making concentric hole

(ii) Semi-centrifugal Casting

- Centrifugal force assists the flow of metal from a central reservoir to the extremities of a rotating symmetrical mold, which may be either expendable or multiple-use Rotational speeds are lower than for true centrifugal casting. Cores can be used to increase the complexity of the product.

(iii) Centrifuging

- Uses centrifuging action to force the metal from a central pouring reservoir into separate mold cavities that are offset from the axis of rotation.

3.14.6 Slush Casting

- Slush casting is a variation of the permanent mold process in which the metal is permitted to remain in the mold only until a shell of the desired thickness has formed. The mold is then inverted and the remaining liquid is poured out.

3.14.7 Squeeze Casting

Molten metal is poured into an open face die. A punch is advanced into the die, and to the metal. Pressure (less than forging) is applied to the punch and die while the part solidifies. The punch is retracted, and the part is knocked out with an ejector pin.

3.14.8 Plaster Casting

A slurry of plaster, water, and various additives is additives is pouted over a pattern and allowed to set. The pattern is removed and the mould is baked to remove excess water. After pouring and solidification, the mould is broken and the casting is removed.

3.14.9 Loam Moulding

Moulding loam is generally artificially composed of common brick-clay, and sharp sand. Loam means mud. Loam Moulding is restricted to forms which cannot be cast conveniently in any other process.

3.15 Type of Furnace

3.15.1 Cupola

- Cupola has been the most widely used furnace for melting cast iron. In hot blast cupola, the flue gases are used to preheat the air blast to the cupola so that the temperature in the furnace is considerably higher than that in a conventional cupola. Coke is fuel and Lime stone ($CaCO_3$) is mostly used flux.

3.15.2 Electric Arc Furnace

- For heavy steel castings, the open-hearth type of furnaces with electric arc or oil fired would be generally suitable in view of the large heat required for melting. Electric arc furnaces are more suitable for ferrous materials and are larger in capacity.

3.15.3 Crucible Furnace

- Smaller foundries generally prefer the crucible furnace.
- The crucible is generally heated by **electric resistance or gas flame**.

3.15.4 Induction Furnace

- The induction furnaces are used for all types of materials, the chief advantage being that the heat source is isolated from the charge and the slag and flux get the necessary heat directly from the charge instead of the heat source.

3.16 Casting Cleaning (Fettling)

Impurities in the molten metal are prevented from reaching the mould cavity by providing a

(i) Strainer
(ii) Bottom well
(iii) Skim bob

❑❑❑

4 WELDING

4.1 Welding

Welding is a process by which two materials, usually metals, are permanently joined together by coalescence, which is induced by a combination of temperature, pressure, and metallurgical conditions.

4.1.1 Types of Joints

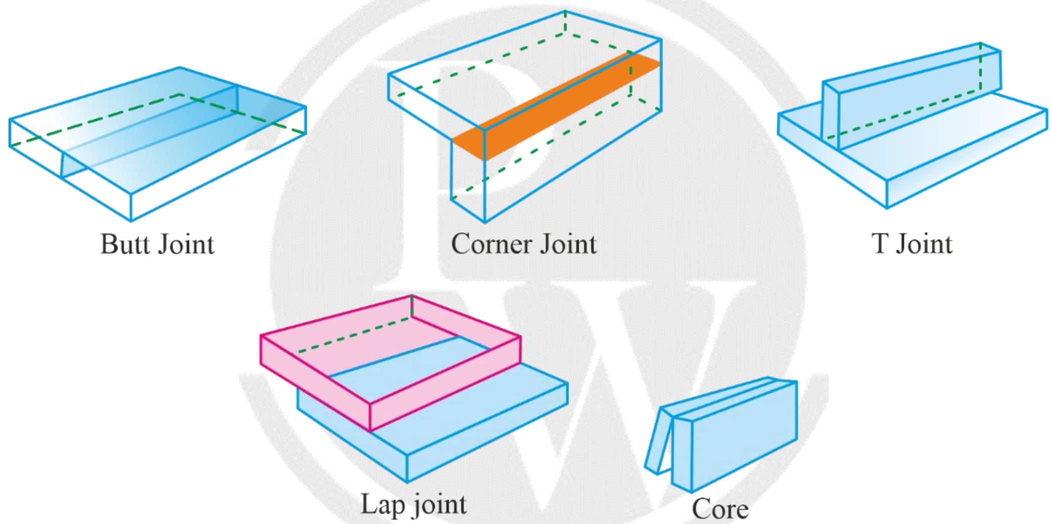


Fig. 4.1 Types of Joints

4.2 Electric Arc Welding

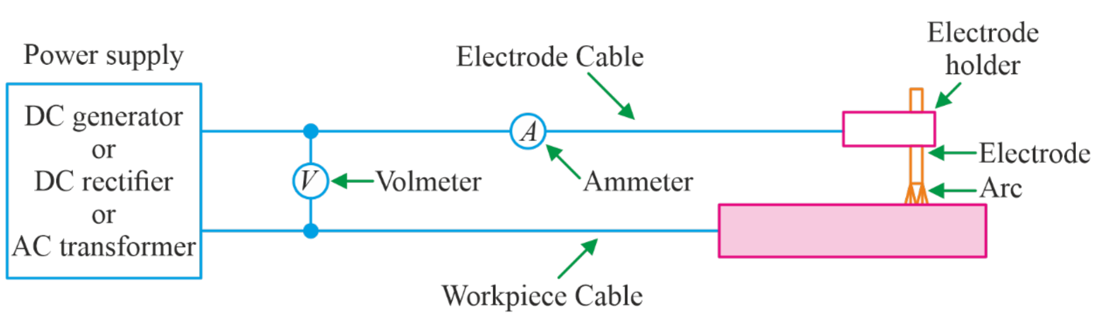


Fig. 4.2 Electric Arc Welding

An arc is generated between cathode and anode when they are touched to establish the flow of current and then separated by a small distance. 65% to 75% heat is generated at the anode.

If DC is used and the work is positive (the anode of the circuit), the condition is known as straight polarity (SPDC). Work is negative and electrode is positive is reverse polarity (RPDC).

Note:

RPDC arc-welding maintain a stable arc and preferred for difficult tasks such as overhead welding

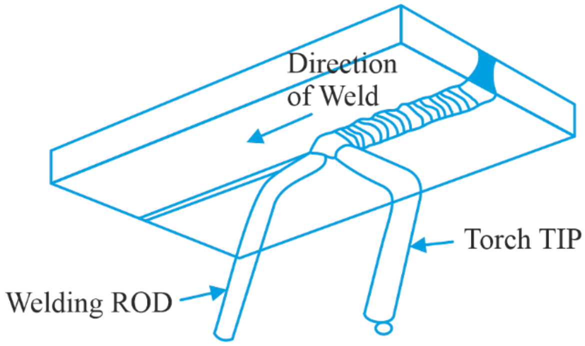


Fig. 4.3 Overhead Welding

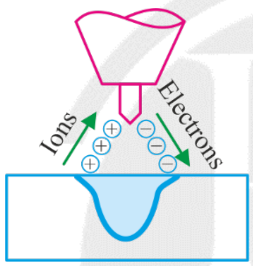
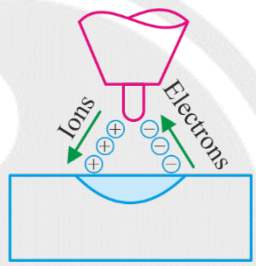
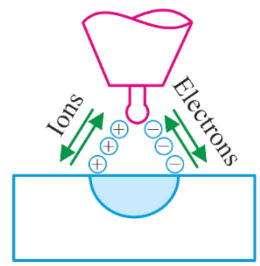
Electrode Polarity	Negative	Positive	AC
Electron and Ion Flow Penetration Characteristics			
Oxide Cleaning Action	No	Yes	Yes-Once Every Half Cycle
Heat Balance In The Arc (Approx.)	70% At Work End 30% At Electrode End	30% At Work End 70% At Electrode End	50% At Work End 50% At Electrode End
Penetration	Deep; Narrow	Shallow; Wide	Medium

Table 4.1

There are three modes of metal transfer (globular, spray and short-circuit).

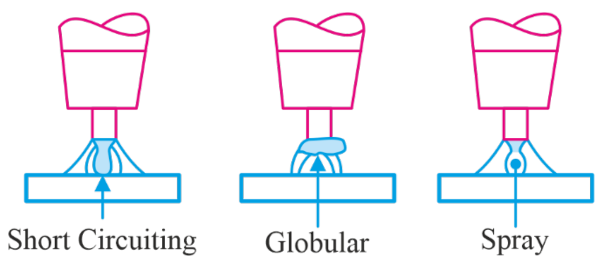


Fig. 4.4 Metal Transfer

Bead is the metal added during single pass of welding. Bead material is same as base metal.

In d.c. welding, the straight polarity (electrode negative) results in Lower deposition rate

4.3 Arc welding equipment's

4.3.1 Droppers: Constant current welding machines

Good for manual welding

$I_{arc} = I_{trnf}$

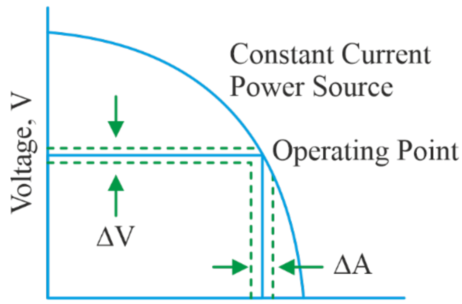


Fig. 4.5

4.3.2 Constant voltage machines

Good for automatic welding

$V_{arc} = V_{trnf}$

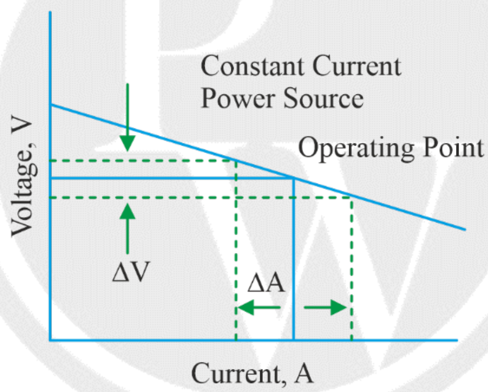


Fig. 4.6

4.4 Constant voltage machines Formula

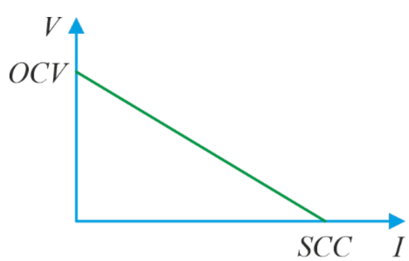


Fig. 4.7

OCV = open circuit voltage

SCC = short circuit current

$$\frac{V}{OCV} + \frac{I}{SCC} = 1$$

OCV: It is the maximum rated voltage between open terminals under no loading conditions.

SCC: It is the maximum rated current that is required during arc generation.

Note:
In arc welding, the arc length should be equal to Rod diameter

In manual arc welding, the equipment should have drooping characteristics in order to maintain Current constant when arc length changes

In arc welding, d.c. reverse polarity is used to bear greater advantage in Overhead welding.

For maximum power applied current(I) and voltage (V) are:

$$I = \frac{SCC}{2}$$

$$V = \frac{OCV}{2}$$

4.4.1 Heat Input (H_{in})

$$\text{Heat input} = \frac{VI}{A_b v} \text{ (Joule/mm}^3\text{)}$$

A_b = weld bead area (mm^2)

v = velocity mm/sec

$$\eta_t = \frac{H_m}{H_{in}}$$

Where

H_m = Heat required for melting

H_{in} = Heat input

η_t = Melting efficiency

4.4.2 Duty Cycle

Duty cycle is a welding equipment specification which defines the number of minutes, within a 10 minutes period, during which a given welder can safely produce a particular welding current.

$$\text{Required duty cycle } T_a = \left(\frac{I}{I_a}\right)^2 T$$

Where,

T = rated duty cycle

I = rated current at the rated duty cycle

I_a = Maximum current at the rated duty cycle

Note:
For manual welding a 60% duty cycle is suggested and for automatic welding 100% duty cycle.

4.5 Electrode coating characteristic

1. Provide a protective atmosphere.
2. Stabilize the arc.
3. Provide a protective slag coating to accumulate impurities, prevent oxidation, and slow the cooling of the weld metal.
4. Reduce spatter.
5. Add alloying elements.
6. Affect arc penetration

Note:

The electrodes used in arc welding are coated. This coating is not expected to Prevents electrode from contaminate

The coating material of an arc welding electrode contains which of the following?

1. Deoxidising agent
2. Arc stabilizing agent
3. Slag forming agent

Note:

- Arc Length must be short because
  1. Heat is concentrated.
  2. More stable
  3. More protective atmosphere.
- A long arc has following draw back
  1. Large heat loss into atmosphere.
  2. Unstable arc.
  3. Weld pool is not protected.
  4. Weld has low strength, less ductility, poor fusion and excessive spatter.

4.6 Arc blow in DC arc welding

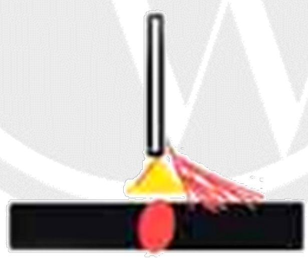


Fig. 4.8

Arc blow occurs during the welding of magnetic materials with DC. The effect is particularly noticeable when welding with bare electrodes or when using currents below or above. Again, the problem of arc blow gets magnified when welding highly magnetic materials

Disadvantage of arc blow:

1. Low heat penetration.
2. Excessive weld spatter.
3. Pinch effect in welding is the result of electromagnetic forces

Note:

Arc blow is more common in D.C. welding with bare electrodes

Pinch effect in welding is the result of Electromagnetic forces

4.7 Gas shields

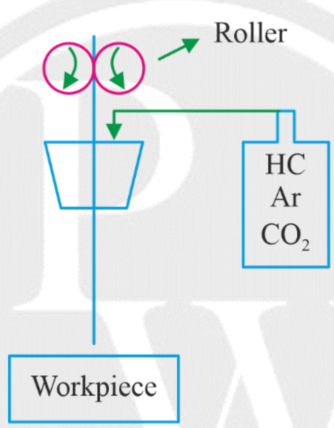
An inert gas is blown into the weld zone to drive away other atmospheric gases. Gases are argon, helium, nitrogen, carbon dioxide and a mixture of the above gases.

4.8 Tungsten Inert Gas welding (TIG)

Arc is established between a non-consumable tungsten electrode and the workpiece. Arc length is constant, arc is stable and easy to maintain. With or without filler.

Note:
- Gas tungsten arc welding process used non – consumable electrode
- In an inert gas welding process, the commonly used gas is Helium or Argon.

4.9 Gas Metal Arc Welding (GMAW)/MIG



(Set up)

Fig. 4.9 MIG Welding

- Arc is generated between consumable electrode and workpiece. Electrode is in form of small ida (1-2.5mm) will and it will continually supply to workpiece through roller movement. (spray transfer)
- Liquid metal can be protected by inert gas

Note:
- In MIG welding, the metal is transferred into the fine spray of metal.
- MIG welding process uses Consumable electrode D.C. power supply.

4.10 Submerged Arc welding (SAW)

Joining of High thickness object in a single pass, this technique used. Arc is generated between consumable electrode & W/P through welding torch, solid form of **granular flux (CaO, CaF_2)** will be continuously supply. Arc will be submerged under solid flux

- There is No Heat transfer loss, No splashing & weld spatter.
- Thickness-10-50mm, I = 200- 2000A, speed = 5m/min
- High weld deformation rate and High welding speed.
- Limited to Horizontal position.
- Use: Pressure vessel, ship bridges, LPG cylinder etc.

Note:
High welding speeds and High deposition rates are the major characteristics of submerged arc welding.

4.11 Gas Flame processes:

- Oxyacetylene welding, commonly referred to as gas welding, is a process which relies on combustion of oxygen and acetylene. When mixed together in correct proportions within a hand-held torch or blowpipe, a relatively hot flame is produced.
- **Acetylene** is the principal fuel gas employed.

Combustion of oxygen and acetylene (C_2H_2) in a welding torch produces a temp. in a two-stage reaction.

In the first stage

$$C_2H_2 + O_2 \rightarrow 2CO + H_2 + \text{Heat}$$

In the second stage combustion of the CO and H_2 occurs just beyond the first combustion zone.

$$2CO + O_2 \rightarrow 2CO_2 + \text{Heat}$$

$$H_2 + O_2 \rightarrow H_2O + \text{Heat}$$

Note:
Oxygen for secondary reactions is obtained from the atmosphere.

Three types of flames can be obtained by varying the oxygen/acetylene ratio.

4.11.1 Neutral Flame

The ratio (O_2: C_2H_2) is about 1:1, all reactions are carried to completion and a neutral flame is produced. It is chemically neutral and neither oxidizes or carburizes the metal being welded.

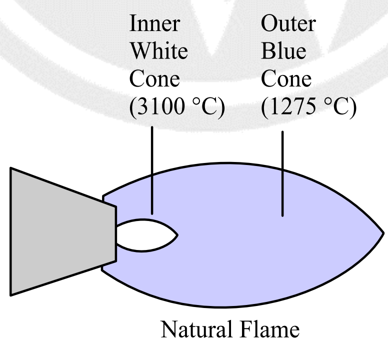


Fig. 4.10

4.11.2 Oxidizing flame

A higher ratio (O_2 > C_2H_2), such as 1.5:1, produces an oxidizing flame, hotter than the neutral flame (about 3300° C). Used when welding some nonferrous alloys such as copper-base alloys and zinc base alloys.

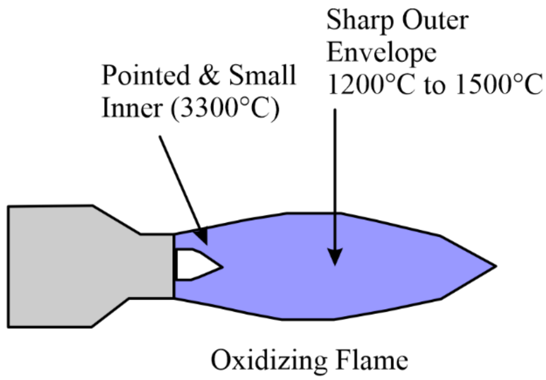


Fig. 4.11

4.11.3 Carburizing flame

Excess fuel, on the other hand, produces a carburizing flame. Carburizing flame can carburize metal also. The excess fuel decomposes to carbon and hydrogen, and the flame temperature is not as great (about 3000°C).

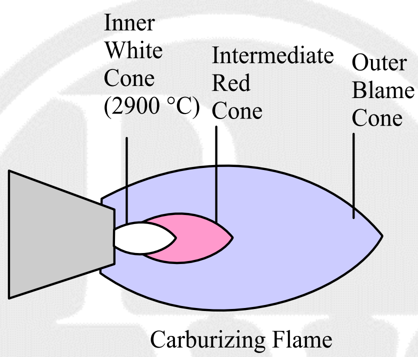


Fig. 4.12

Note:

- OFW is fusion welding.
- No pressure is involved.
- **Fluxes may** be used
- Flux can be added as a powder, the welding rod can be dipped in a flux paste, or the rods can be pre-coated.
- The ratio between Oxygen and Acetylene gases for neutral flame in gas welding is 1:1.
- In Oxyacetylene gas welding, temperature at the inner cone of the flame is around 3200°C.

4.12 Oxygen Torch Cutting (Gas Cutting)

Iron and steel oxidize (burn) when heated to a temperature between 800°C to 1000°C. High-pressure oxygen jet (300 KPa) is directed against a heated steel plate, the oxygen jet burns the metal and blows it away causing the cut (kerf).

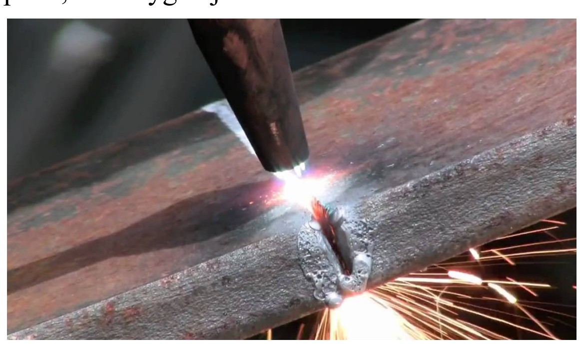


Fig. 4.13 Gas Welding

Note:

- Final microstructure depends on cooling rate.
- Steels with less than 0.3 % carbon cause no problem.
- Cutting CI is difficult, since its melting temp. is lower than iron oxide.

(a) Powder Cutting

- Difficult to cut metals by oxy-fuel cutting process are: Cast iron, stainless steel, and others high alloy steels. So, we can use powder cutting.
- By injecting a finely divided 200-mesh **iron powder** into the flame.

(b) Plasma Cutting

- Uses ionized gas jet (plasma) to cut materials resistant to oxy-fuel cutting, the ionized gas is forced through nozzle (up to 500 m/s), and the jet heats the metal, and blasts the molten metal away.
- HAZ is $\frac{1}{3}^{rd}$ to $\frac{1}{4}^{th}$ than oxyfuel cutting.
- Maximum plate thickness = 200 mm

4.13 Resistance Welding

4.13.1 Spot Welding

Resistance welding is the joining of metals by applying pressure and passing current for a length of time through the metal area which is to be joined. The key advantage of resistance welding is that no other materials are needed to create the bond, which makes this process extremely cost effective.

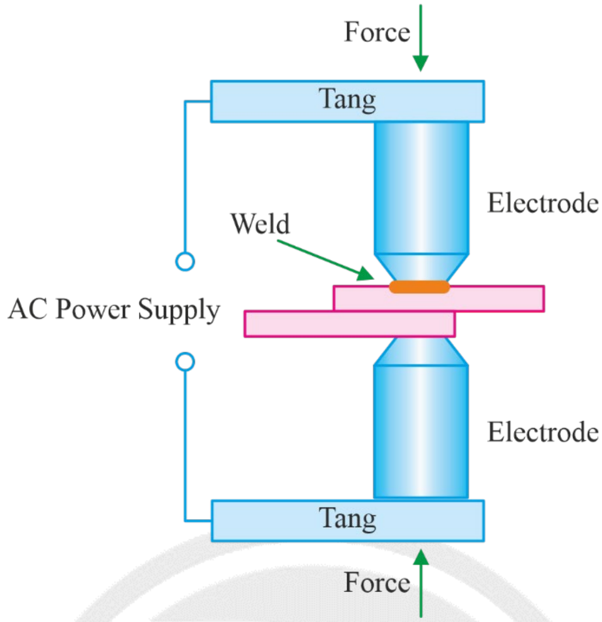


Fig. 4.14 Spot Resistance Welding

Note:

- Overall resistance is very low between the overlapping plate.
- Very high-current (up to 100,000 A) and Very low-voltage (0.5 to 10 V) is used.
- The maximum heat in resistance welding is at the Interface between the two plates being Joined.

4.13.2 Resistance seam welding

Resistance Seam Welding is a subset of Resistance Spot Welding using wheel-shaped electrodes to deliver force and welding current to the parts. The difference is that the workpiece rolls between the wheel-shaped electrodes while weld current is applied.

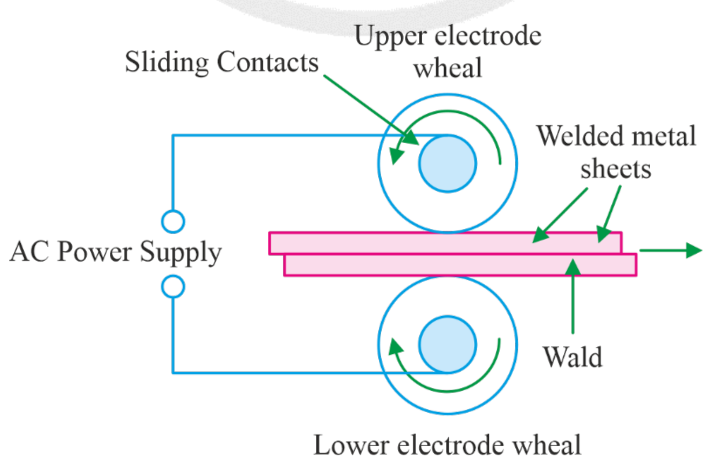


Fig. 4.15 Seam Resistance Welding

Note:
In resistance seam welding, the electrode is in the form of a circular disc.

4.13.3 Projection welding

Like spot welding, the projection welding process relies on heat generated by an electric current to join metal pieces together. Projection electrodes are capable of carrying more current than spot welding electrodes and can, therefore, weld much thicker materials.

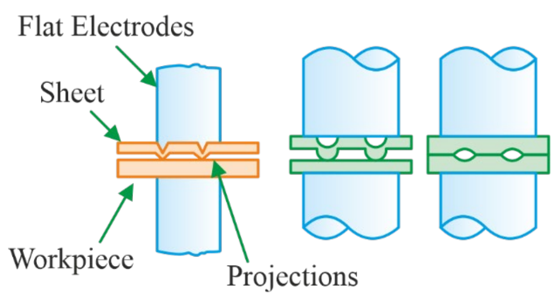


Fig. 4.16 Projection Resistance Welding

4.13.4 Upset welding

Upset welding or resistance butt welding is a welding technique that produces coalescence simultaneously over the entire area of abutting surfaces or progressively along a joint, by the heat obtained from resistance to electric current through the area where those surfaces are in contact.

4.13.5 Flash Welding

It is similar to upset welding except the arc rather than resistance heating.

4.13.6 Percussion Welding

- Similar to flash welding **except arc** power by a rapid discharge of stored electrical energy.
- The arc duration is only **1 to 10 ms,** heat is intense and highly concentrated.

4.14 Thermit Welding

Thermit welding (TW) is a process that uses heat from an **exothermic reaction** to produce **coalescence** between metals. The name is derived from 'thermite' the generic name given to reactions between metal oxides and reducing agents. The thermite mixture consists of **metal oxides** with low heats of formation and metallic reducing agents which, when oxidized, have high heats of formation. The excess heats of formation of

$$8Al + 3Fe_3O_4 \rightarrow 9Fe + 4Al_2O_3 + heat$$

4.15 Electro Slag Welding

- Electroslag Welding is a welding process, in which the heat is generated by an electric current passing between the consumable electrode (filler metal) and the work piece through a molten slag covering the weld surface.
- Heat, generated by the arc, melts the fluxing powder and forms molten slag. The slag, having low electric conductivity, is maintained in liquid state due to heat produced by the electric current.

Electroslag Welding

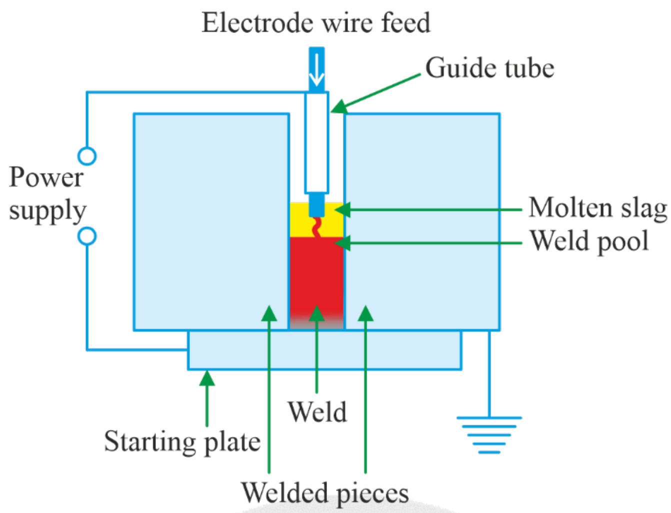


Fig. 4.17 Electroslag Welding

4.16 Electron Beam Welding (EBW)

- A beam of electrons is magnetically focused on the work piece in a vacuum chamber.

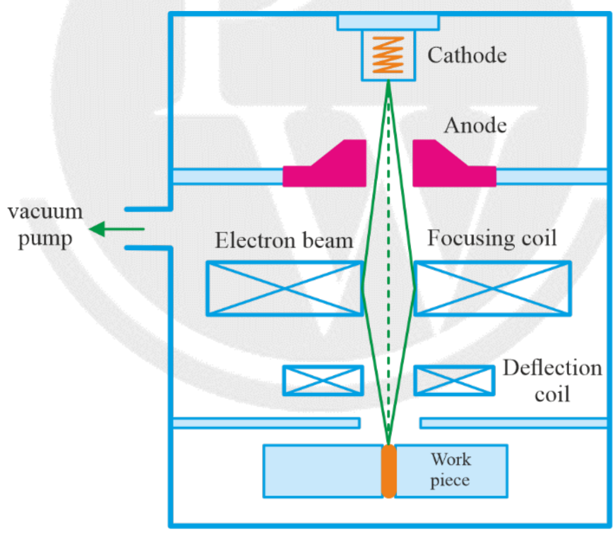


Fig. 4.18 Electron Beam Welding

4.17 Laser Beam Welding (LBW)

- Laser welding utilizes the heat from a high-power concentrated laser beam to melt thin or thick metal interfaces. It is generally used for producing narrow and deep joints of depth to width ratio ranging between 4 and 10

Note:
Increasing order of Heat affected zone (HAZ) are
Laser beam welding < MIG welding < Submerged arc welding < Arc welding

Shielding method	**Welding Process**
A. Flux coating	1. Shielded metal arc welding
B. Flux granules	2. Submerged arc welding
C. CO_2	3. Gas metal arc welding
D. Vacuum	4. Electron beam welding

4.18 Friction Welding

Friction welding (FRW) is a solid-state welding process that generates heat through mechanical friction between workpieces in relative motion to one another, with the addition of a lateral force called "upset" to plastically displace and fuse the materials.

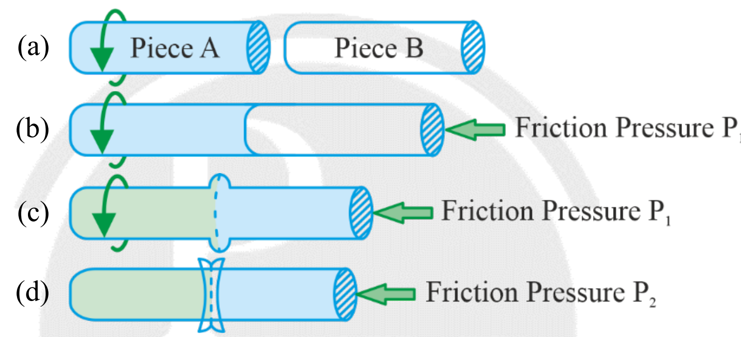


Fig. 4.19 Friction Welding

4.19 Ultrasonic Welding (USW)

- USW is a solid-state welding.
- High-frequency (10 to 200, KHz) is applied.
- Surfaces are held together under light normal pressure.
- Temp. do not exceed one-half of the melting point.
- The ultrasonic transducer is same as ultrasonic machining.

4.20 Explosion Welding

Explosion Welding

- Done at room temperature in air, water or vacuum.
- Surface contaminants tend to be blown off the surface.
- Typical impact pressures are **millions of psi**.
- Well suited to metals that is prone to brittle joints when heat welded, such as,
- Aluminium on steel
- Titanium on steel

Important factors are,

- Critical velocity
- Critical angle
- The cladding plate can be supported with tack welded supports at the edges, or the metal inserts.

4.21 Brazing and Soldering

Fig. 4.20 Brazing and Soldering

4.21.1 Brazing

- Brazing is the joining of metals through the use of heat and a filler metal whose melting temperature is above 450°C; but below the melting point of the metals being joined.
- Fluxes used are combinations of borax, boric acid, chlorides, fluorides, tetra-borates and other wetting agents.

Note:
The strength of a brazed joint Increases up to certain gap between the two joining surfaces beyond which it decreases.

4.21.2 Soldering

- By definition, soldering is a brazing type of operation where the filler metal has a melting temperature **below 450°C**.
- Soldering is used for a **neat leak-proof joint** or a low resistance electrical joint.

❑❑❑

5 METAL FORMING

5.1 Recrystallisation Temperature (Rx)

"The minimum temperature at which the completed recrystallisation of a cold worked metal occurs within a specified period of approximately one hour".

Note:

Rx varies between 1/3 to 1/2 melting point.

Rx = 0.4 x Melting temp.

Rx of Iron is 450°C and for steels around 1000°C

5.1.1 Grain growth

Grain growth follows complete crystallization if the materials left at elevated temperatures.

Heating beyond recrystallization temperature range causes the size of the recrystallized grains to increase, some of the grains grow by consuming others.

Note:

Grain growth is very strongly dependent on temperature.

5.2 Cold working

- Cold working of a metal is carried out below its recrystallisation temperature.
- Although normal room temperatures are ordinarily used for cold working of various types of steel, temperatures up to the recrystallisation range are sometimes used.
- In cold working, recovery processes are not effective.

Advantages of Cold Working

- In cold working processes, smooth surface finish can be easily produced.
- Accurate dimensions of parts can be maintained.
- Strength and hardness of the metal are increased but ductility decreased.
- Since the working is done in cold state, no oxide would form on the surface and Consequently good surface finish is obtained.
- Cold working increases the strength and hardness of the material due to the strain hardening which would be beneficial in some situations.
- There is no possibility of decarburization of the surface.
- Better dimensional accuracy is achieved.

Disadvantages of Cold Working

- Some materials, which are brittle, cannot be cold worked easily.
- Since the material has higher yield strength at lower temperatures, the amount of deformation that can be given to is limited by the capability of the presses or hammers used.
- A distortion of the grain structure is created.
- Since the material gets strain hardened, the maximum amount of deformation that can be given is limited. Any further deformation can be given after annealing.

5.3 Hot working

Plastic deformation of metal carried out at temperature above recrystallization temperature, is called hot working

- Recrystallization temperature = about one half of - melting point on absolute scale
- In practice, hot working usually performed somewhat above 0.5Tm
- Metal continues to soften as temperature increases above 0.5Tm, enhancing advantage of hot working above this level

Advantage of hot working

- Work part shape can be significantly altered
- Lower forces and power required
- Metals that usually fracture in cold working can be hot formed
- Strength properties of product are generally isotropic
- No strengthening of part occurs from work hardening
- Advantageous in cases when part is to be subsequently processed by cold forming.

Dis-advantages of Hot Working

- Heat energy is needed
- It requires expensive tools.
- Poor surface finish of material due to scaling of surface due to the rapid oxidation
- Due to the poor surface finish, close tolerance cannot be maintained.

5.4 Rolling

- Rolling is the process of reducing the thickness or changing the cross section of a long workpiece by compressive forces applied through a set of rolls, as shown in figure.
- Most rolling is carried out by hot working

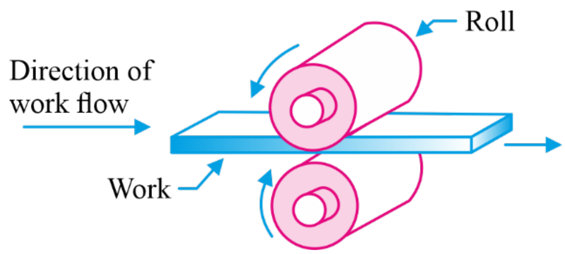


Fig. 5.1 Rolling Process

(a) Continuity Equation

$h_o b_o v_o = h_f b_f v_f$

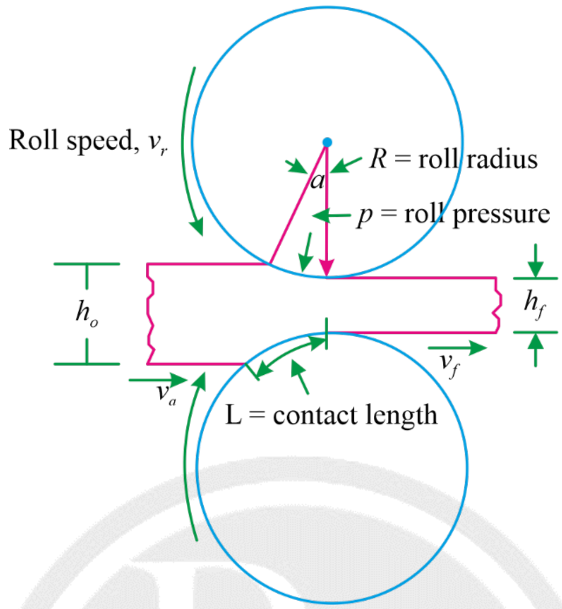


Fig. 5.2 Rolling process

(b) Hot Rolling

- Done above the recrystallization temp.
- Results fine grained structure.
- Surface quality and final dimensions are less accurate.

(c) Cold Rolling

Done below the recrystallization temp.

Products are sheet, strip, foil etc. with good surface finish and increased mechanical strength with close product dimensions

(d) Defects in Rolling

Defects	What is	Cause
Wavy edges	Strip is thinner along its edges than at its Centre.	Due to roll bending edges elongates more and buckle.
Alligatoring	Edge breaks	Non-uniform deformation

(e) Draft/reduction(Δh)

Rolling

R = roll radius

L = contact arc length

L_p = projected arc length

H_f = strip final thickness

V_r = velocity of the roll

V_f = velocity of the strip at roll exit

h_o = strip initial thickness

N = neutral point

a = angle of bite

V_o = velocity of strip at entrance to roll

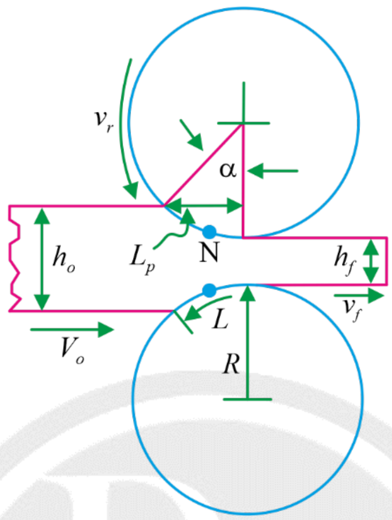


Fig. 5.3 Side view of flat rolling, indicating before and after thickness, work velocities, angle of contact with rolls, and other features.

Maximum Draft Possible (Δh) max

$$(\Delta h)_{max} = \mu^2 R$$

$$\alpha_{max} = \tan^{-1}(\mu)$$

Note:

If α_{max} is larger than this value, the rolls begin to slip,

Number of pass needed

$$n = \frac{\Delta h_{required}}{\Delta h_{max}}$$

(f) Elongation Factor or Elongation Co-efficient (E/E^n)

$$E = \frac{L_1}{L_0} = \frac{A_0}{A_1} \text{ for single pass}$$

$$E^n = \frac{L_n}{L_0} = \frac{A_0}{A_n} \text{ for n – pass}$$

(g) Torque and Power

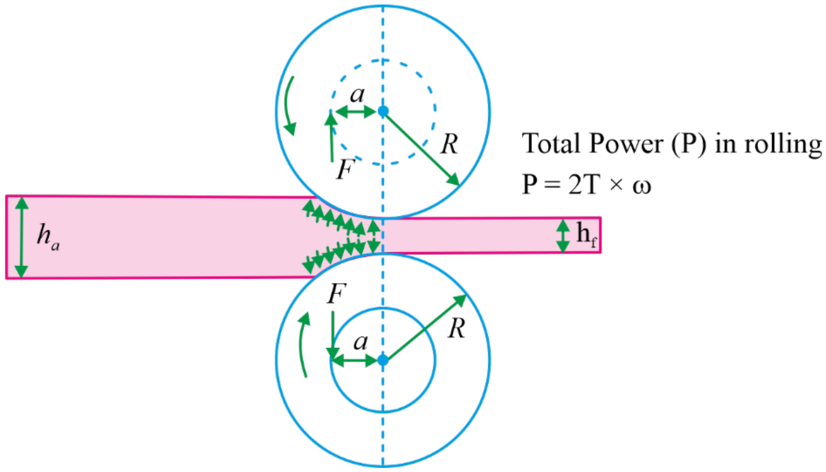


Fig. 5.4

$$\lambda = \frac{a}{L_p} = \frac{a}{\sqrt{R\Delta h}}$$

Where,

L_p = Projected length

R = radius of roller

Δ_h = Draft

T = Torque per roller

F = Roll Separating Force

a = Radius from the center where roll separating force(F) is acting

ω = Angular velocity

Where λ is 0.5 for hot-rolling and 0.45 for cold-rolling.

5.5 Forging

Process in which material is shaped by the application of localized compressive forces exerted manually or with power hammers, presses or special forging machines.

Impression Die forging Here half the impression of the finished forging is sunk or made in the top die and other half of the impression is sunk in the bottom die. In impression die forging, the work piece is pressed between the dies. As the metal spreads to fill up the cavities sunk in the dies, the requisite shape is formed between the closing dies

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 is a process by which products are made through a series of incremental deformation using dies of relatively simple shape.

Closed die forging Closed die forging is very similar to impression die forging, but in true closed die forging, the amount of material initially taken is very carefully controlled, so that no flash is formed

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.

5.5.1 Operations involved in forging

Steps involved in hammer forging

- Fullering or swaging
- Edging or rolling
- Bending
- Drawing or cogging
- Flattening
- Blocking
- Finishing operation
- Trimming or cut off

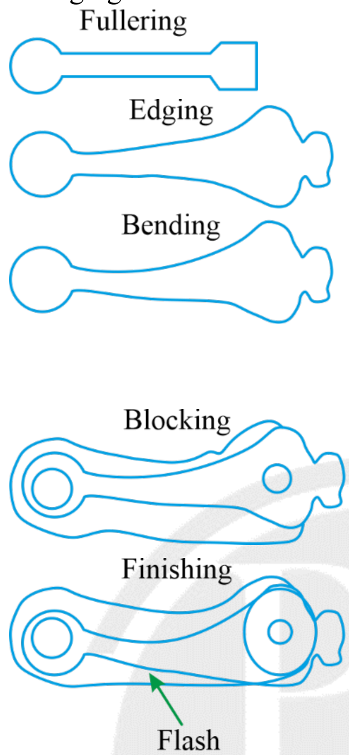


Fig. 5.5 Forging Operations

5.5.2 Die Materials Should have

- Thermal shock resistance
- Thermal fatigue resistance
- High temperature strength
- High wear resistance
- High toughness and ductility
- High hardenability
- High dimensional stability during hardening
- High machinability.
- Die materials: alloyed steels (with Cr, Mo, W, V), tool steels, cast steels or cast iron

> **Note:**
> 1. Carbon steels with 0.7-0.85% C are appropriate for small tools and flat impressions.
> 2. Medium-alloyed tool steels for hammer dies.
> 3. Highly alloyed steels for high temperature resistant dies used in presses and horizontal forging machines.

5.5.3 Typical forging defects

- Incomplete forging penetration- should forge on the press.
- Microstructural differences resulting in pronounced property variation.
- Hot shortness, due to high sulphur concentration in steel and nickel.
- Pitted surface, due to oxide scales occurring at high temperature stick on the dies.
- Buckling, in upsetting forging. Subject to high compressive stress.
- Surface cracking, due to temperature differential between surface and center, or excessive working of the surface at too low temperature.
- Microcracking, due to residual stress.
- Flash line crack, after trimming-occurs more often in thin workpieces. Therefore, should increase the thickness of the flash.
- Cold shut or fold, due to flash or fin from prior forging steps is forced into the workpiece.
- Internal cracking, due to secondary tensile stress.

5.6 Sheet Metal Working

- Shearing is a cutting operation used to remove a blank of required dimension from a large sheet.

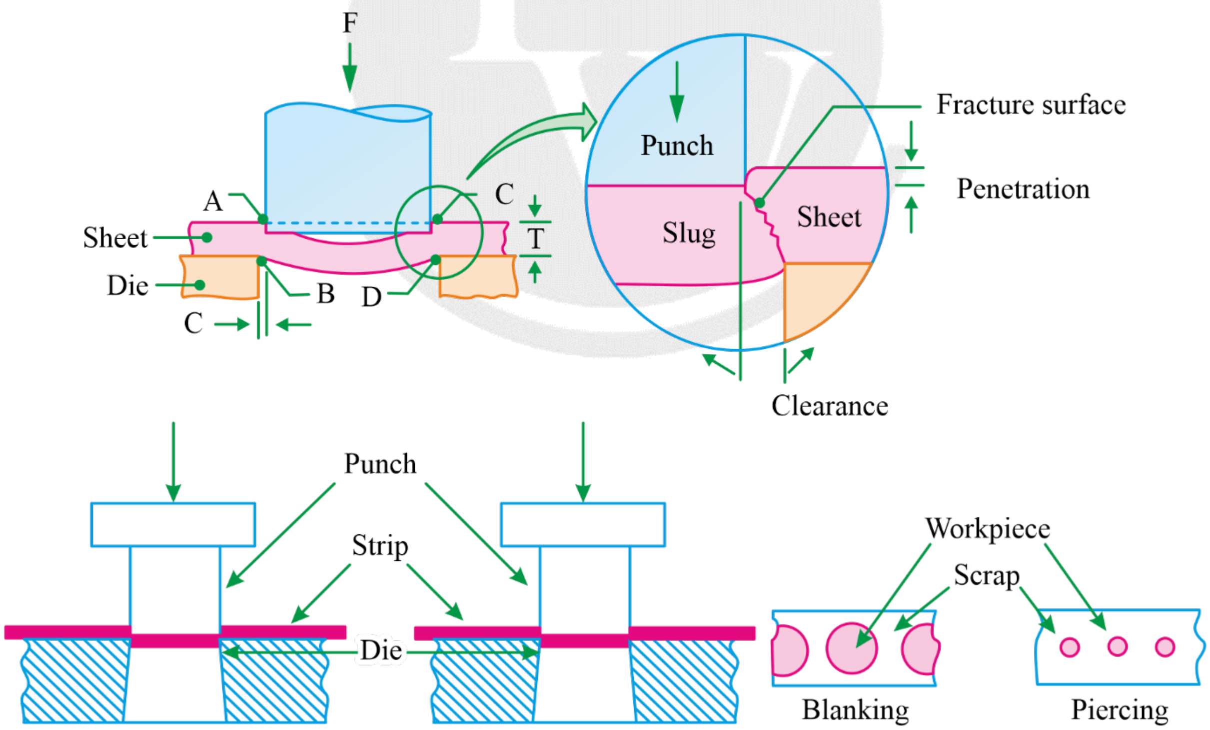


Fig. 5.5 Punching and Blanking operation

In blanking, the piece being punched out becomes the workpiece and any major burrs or undesirable features should be left on the remaining strip.

In piercing (Punching), the punch-out is the scrap, and the remaining strip is the workpiece.

(a) Clearance

- Die opening must be larger than punch and known as 'clearance'.
- Punching

  Punch = size of hole

  Die = punch size +2 clearance

Note: In punching punch is correct size.

(b) Blanking

- Die = size of product
- Punch = Die size –2 clearance

Note:
In blanking die size will be correct.

Clearance formula

1. $c = 0.0032t\sqrt{\tau}$ or
2. C = allowance (t)
3. C = (x%)t

Where,

t = sheet thickness (mm)

τ = shear strength (N/mm^2)

C = Clearance

(c) Punching Force and Blanking Force

$$F_{max} = Lt\tau$$

Where

F_{max} = Maximum force

L = cutting parameter(mm)

t = thickness of sheet (mm)

τ = shear strength (N/mm^2)

The punching force for holes which are smaller than the stock thickness may be estimated as follows:

$$F_{max} = \frac{\pi d t \sigma}{\sqrt[3]{\frac{d}{t}}}$$

Where

F_{max} = Maximum force

d = diameter of punch(mm)

t = thickness of sheet (mm)

σ = Tensile strength (N/mm^2)

(d) Shear on Punch

To reduce shearing force, shear is ground on the face of the die or punch. It distributes the cutting action over a period of time.

> **Note:**
> Shear only reduces the maximum force to be applied but total work done remains same.

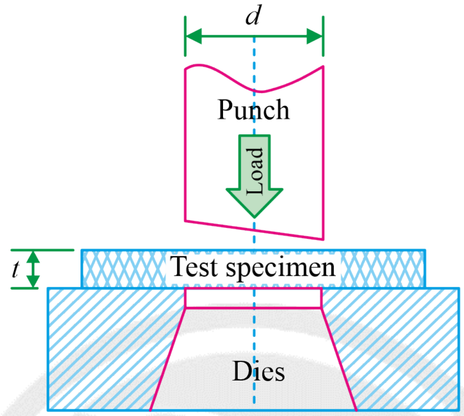


Fig. 5.6

Maximum shear force(F_s)

$$F_s = \frac{F_{max}(Pt)}{Pt + S}$$

If $S > Pt$ then

$$F_s = \frac{F_{max}(Pt)}{S}$$

Where,

F_{max} = Maximum force
P = percentage penetration
t = thickness of sheet (mm)
S = shear height (mm)

5.7 Drawing

Drawing is a plastic deformation process in which a flat sheet or plate is formed into a three-dimensional part with a **depth more than several times the thickness of the metal.**

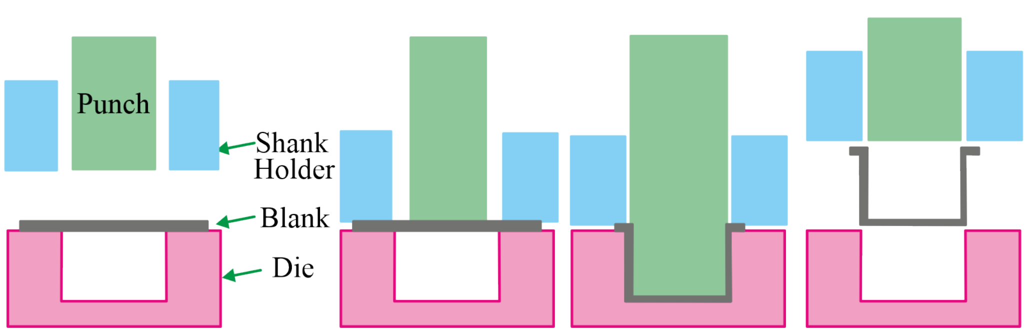


Fig. 5.7 Drawing Operation

Blank Size

$$D = \sqrt{d^2 + 4dh}$$

$$D = \sqrt{d^2 + 4dh} - 0.5r \quad \text{when } 15r \le d \le 20r$$

$$D = \sqrt{(d-2r)^2 + 4d(h-r) + 2\pi r(d-0.7r)} \quad \text{when } d < 10r$$

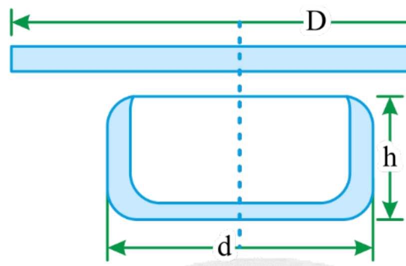


Fig. 5.8

5.8 Deep drawing

Drawing when cup height is more than half the diameter is termed deep drawing. This can be achieved by redrawing the part through a series of dies.

Note:
Deep drawing - is a combination of drawing and stretching.

5.8.1 Deep Drawability

- The ratio of the maximum blank diameter to the diameter of the cup drawn. i.e. D/d.
- The average reduction in deep drawing, thumb rule for reduction

$$\frac{d}{D} = 0.5$$

$$\text{Reduction} = \left(1 - \frac{d}{D}\right) \times 100\% = 50\%$$

Thumb rule:

First draw: Reduction = 50%

Second draw: Reduction = 30%

Third draw: Reduction = 25%

Fourth draw: Reduction = 16%

Fifth draw: Reduction = 13%

5.8.2 Defects in Drawing

- **Wrinkle:** An insufficient blank holder pressure causes wrinkles to develop on the flange, which may also extend to the wall of the cup.

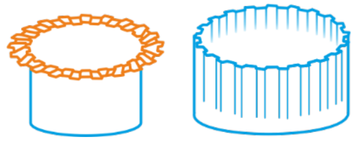


Fig. 5.9 Wrinkle

- **Fracture:** Further, 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).

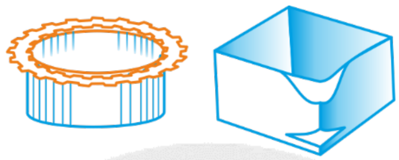


Fig. 5.10 Fracture

- **Earing:** While drawing a rolled stock, ears or lobes tend to occur because of the anisotropy induced by the rolling operation.

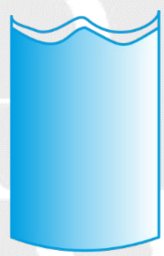


Fig. 5.11 Earing

- **Miss strike:** Due to the misplacement of the stock, unsymmetrical flanges may result. This defect is known as miss strike.

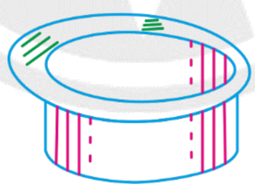


Fig. 5.12 Miss Strike

- **Surface scratches:** Die or punch not having a smooth surface, insufficient lubrication

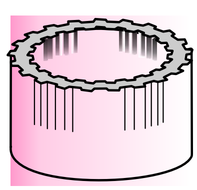


Fig. 5.13 Scratches

5.9 Spinning

- Spinning is a cold-forming operation in which a rotating disk of sheet metal is shaped over a male form, or mandrel. Localized pressure is applied through a simple round-ended wooden or metal tool or small roller, which traverses the entire surface of the part.

  Relation between cone and blank

$$t_c = t_b \sin\alpha$$

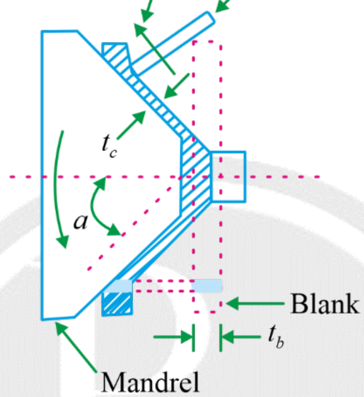


Fig. 5.14 Spinning process

T_c = cone thickness

T_b = blank thickness

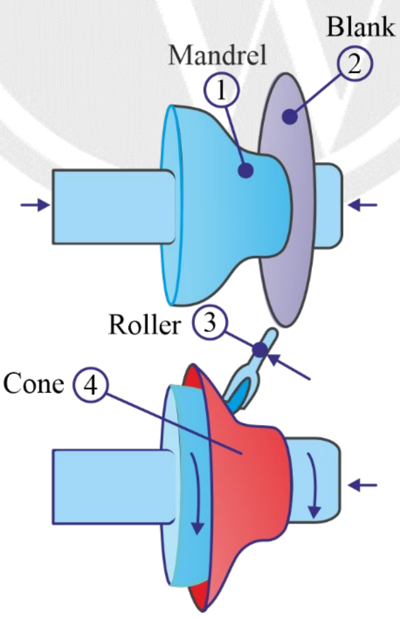


Fig. 5.15 Spinning Process

5.10 Stretch Forming

A sheet of metal is gripped by two or more sets of jaws that stretch it and wrap it around a single form block. Because most of the deformation is induced by the tensile stretching, the forces on the form block are far less than those normally encountered in bending or forming.

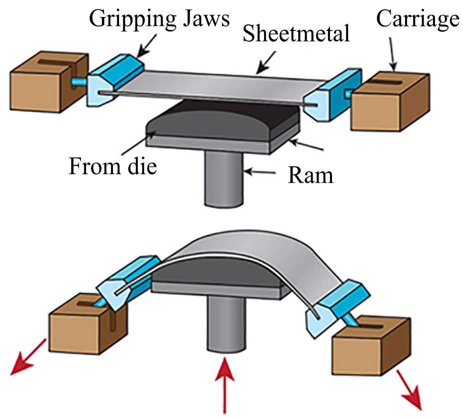


Fig. 5.16

Final thickness(t) formula
For bi-axial stretching of sheets

$$\varepsilon_1 = \ln\left(\frac{l_{i1}}{l_{01}}\right) \quad ; \varepsilon_2 = \ln\left(\frac{l_{i2}}{l_{02}}\right)$$

$$\text{Final thickness} = \frac{\text{Initial thickness(t)}}{e^{\varepsilon_1} \times e^{\varepsilon_2}}$$

where
- l_{i1} = final length in direction 1
- l_{i2} = final length in direction 2
- l_{o1} = initial length in direction 1
- l_{o2} = initial length in direction 2
- ε_1 = strain in direction 1
- ε_2 = strain in direction 2

5.11 Bending

- After basic shearing operation, we can bend a part to give it some shape.
- Bending parts depends upon material properties at the location of the bend.

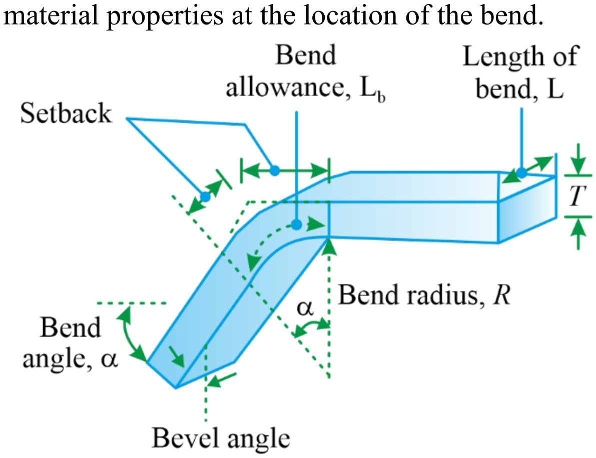


Fig. 5.17 Bending

Bend allowance (L_b), formula

$$L_b = \alpha(R + kt)$$

where

R = bend radius

k = constant (stretch factor)

t = thickness of material

α = bend angle (in radian)

5.12 Extrusion

- Extrusion is a compression process in which the work metal is forced to flow through a die opening to produce a desired cross-sectional shape. As shown in figure

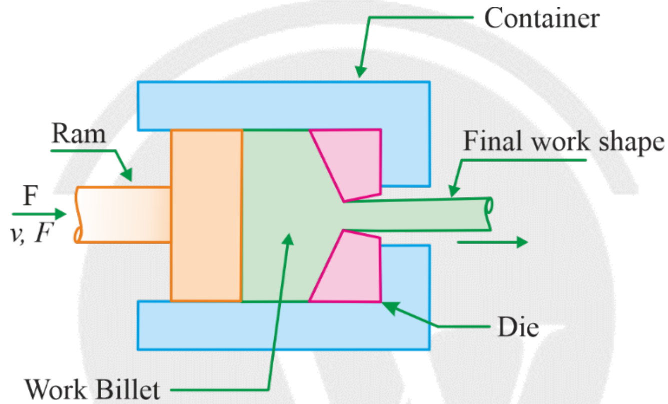


Fig. 5.18

5.12.1 Extrusion Ratio

- Ratio of the cross-sectional area of the billet to the cross-sectional area of the product.

5.12.2 Direct Extrusion

- A solid ram drives the entire billet to and through a stationary die and must provide additional power to overcome the frictional resistance between the surface of the moving billet and the confining chamber.

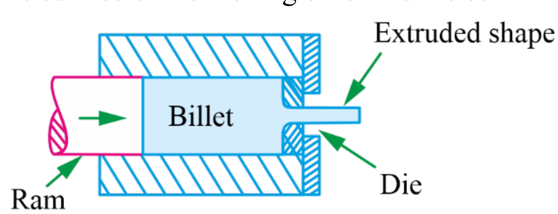


Fig. 5.19 Direct extrusion

5.12.3 Indirect Extrusion

- A hollow ram drives the die back through a stationary, confined billet. Since no relative motion, friction between the billet and the chamber is eliminated.

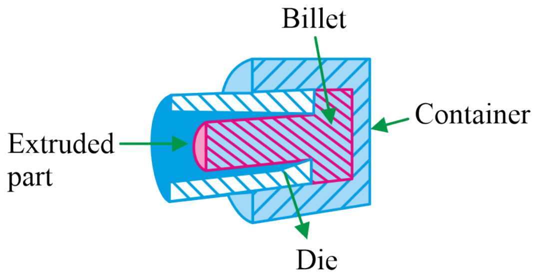


Fig. 5.20 Indirect Extrusion

5.12.4 Hydrostatic Extrusion

In hydrostatic extrusion the container is filled with a fluid. Extrusion pressure is transmitted through the fluid to the billet. Friction is eliminated in this process because of there is no contact between billet and container wall. Brittle materials can be extruded by this process. Highly brittle materials can be extruded into a pressure chamber.

Hydrostatic extrusion is a process in which the billet is completely circumscribed by a pressurized liquid in all the cases, with the exception being the case where billet is in the contact with die. This process can be carried out in many ways including warm, cold or hot but due to the stability of the used fluid, the temperature is limited. Hydrostatic extrusion has to be carried out in a completely sealed cylinder for containing the hydrostatic medium

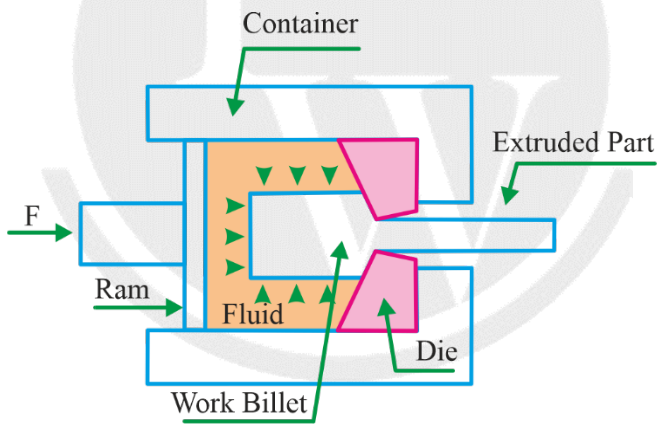


Fig. 5.21 Hydrostatic Extrusion

5.13 Wire Drawing

A cold working process to obtain wires from rods of bigger diameters through a die. For fine wire, the material may be passed through a number of dies, receiving successive reductions in diameter, before being coiled. The wire is subjected to tension only.

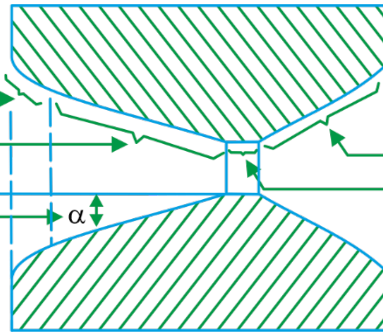


Fig. 5.22 Drawing process

5.13.1 Extrusion Load (F) formula

Extrusion load formula (Uniform deformation, no friction) "work – formula"

$$F = A_o \sigma_o \ln\left(\frac{A_o}{A_f}\right)$$

For real conditions

$$F = K A_o \ln\left(\frac{A_o}{A_f}\right)$$

A_0 = initial cross-sectional area

A_f = final cross-sectional area

σ_0 = yield strength of material

K = extrusion constant

$K = \frac{\sigma_0}{\sqrt{3}}$ (for plane strain)

$= \frac{\sigma_0}{2}$ (for plane stress)

5.13.2 Wire or Tube drawing force(F) formula

- Wire or Tube drawing force formula (Uniform deformation, no friction) "work – formula"

$$F = A_f \sigma_0 \ln\left(\frac{A_o}{A_f}\right)$$

❑❑❑

6 METROLOGY

6.1 Metrology and Inspection

It is the measurement science that 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.

6.1.1 Limit System

- **Basic size:** It is the size with reference to which upper or lower limits of size are defined. It is theoretical size of part as suggested by designer.
- **Actual size:** It is the size actually obtained by machining. It is found by actual measurement
- **Tolerance:**
  (a) The difference between the upper limit and lower limit.
  (b) It is the maximum permissible variation in a dimension.
  (c) The tolerance may be unilateral or bilateral.
  (d) It is always positive.
- **Unilateral Limits** occurs when both maximum limit and minimum limit are either above or below the basic size.
- **Bilateral Limits** occur when the maximum limit is above and the minimum limit is below the basic size.

6.1.2 Fit

Fits: It is the relationship that exists between two mating parts, a hole and shaft with respect to their dimensional difference before assembly.

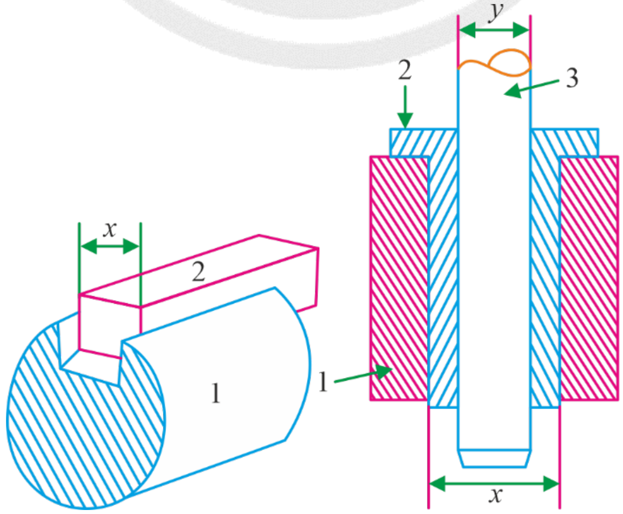


Fig. 6.1 Fit

6.1.3 Allowance

It is Minimum clearance or maximum interference. It is the intentional difference between the basic dimensions of the mating parts. The allowance may be positive or negative.

6.2 Hole basis and Shaft basis System

6.2.1 Basis of Fits - Hole Basis

In this system, the basic diameter of the hole is constant while the shaft size varies according to the type of fit.

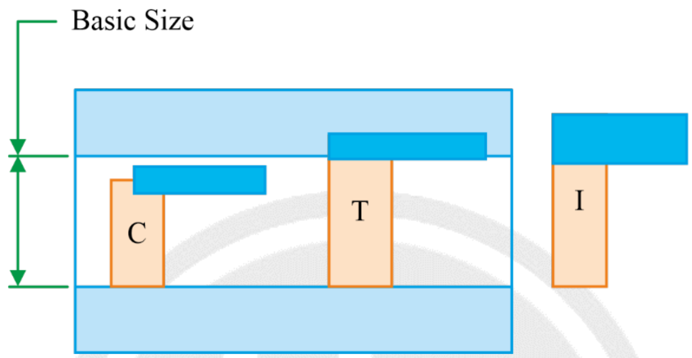
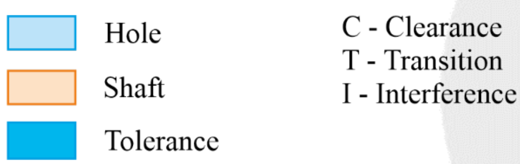


Fig. 6.2 Hole Basis Fits



6.2.2 Basis of Fits - Shaft Basis

Here the hole size is varied to produce the required class of fit with a basic-size shaft.

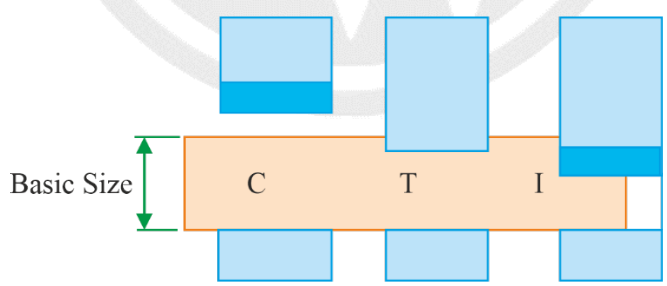
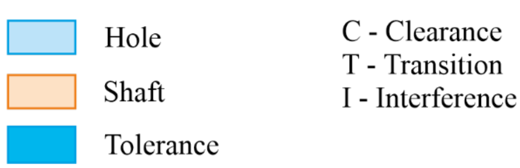


Fig. 6.3 Shaft Basis Fits



6.3 Limits and Fits

- Limits and fits comprise 18 grades of fundamental tolerances for both shaft and hole, designated as IT01, ITO and IT1 to IT16. These are called standard tolerances. (IS-919) But ISO 286 specify 20 grades up to IT18
- There are 25 (IS 919) and 28 (ISO 286) types of fundamental deviations.

  Hole: A, B, C, CD, D, E, EF, F, FG, G, H, J, JS, K, M, N, P, R, S, T, U, V, X, Y, Z, ZA, ZB, ZC.

  Shaft: a, b, c, cd, d, e, ef, f, fg, g, h, j, js, k, m, n, p, r, s, t, u, v, x, y, z, za, zb, zc.

- A unilateral hole basis system is recommended but if necessary a unilateral or bilateral shaft basis system may also be used.

  'Standard tolerance unit', (i) inμm

$$i = \text{Fundamental tolerance}$$

$$i = 0.45\sqrt[3]{D} + 0.001D$$

(unit tolerance, in μm)

$$D = \sqrt{D_1 D_2}$$

(D_1 and D_2 are the nominal sizes marking the beginning and the end of a range of sizes, in mm)

Value of the Tolerance

IT01 $0.3 + 0.008D$	IT0 $0.5 + 0.012D$	IT1 $0.8 + 0.02D = a$	IT2 $ar^2 = 10^{1/5}$
IT3 ar^2	IT4 ar^3	IT5 $ar^4 = 7i$	IT6 $10(1.6)^{(ITn-IT6)} = 10i$
IT7 $10(1.6)^{(ITn-IT6)} = 16i$	IT8 $10(1.6)^{(ITn-IT6)} = 25i$	IT9 $10(1.6)^{(ITn-IT6)} = 40i$	IT10 $10(1.6)^{(ITn-IT6)} = 64i$
IT11 $10(1.6)^{(ITn-IT6)} = 100i$	IT12 $10(1.6)^{(ITn-IT6)} = 160i$	IT13 $10(1.6)^{(ITn-IT6)} = 250i$	IT14 $10(1.6)^{(ITn-IT6)} = 400i$
IT15 $10(1.6)^{(ITn-IT6)} = 640i$	IT16 $10(1.6)^{(ITn-IT6)} = 1000i$		

Table 6.1 Fundamental Tolerances

6.4 Fundamental Deviation

It is chosen to locate the tolerance zone w.r.t. the zero line

- Holes are designated by capital letter:
- Letters A to G - oversized holes
- Letters P to ZC - undersized holes

Shafts are designated by small letter:

Letters m to zc - oversized shafts
Letters a to g - undersized shafts
H is used for holes and **h** is used for shafts whose fundamental deviation is zero

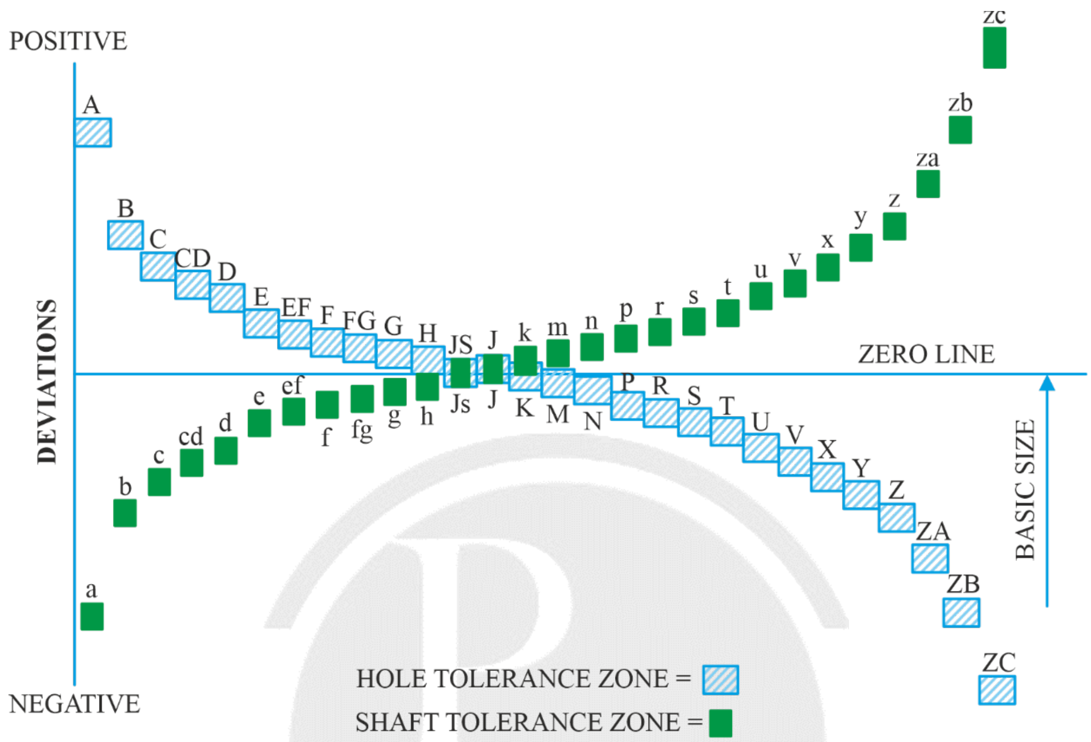


Fig. 6.4 Fundamental Deviations

6.5 Taylor's Principle of Gauging

- **A GO** Gauge will check all the dimension of the work piece in the maximum metal condition (indicating the presence of the greatest amount of material permitted at a prescribed surface). It should check the size of the component also the geometrical shape.
- **NOT GO** Gauges will check only one dimension of the work piece at a time, for the minimum metal conditions (indicating the presence of the least amount of material permitted at a prescribed surface).
- **Plug gauge:** used to check the holes. The GO plug gauge is the size of the low limit of the hole while the NOT GO plug gauge corresponds to the high limit of the hole.
- **Snap, Gap or Ring gauge:** used for gauging the shaft and male components. The Go snap gauge is of a size corresponding to the high (maximum) limit of the shaft, while the NOT GO gauge corresponds to the low (minimum limit).

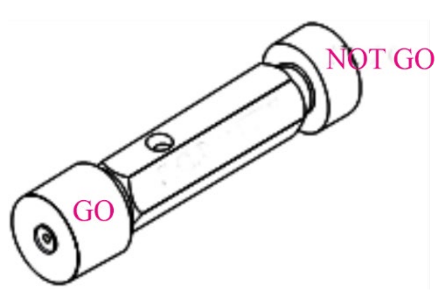


Fig. 6.5 Plug gauge

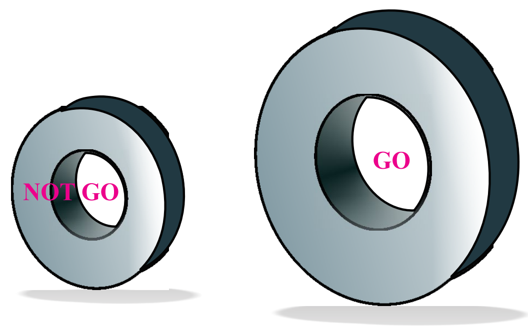


Fig. 6.6 Ring and snap gauges

Note:

1. Wear allowance: GO gauges which constantly rub against the surface of the parts in the inspection are subjected to wear and lose their initial size.
2. The size of go plug gauge is reduced while that of go snap gauge increases.
3. Wear allowance is usually taken as 5% of the work tolerance.

6.6 Process capability Index

$\bar{x} \pm 3\sigma$ Desired Tolerance

6σ = Process capability

C_p > 1 highly capable

= 1 Just capable

< 1 Not capable

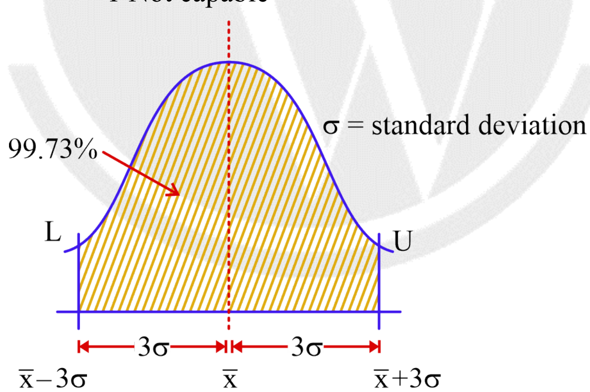


Fig. 6.7

$$C_P = \frac{U-L}{6\sigma} \qquad C_{B\ell} = \frac{\bar{x}-L}{3\sigma} \qquad C_{P_u} = \frac{U-\bar{x}}{3\sigma}$$

$$C_{P_k} = \text{Min}\left[C_{P\ell}, C_{Pu}\right]$$

Hole & Shaft: 95% cases hole is made first due to standard sizes of drills and reamers available in market.

Accuracy - Closeness to target value (refers to individual [Mode a Median of normal distribution]

Precision - Repeatability (Refers to a group) [Standard Deviation]

Full interchangeability:

In such case the process capability of machine is equal to the desired tolerance.

But practically process capabilities much larger than designed tolerance

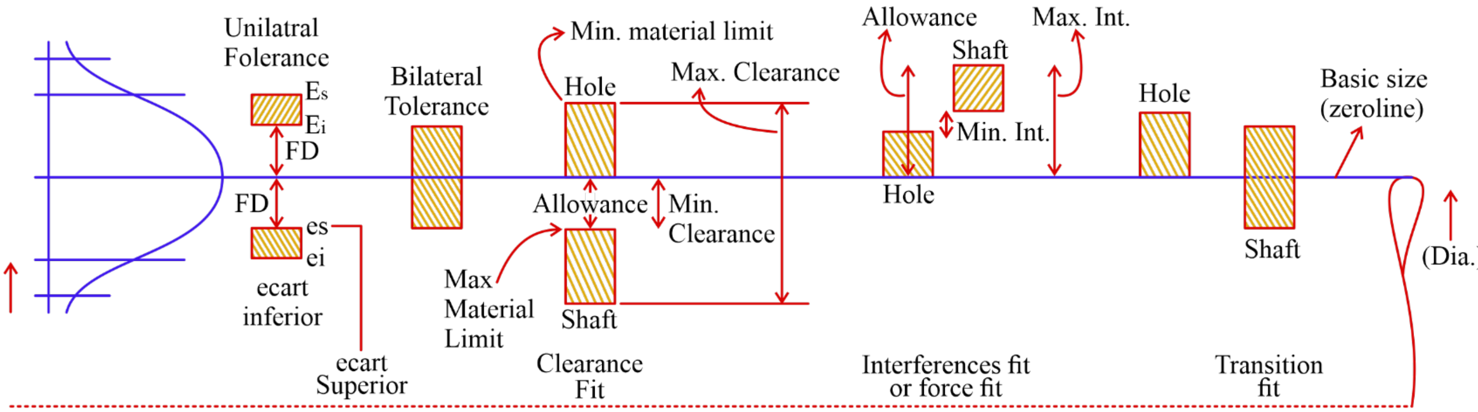


Fig. 6.8

> **Note:**
> Negative clearance is called interference and negative interference is called clearance.

Fundamental deviations = 25

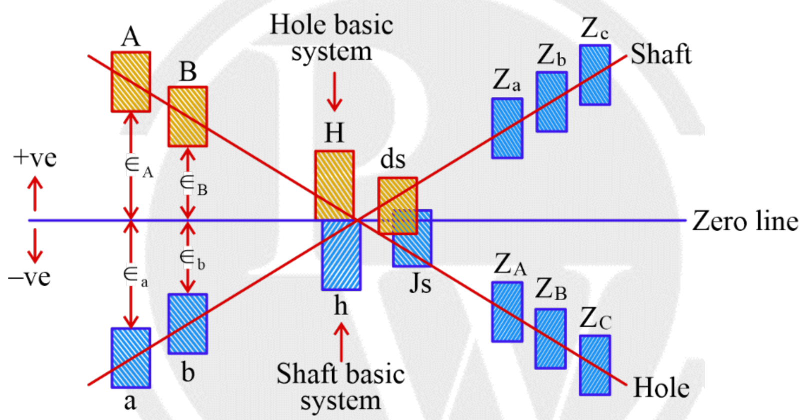


Fig. 6.9

J_s is only bilateral

FD is dist. Between zero line and limit closer to it.

6.7 Grade of Tolerance

$i = 0.45D^{1/3} + 0.001D$; $D = \sqrt{D_1 D_2}$

Diameter range →

D1	–	D2
0	–	3
3	–	6
6	–	10
10	–	18
18	–	30
30	–	50

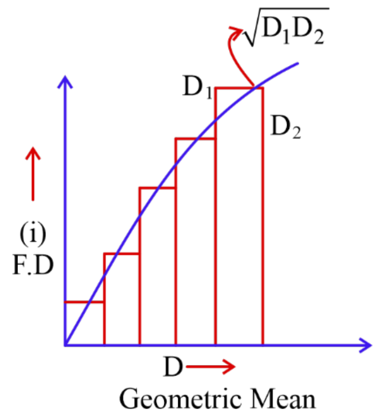


Fig. 6.10

Where D is in mm and tolerance is meter microns.

IT01 — IT0 — IT1: Emperical formula

IT2 — IT1: $10^{(1/5)} i$

IT01 — IT1: Sip guage

IT2 — IT1: Buffing, horning

IT4	IT5	IT6	IT7	IT8
Geometric series	$10^{(4/5)} i$	Preferred series		
		$10i$	$10(10)^{1/5} i = 16i$	$25i$

IT4 — IT5: Grinding

IT6 — IT13: Machining

IT9	IT10	IT11	IT12	IT13
40i	64i	100i	160i	250i

IT9 — IT10: Forming

IT14	IT15	IT16
400i	640i	1000i

IT14 — IT16: Casting

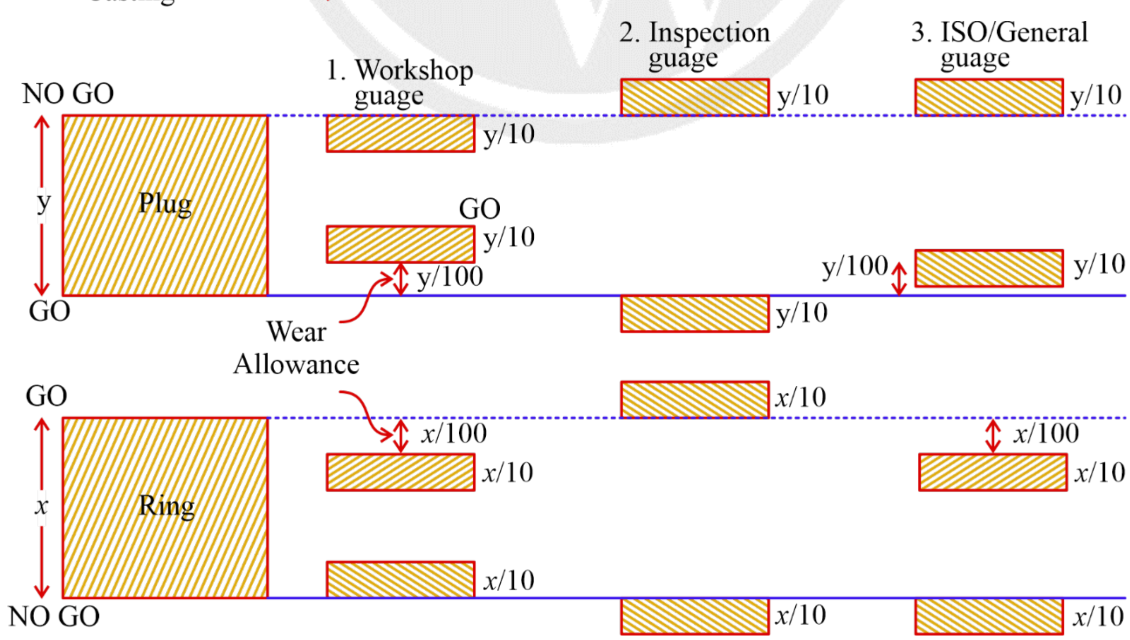


Fig. 6.11

Guage tolerance $= \frac{1}{10}$ (work tolerance)

Wear allowance $= \frac{1}{10}$ (Guage tolerance) $= \frac{1}{100}$ (work tolerance)

Properties of Guages	Materials for Guages
(1) Hardness	(a) En – 24 (High steel)
(2) Low α (thermal exp.)	(b) Invar (36% Ni)
(3) ρ (density)	(c) Elinver (42% Ni)
(4) Corrosion resistant	(d) Glass (For guns and rifle)
(5) Machinability	

Tolerance Sink

Tolerance of sink is algebraic summation of all the other tolerances but only like-minded tolerances can be added and it will be least accurate section of assembly.

Micrometer is more accurate instrument than vernier caliper because it has point contact and vernier has area contact so reference plane of measurement keeps on changing.

6.8 Slip Gauges

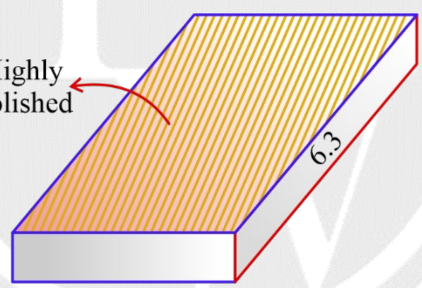


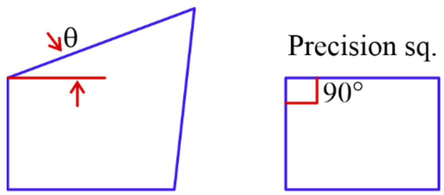
Fig. 6.12 Slip Gauges

Normal set (M45)	Special set (M87)
$1.001 - 1.009 = 9$	$1.001 - 1.009 = 9$
$1.01 - 1.09 = 9$	$1.01 - 1.49 = 49$
$1.1 - 1.9 = 9$	$0.5 - 9.5 = 19$
$1 - 9 = 9$	$10 - 90 = 9$
$10 - 90 = \frac{9}{45}$	$1.005 = \frac{1}{87}$

Minimum number of slips gauges should be used to reduces tolerances.

6.8.1 Angle Blocks

(Used to measure angular datum)



Set - 13

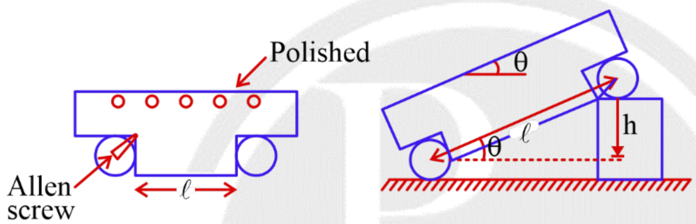
Degrees -	1	3	9	27	41
Min. -	1	3	9	27	
Fractions -	0.05	0.1	0.3	0.5	

0.05 → Least count

Fig. 6.13

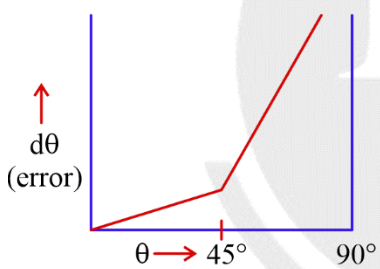
- For adding angles place inclined side of one on flat side of the other.
- For subtracting angles place both incline sides one over other
- For adding and subtracting 90° use precision square.

6.9 Sine Bar



$$\sin\theta = \frac{h}{\ell}$$

$$d\theta = -\tan\theta \frac{d\ell}{\ell}$$



If $\theta = 45°$
$\tan\theta = 1$

If $\theta = 90°$
$\tan\theta = \infty$

Fig. 6.14

That only sine bars are not used beyond 45° angle.

6.10 Precision Ball Measurement

$$\text{cosec}\theta = \frac{h_2 - h_1}{r_2 - r_1} - 1$$

$$\text{cosec}\theta = \frac{dh}{dr} - 1$$

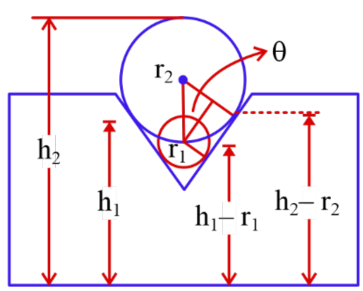


Fig. 6.15

6.11 Taper of Plug Gauge

$$\tan\theta = \frac{2h}{\ell_2 - \ell_1}$$

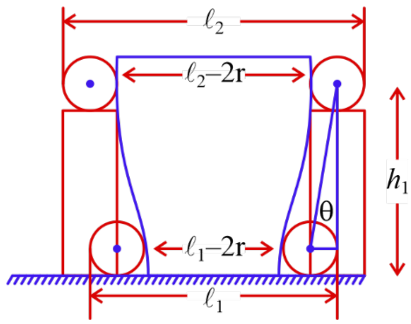


Fig. 6.16

6.12 Types of Error

(1) **System error [Systematic error]:** Follow = pattern & eliminated by calibrating the equipment.
(2) **Short period error:** due to change in environmental conditions taken care by neglecting data.
(3) **Erratic error:** due to maintenance of equipment.

6.12.1 Measurement Errors

(a) Cosine error

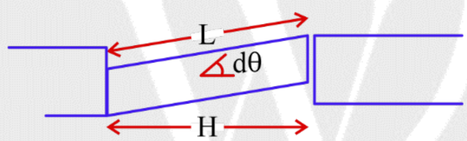


Fig. 6.17 Cosine Error

Error = L – L cos θ, can be neglected.

(b) Sine error

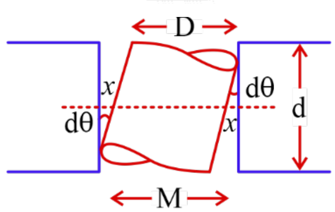


Fig. 6.18 Sine Error

$$\text{Error} = 2x = d \times \delta\theta$$

$$\frac{x}{\frac{d}{2}} = \tan\delta\theta = \delta\theta$$

$$\boxed{x = \frac{d}{2}\delta\theta}$$

6.13 Screw Turned Metrology:

6.13.1 Pitch measurement

The most commonly used methods for measuring the pitch are:

(1) Pitch measuring machine

(2) Tool makers microscope

(3) Screw pitch gauge

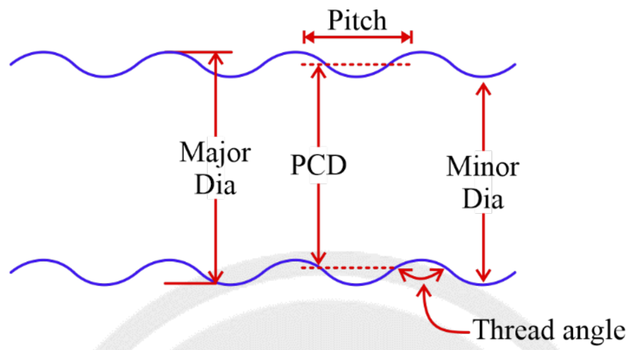


Fig. 6.19

Internal threads are analysed by putting sulphur or wax into the caving (half filled)

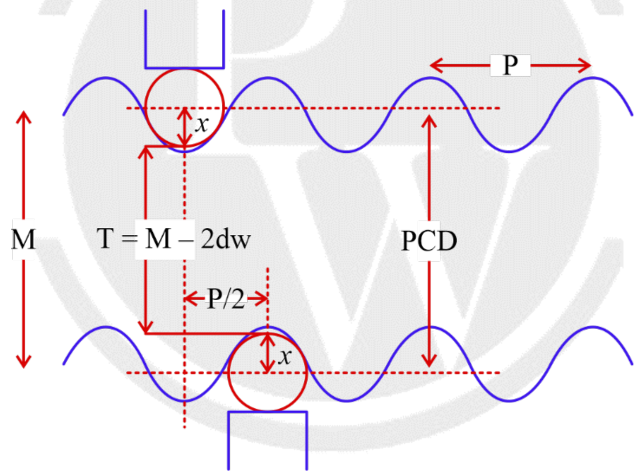


Fig. 6.20

$$PCD = T + 2x$$

$$PCD = T + d\omega(1 - \operatorname{cosec}\theta) + \frac{p}{2}\cot\theta$$

Best wire size is $$dw_b = {}^{p}\!/_{2} \sec\theta$$

6.14 Methods for Qualifying Surface Roughness

6.14.1 Peak to valley height (R_t, R_{max}, $H_{max.}$):

(a) If only f (feed) and R (nose radius) is given

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

(b) If tool signature is given than use

$$H_{max} = \frac{f}{\tan\Psi + \cot\Psi_1}$$ Ψ = side cutting edge angle, ψ_1 = end cutting edge angle

6.14.2 Centre line average value (CLA, R_a):

(a) $R_a = \dfrac{y_1 + y_2 + y_3 .....y_n}{n}$

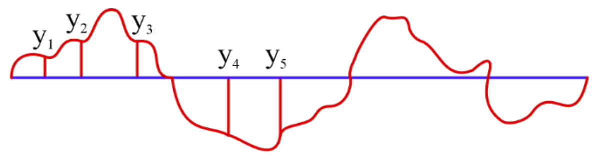


Fig. 6.21

(b) $R_a = \dfrac{\sum a + \sum b}{L}$

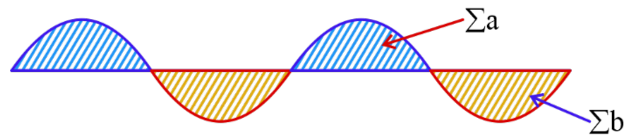


Fig. 6.22

(c) $R_a = \dfrac{1}{L}\int_0^L (y)dx$ if equation of curve is given eg. $Y = f(x)$

(d) $R \approx \dfrac{H_{max}}{4}$ No data except $H_{max.}$ is given

$$R_a = \frac{\text{Peak height} \times \text{number of peak} + \text{valley depth} \times \text{number of valleys}}{\text{Number of peak} + \text{number of valleys}}$$

6.14.3 Root mean square value (RMS, Rg):

$$R_g = \sqrt{\frac{y_1^2 + y_2^2 + y_3^2 .....y_n^2}{n}}$$

$H_{max} > R_g > R_a$

10 points value (R_z): Average of 5 highest and 5 deepest valleys.

6.15 Representation of Surface Roughness

Machining Symbol

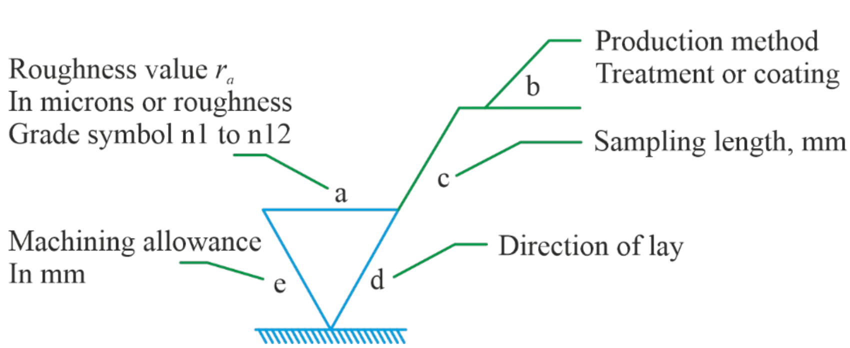


Fig. 6.23 Surface Roughness

6.16 Lay

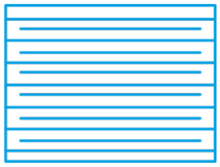
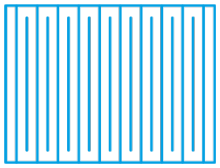
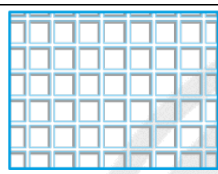
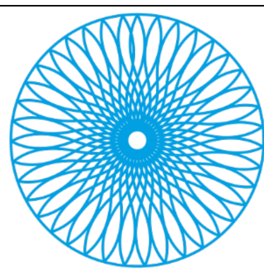
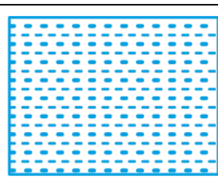
Lay Symbol	Surface pattern	Description
=		**Parallel Lay:** Lay parallel to the Surface. Surface is produced by shaping, planning etc.
⊥		**Perpendicular Lay:** Lay perpendicular to the Surface. Surface is produced by shaping and planning.
×		**Crossed Lay:** Lay angular in both surfaces is produced by knurling, honing.
M		**Multidirectional lay:** Lay multidirectional. Surface is produced by grinding, lapping, super finishing.
C		**Circular lay:** Approximately circular relative to the center. Surface is produced by facing.
R		**Radial lay:** Approximately radial relative to the center to the nominal surface.
P		Lay is particulate, nonchemical of probuberant.

Table 6.2 Different types of Lay

6.17 Optical Flat

$$A'B' \approx B'C$$

$$A'B' = \frac{n\lambda}{2}$$

Where n = number of fringes

λ is wavelength

$$\tan\theta \approx \theta = \frac{A'B'}{L} = \frac{n\lambda}{2L}$$

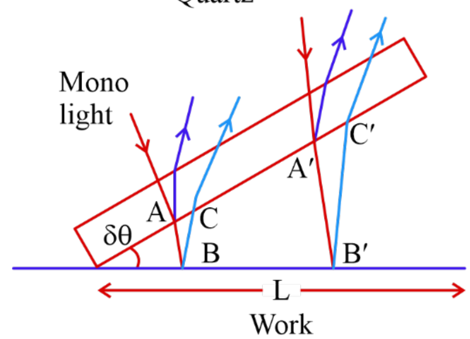


Fig. 6.24 Optical Flat over a Surface

6.18 Optical flat as a Comparator

ΔABC and ΔCDE are similar

$$\boxed{De = \frac{n\lambda}{2}}$$

$$\boxed{\Delta n = \left(\frac{n\lambda}{2}\right)\left(\frac{G}{L}\right)}$$

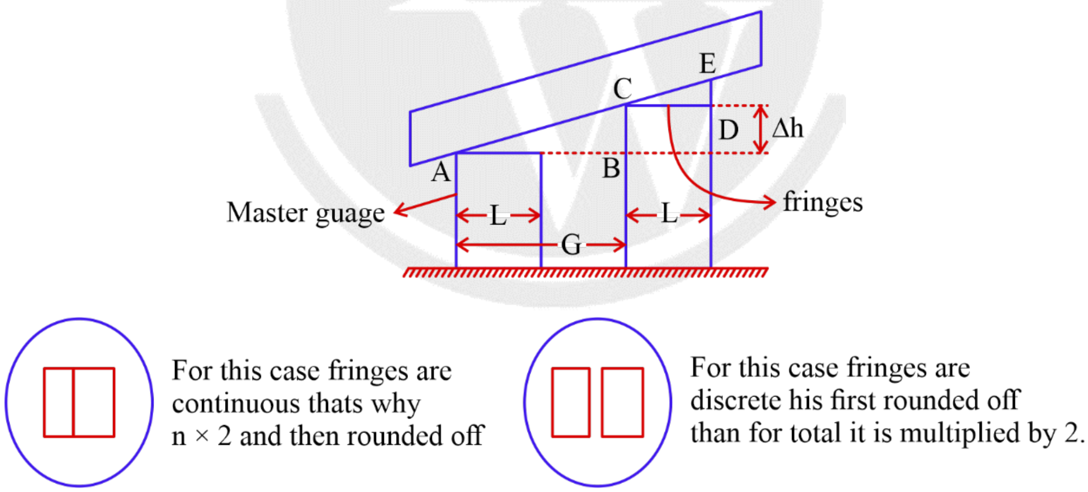


Fig. 6.25

$$\text{Parallelism error} = \frac{h_1 - h_2}{2}$$

Straightness

(1) Straight edge

(2) Sprit level

(3) Auto collimator $(\Delta s = 2f\delta\theta)$, f = focal length

6.19 Comparators:

- → Mechanical
  - → Sigma comparator
  - → Mikrokator
- → Pneumatic
  - → Rota meter
  - → Differential type
  - → Back pressure type

Fig. 6.25

Area of control orifice $C = \frac{\pi}{4} dc^2$

Area of measuring orifice $M = \pi d_m \ell$

Characteristic equation $\boxed{\frac{p}{P} = A - b\left(\frac{M}{C}\right)}$

With A, B, continue for higher P/p the value of M/C will be less.

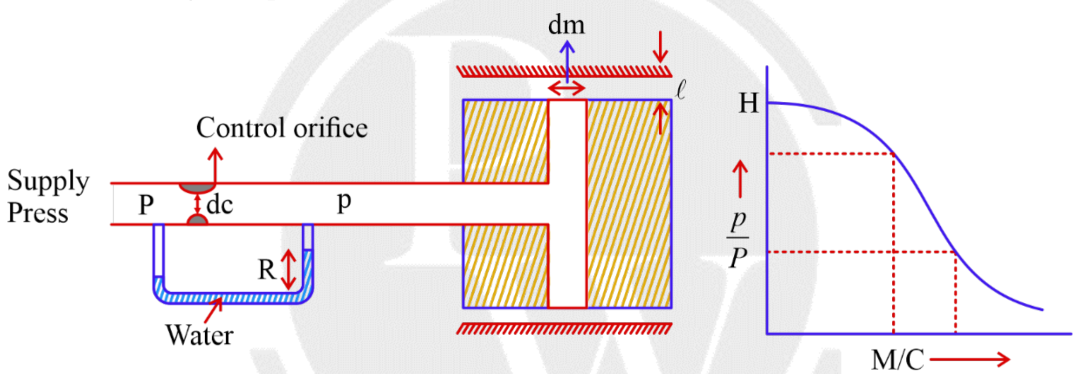


Fig. 6.26

$$M_{max.} - M_{min} = \frac{2}{3} M_{in.} = \text{Range}$$

$$M_{avg.} = \frac{4}{3} M_{min} - 2 \text{ Range}$$

$$\frac{dp}{dM} = \frac{0.4P}{M_{avg}} \quad \text{Pneumatic sensitivity}$$

Magnification factor $= \dfrac{\text{Output}}{\text{Input}}$

$$= \underbrace{\frac{dp}{dP}}_{\text{Indicator sensitivity}} \times \underbrace{\frac{dp}{dM}}_{\text{Pneumatic sensitivity}} \times \frac{dM}{d\ell} \rightarrow \text{Measuring head sensitivity} \left[\begin{array}{l} M = \pi d_m \ell \\ \frac{dM}{d\ell} = \pi d_m \end{array}\right]$$

- Offset in tail stock offset for producing taper

$$\text{Offset} = \ell \frac{\sin\alpha}{2}$$

❑❑❑

7 ADVANCE MACHINING METHOD

7.1 ADVANCE MACHINING METHOD

- **Numerical Control (NC):** Numerical control is defined as the form of programmable automation, in which the process is controlled by the number, letters, and symbols. In case of the machine tools this programmable automation is used for the operation of the machines.
- **Computer Numerical Control (CNC):** In CNC machines programs are fed in the computer was used to control the operations of the machines. Thus, the control unit used that would read the punched cards in the NC machines was replaced by the microcomputer in the CNC machines.

7.2 CNC Principles

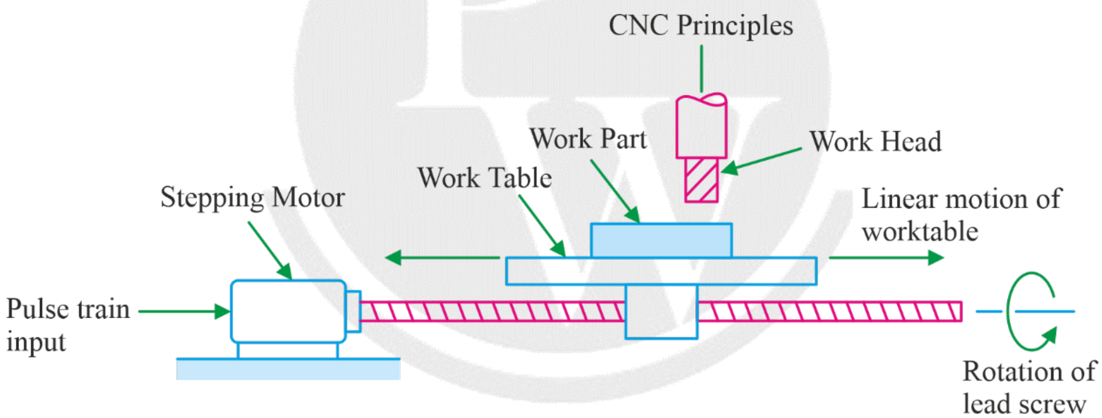


Fig. 7.1

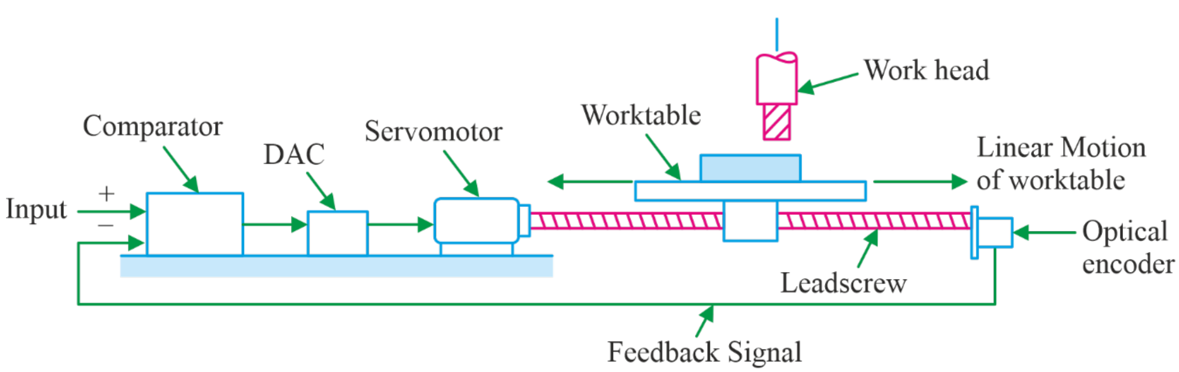


Fig. 7.2

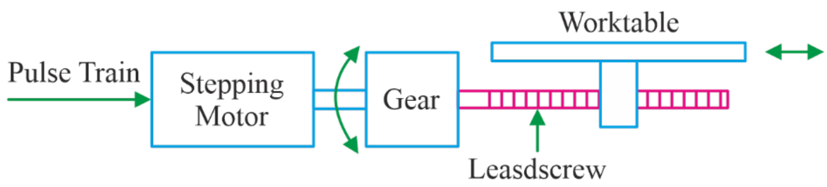


Fig. 7.3

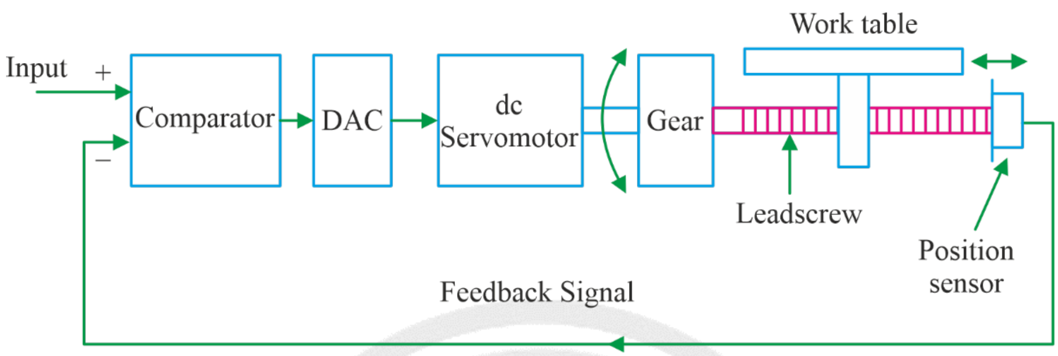


Fig. 7.4

7.3 Types of Motor

- Special motors called servos are used for executing machine movements in closed loop system.

Motor type can be

- AC servos,
- DC servos,
- Hydraulic servos.
- The speed depends on amount of current or hydraulic fluid passing through it.
- Servos are connected to the spindle and they are connected to the machine table through the ball lead screw

7.4 Basic Length Unit (BLU)

In NC machine, the displacement length per one pulse output from machine is defined as a Basic Length Unit (BLU).

(I) $$\text{BLU} = \frac{\text{Pitch of lead screw}}{\text{Number of pulse required for one rotation}}$$

(II) $$\text{BLU} = U \times n \times P \times N$$

U = Gear ratio, n = No. of starts of lead screw

P = Pitch of lead screw, N = No. of revolutions/step

(III) $$\text{Frequency of pulse} = \frac{\text{Table speed}}{\text{BLU}}$$

7.5 Types of tool positioning

7.5.1 Incremental Positioning

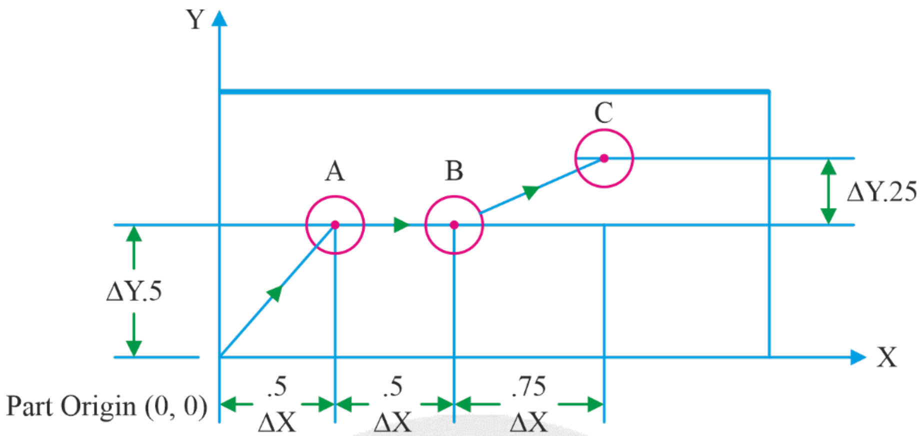


Fig. 7.5

Tool Position	Location	
	ΔX	ΔY
A	.5	.5
B	.5	0
C	.75	.25

7.5.2 Absolute Positioning

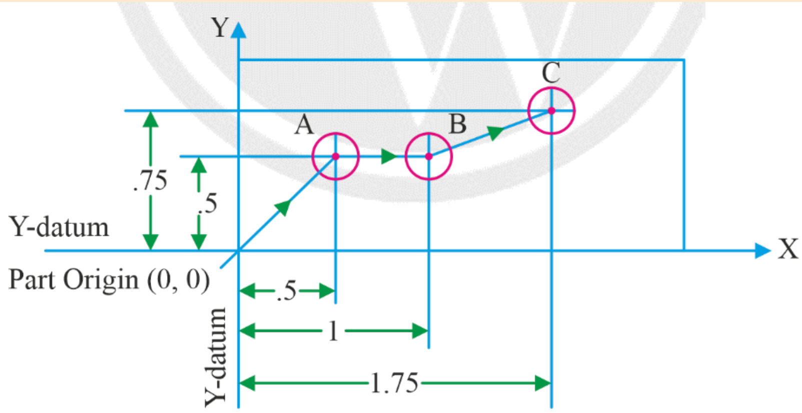


Fig. 7.6

Tool Position	Location	
	ΔX	ΔY
A	.5	.5
B	1	.5
C	1.75	.75

7.6 Automation

Japanese	American
Family	Hire & Fire
Puu	Push
Poka Yoke (O Defect)	Inspection
JIT (Just In The)	Inventories

(i) Routing is the path followed by any raw material inside the production system

(ii) Scheduling in which product will be processed on which machine and within what time period.

(iii) Dispatching is an activity that triggers the production it involves issuing of raw materials tools & sub-assemblies to shop floor.

7.7 Aggregate Planning (Short Forecast)

It is an analysis of how to best balance the total available resources against the demand expected. There are 4 option in the hand of aggregate planner.

(i) Overtime

Demand (Expected) can be achieved by making our existing staff to do overtime. But this option is having two problem.

(a) Worker efficiency less &

(b) As per (ILO) (International Labour organisation) During overtime workers' wages should be doubled.

(ii) Vary the Work Force

If the expected demand is high. I can operation two shifts rather than one for the second shift we can hire separate set of workers. But as per ILO we cannot fire the workers we want.

(iii) Sub Contracting

Although this option looks easy but by subcontracting we are losing our profit marking because it is your product which is selling.

(iv) Building Inventory

The period during which over demand is less will manufacture my products & put those products into my stores whenever there is excess demand. I will release inventory from the stores. But inventory not only block the working capital but also, we have to spent money in maintaining inventory in the stores.

7.8 Master Production Schedule (MPS)

Outcome of aggregate planning is master production schedule. It tells you how many & when final products will be ready for shipments.

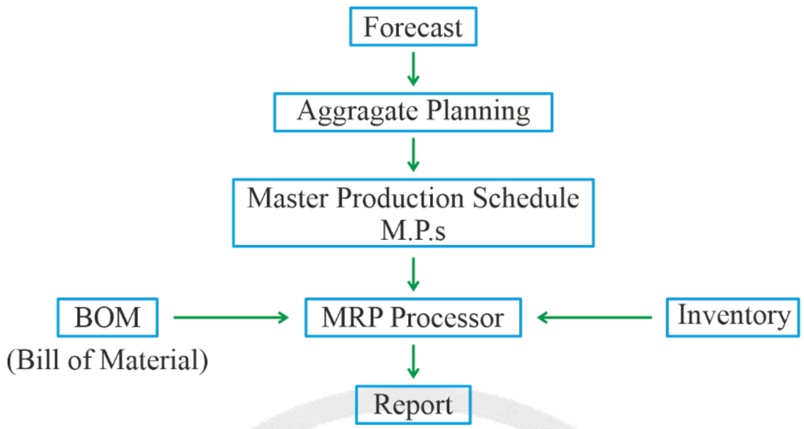


Fig. 7.7 MPS

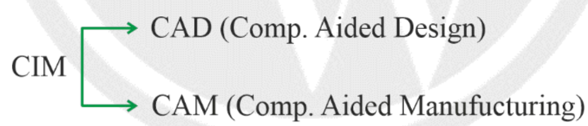
MRP - II : Finance + Marketing + MRPI

(MRP - I): Materials Req^n planning

MRP - I is a computational technique that coverts master schedule for end products into detailed scheduled for raw material & component used in the final product.

Manufacturing Resource planning (MRP – II) is having broader meaning than (MRP – I) it involves all the function of MRP – I & also includes marketing & finance division of company.

7.9 Computer Integrated Manufacturing (CIM)



7.9.1 CAD

Computer Aided design (CAD) can be defined as any design activity that involves effective use of computer to create, modify or document an engineering design. Its uses are

(1) To increase the productivity of designer.
(2) To improve quality of design.
(3) To improve design documentations.
(4) To create manufacturing database.

Finite element Tools

ANSYS
LSDVNA
DEFORM

- Re-engineering is relooking at our own design for betterment & reverse engineering is developing the design from somebody eyes product.

- In reverse engineering we are extracting the data from product & developing a part program that means generating cutter location data (CL Data) & from that we can produce component is mass.
- Any finite element tool will have b-divisions i.e. Preprocessor, solver, Post processor.
- Pre-Processor is almost similar to Autocad or Pro-E in which we are design the product
- Preprocessor does additional function to discretize (divide) the geometry into finite number of element solver solves the governing eq^n element by element. This governing eq^n given by us is preprocessor.
- Post processor is to view the result of solver.

7.9.2 CAM

Computer Aided Manufacturing is a effective use of computer in planning, management & control. Like Computer Aided process planning (Routing, scheduling, dispatching), Computer assistance line balancing, Computer Aided Part programming (CAPP) & virtual manufacturing virtual manufacturing means mimicking the O/P of shop floor over the computer screen.

CIM is having broacher meaning than CAD & CAM. CIM includes all the functions of CAD/CAM & it also includes all the other business function of firm & sometime it also includes the field support.

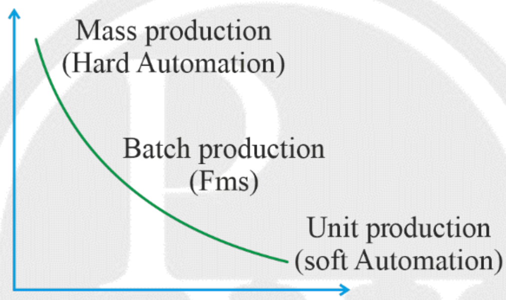


Fig. 7.8

7.10 Flexible Manufacturing System (FMS)

Requirements

(1) NC / CNC
(2) DNC
(3) Automatic Guided Vehicle (AGV)
(4) Simulator support.

When the company is offering frequent design change of the product it is called paperless automation or soft automation. Hard automation is the automation governed by can & follower arrangement & it is means for mass production. Flexible manufacturing system (FIMs) is meant for batch production & in this there is quick & inexpensive change in the design. To implement any FIMs in any unit following are requirements.

(i) All the machines in the unit should be either NC / CNC

(ii) There has to be DNC system (Direct/Distributed NC) DNC is the main frame computer (server). It is not directly involved in manufacturing but it controls no. of NC/CNC installation in plants. Highest level of automation is required in DNC.

Process Planning – Routing, dispatching, scheduling.

(iii) Material handling is done by Automatic Guided Vehicle.

(iv) Simulation support to provide for identifying the bottleneck system.

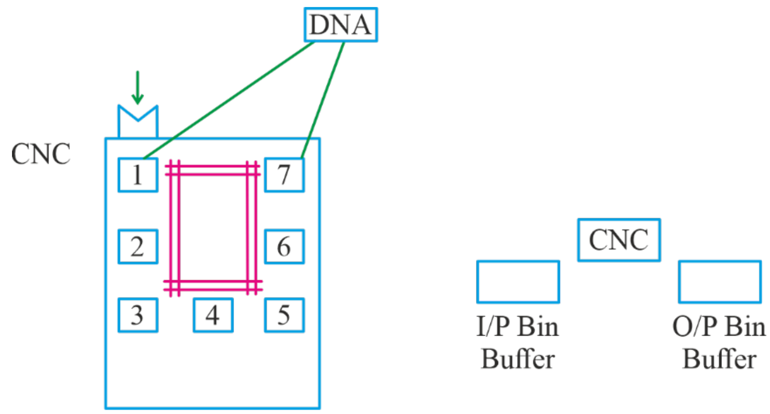


Fig. 7.9

All the NC/CNC are connected with the help of track & AGV is moves over the track. Track is segmented for purpose of Collison control. Each & every CNC will have i/p & o/p Bins & these bins have fixed no. of stations. Robot is working on each & every machine & as per Part entry control strategy robot will pick up raw material from i/p bin & placed it on machining centre. After machining the same robot will pick up semi-finished product & place it in the o/p bin. AGV will pick up the semi finish product from o/p bin of any CNC & placed it in input bin of anyone CNC as per routing.

In CNC program is developed by taking cutter centre as the reference but in machining no. of tools will be used having different diam. & diff. lengths. It is the cutter compensation that Co-ordinates this variation in the program. To minimize the processing time if FMs in number of products are grouped together according to the similarity in design & manufacturing. When this group is presented to FMs unit it decreases the process time because tool changing time will decrease & also lesser time will be consumed in cutter compensation. No. of machines involved in processing of particular group is caused a 'Cell'. Outcome of group technology is cellular manufacturing a cell can be a single CNC or group of CNC's or the entire FMs unit can be cell.

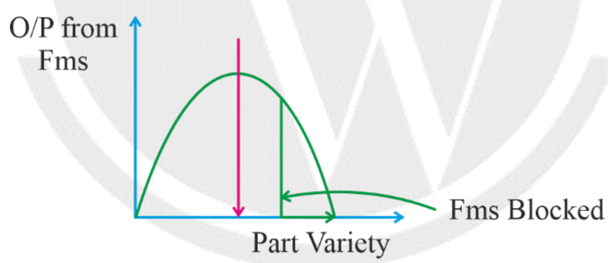


Fig. 7.10

By increasing the part variety output of FMs system also increases but any FMs system can handle maximum part variety. When the part variety exceed beyond some value blocking will start DNC system should be so sensitive to recognize the blocking in beginning otherwise entire FMs system will be blocked.

7.11 NC/CNC

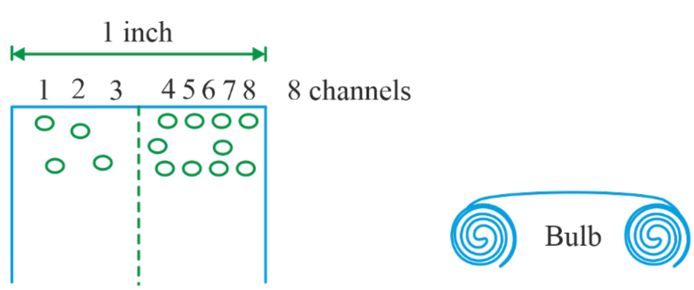


Fig. 7.11

In CNC machine program is street in hard disk & if there is any change in the design it can be add it & use in NC machine program is stored in the Punched Tape & magnetic cassette. If there is a change in a design a separate tape needs to be prepared tape is made out of paper called myler or myler couted plastic. There are 8 channels in the tape & program is punched in binary format below the tape there is bulb & above the tape is a photodiode for each channel.

So, when there is the hole as per the program, through that hole light came out & when the light falls a photodiode signal will be generated.

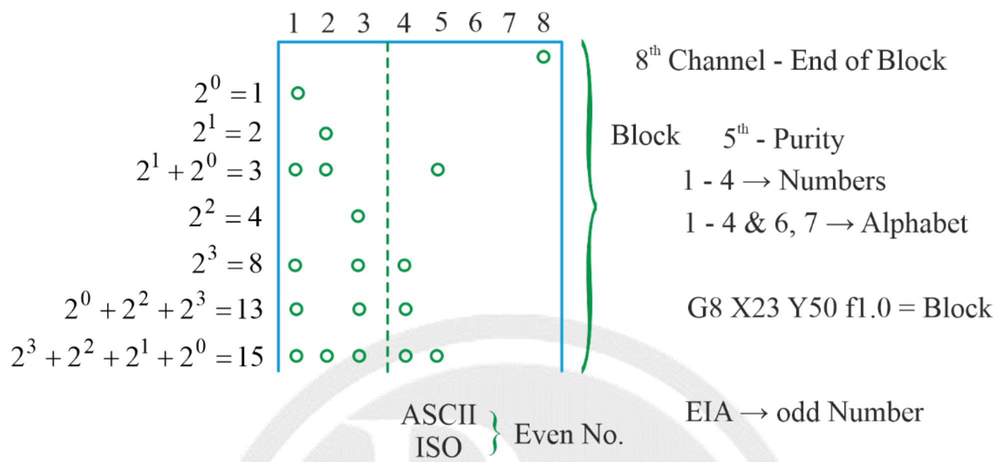


Fig. 7.12

Each line of program corresponds to one block i.e. one piece of information that has to be executed by the machine. But in case of tape it requires multiple rolls to punch the program so 8th channel in tape is reserve for end of block. Program on tape is punch in the binary format.

While punching the program we may experience & difficulties

(i) Removed material may come back & closes the hole,

(ii) Operator, by accident may touch the tape with only hands making it transparent.

(iii) By the repeated use sometime crack may develop bet the two consecutive holes because of these three things a wrong signal may be communicated with the

To take care of this problem there is parity & as per EIA parity is off add number of holes. As per the program if there are even no. of holes in any line we punch additional hole in 5th channel to make the number odd. Before executing the program, tape runs very fest in controller to check this parity & this is called tape proving.

EIA – Electronic Industry Ass.

ASCII – American society code for Info. Interchange

ISO – International organization of standardization.

7.12 Types of Loop System

7.12.1 Close loop system: (Heavy Machine)

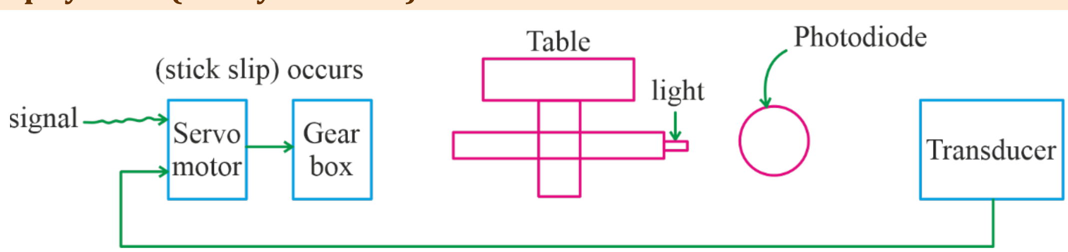


Fig. 7.13

7.12.2 Open loop system: (Small, Medium)

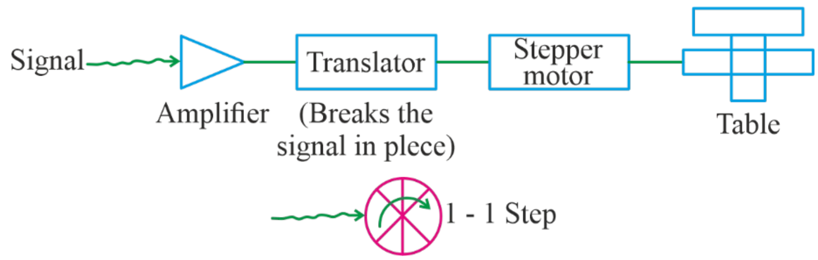


Fig. 7.14

Closed loop System

In this system, control is used transducer which acts as a feedback device. It records the moment of lead screw & if there is any difference bet input & output then electrical drive coil adjust it. This difference may be due to stic slip or backlash.

Open loop System:

This system is used in small & medium capacity machine once the signal is amplified the translator breaks the signal into many pukes. There is small & stepper motor & when 1 pulse received by motor it advanced by 1-slot. There is no stick-slip so feedback is not required.

n_s = no. of slots on stepper

$$\text{Step angle } (\propto) = \frac{360}{n_s}$$

P = No. of pulses received by motor

f_P = freq. of pulses by translator.

t = time

$$P = f_P \times t$$

degrees stepper will move

$= P \bullet \propto$

Degrees $= f_P \bullet t \bullet \propto$

$$\text{RPM of stepper } = \left(\frac{f_p \times \frac{360}{n_s}}{360} \right) \times t \times \frac{60}{t} RPm$$

$$\text{RPM of stepper} = \frac{60 f_P}{n_s}$$

Linear speed of table = rpm × pitch

$$= \text{RPM} \times \text{Pitch}$$

$$= \frac{rev}{min} \times \frac{mm}{rev} = \frac{mm}{min}$$

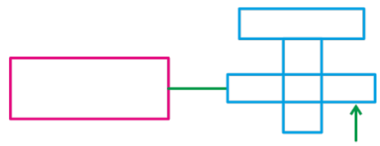


Fig. 7.15

Table resolution (Basic length unit (BLU)

BLU is minimum table movement that can be given to the machine. Corresponding to one pulse received by the motor the minimum advancement of table is called table resolution.

7.13 Interpolation

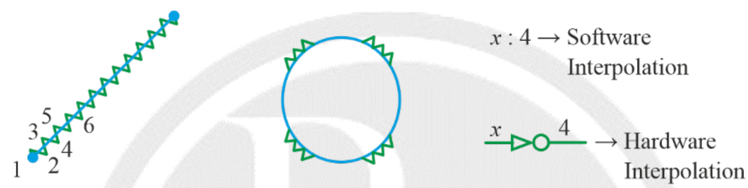


Fig. 7.16

7.13.1 Point to point system:

Interpolation means control of feeds. In PTP system the large number of points are defined around a geometer by either moving x or y variable & the tool moves from one point to another point. Incremental steps are so small that during machining we will not even recognize. When values of these x, y co-ordinates are presented in the form of table & store in the program it is called software interpolation. But where a logic gate relates the value of x & y it is called hardware interpolation. PTP system unnecessarily increases the length of the program. Even today we used PTP system but only in positioning. In PTP system tool moves between path & maximum available speed on the controller.

7.13.2 Linear Interpolation (L – system)

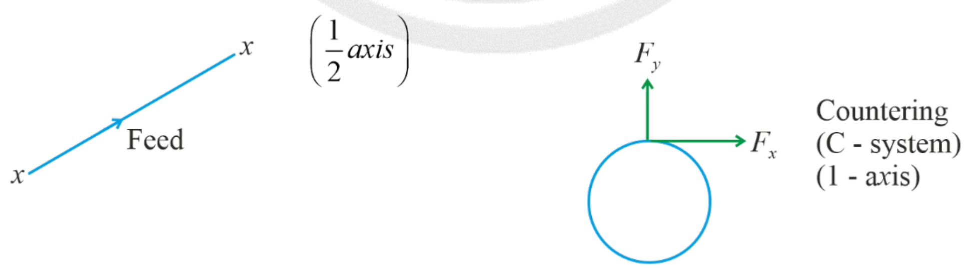


Fig. 7.17

If the machine is having capacity to control feed in 1-direction it is called linear interpolation. L system. When the machine capable to control bi-axial feed in plane it is called countering or C system.

Drill m/c $\rightarrow \frac{1}{2}$axis

Lathe m/c $\rightarrow 1\frac{1}{2}$axis

Milling m/c $\rightarrow 2\frac{1}{2}$axis

In drilling m/c feed can be controlled only in vertical direction so it is half axis machine. In lathe machine, by simultaneous moment of carriage & cross slide one contour can be cut into horizontal plane. Simultaneously, feed can be given by the tail stock. So, it is $1\frac{1}{2}$ axis machine. In case of milling machine contour can be cut in the horizontal & Vertical plane & simultaneous one feed can be given in the vertical direction so it is $2\frac{1}{2}$ axis machine. Higher axis machine can do all the functions of lower axis machine. At present even 12-axis m/c are also available.

7.14 Machining Centre

Any CNC machine having certain facilities is called a machining centre.

(1) Automatic tool changer (ATC)

(2) Automatic Pallet Changer (APC) [pallet-additional table]

(3) Tool transfer in ATC from tool magazine.

(4) Machining centre should be at least $2\frac{1}{2}$ axis .

Horizontal Machining Centre → 20 Tools
→ Movement to tool

Vertical M.C. → 40 Tools
→ Movement to tool

7.15 Part Programming

G – Code
M – Code

7.15.1 G – Code:

G00 – PTP positioning.

G01 – Linear Interpolation.

G02 – CW Circular

G03 – CCW Circular

G04 – Dwell (sharp corner, spot facing etc.)

G 90 – Absolute Programming

G 91 – Incremental Programming.

G 92 – Absolute Preset. (at first line program) as showing this where you are.

In absolute program position of origin doesn’t change in Incremental programming lost machining spot becomes the origin for next matching spot.

Absolute preset is a declaration statement and it tells the machine that at which co-ordinate machine is present in the beginning of executing any program. G 92 will always appear in the first line of program.

G17 – XY

G 18 – XZ

G 19 – YZ

Canned Cycle:

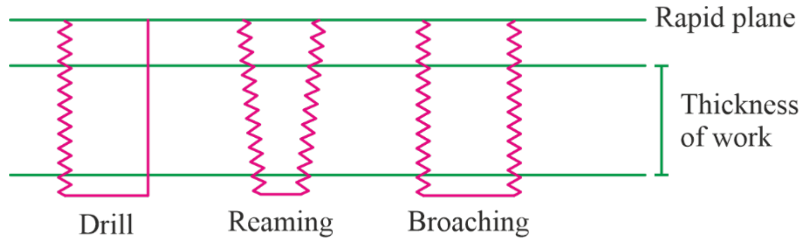


Fig. 7.18

G 81 – Drill

G 85 – Reaming

G 82 – Counter boring

G 86 – Cancel Cannel cycle.

Canned Cycles are like sub routines where sequence of events is represented by a single code. The moment canned cycle is activated. Wherever the tool is from their it will come to rapid plane with the maximum possible speed available on the controller. Feed will start from the rapid plane & after machining tool will come back to rapid plane & wait for the next instructions before executing any other command Canned Cycle needs to be cancel.

7.15.2 M Codes:

M00, M01 } Optional stops (Inspection)

M02 Last line stop

M02 – Will appear in the last line of program after reading M02 program will be completely terminate.

M00, M01 – are called optional stops & are meant for inspection. If M 00 present in any block, after executing that black m/c will stop. There will be a switch on the controller. When it is present m/c will start executing the instruction from next line on wards.

There will be another switch over controller when it is on only then m/c will stop after reading M 01 otherwise machine will ignore the instruction.

M03 – spindle on CW

M04 – spindle on CCW

M05 – spindle OFF

M06 – Tool change

M07 – Coolant No.1 ON

M08 – Coolant No. 2 ON

M09 – Coolant OFF.

Ex.

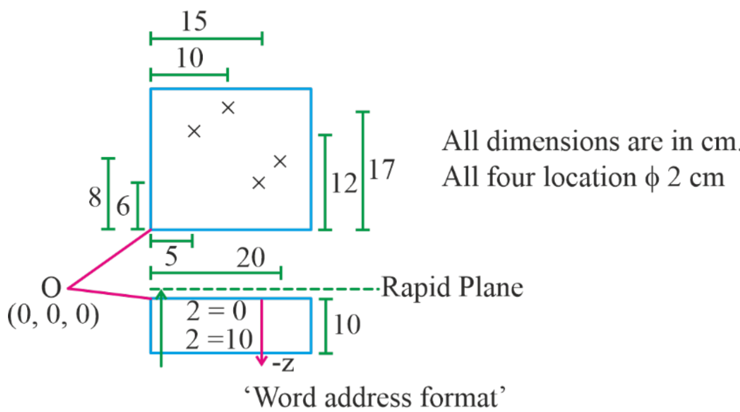


Fig. 7.19

N01	G92	X0	Y0	Z0					
N02	G90	G81	X50	Y120	Z13	R2	M03	M07	S400 F10
N03	X100	Y170							
N04	X150	Y60							
N05	X200	Y80							
N06	G80	G00	X0	Y0	Z100	M05	M09		
N07	M02								

7.16 APT (Automatic Program Tool)

Fig. 7.20

- Geometry Commands
- Auxiliary Statements
- Motion Command

Point:

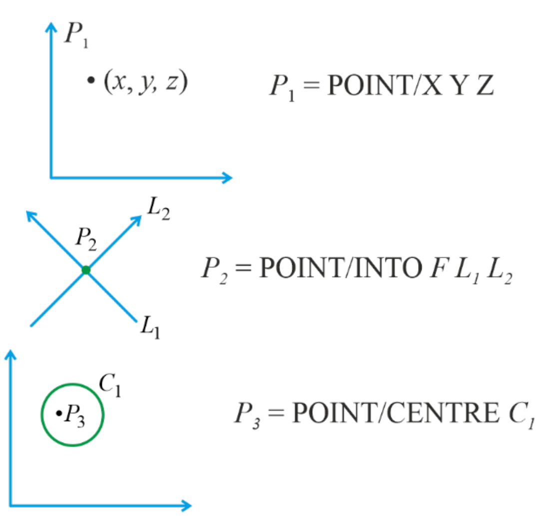
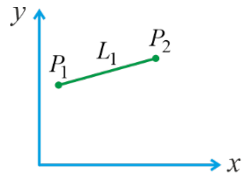
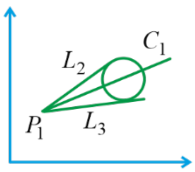


Fig. 7.21

Line:

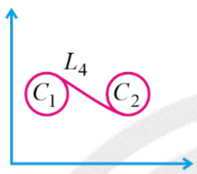


L_1 = LINE/P_1, P_2

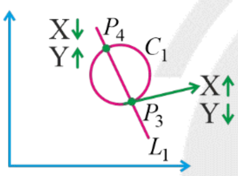


L_2 = LINE/P_1 LFT TAN TO C_1

L_3 = LINE/P_1 RGT TAN TO C_1



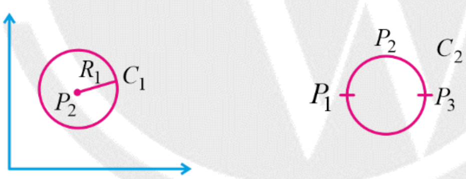
L_4 = LINE/LFT TAN TO C_1
RGT TAN TO C_2



P_3 = POINT/X LARGE Y SMALL IN TOF L_1 C_1

P_4 = POINT/X SMALL Y LARGE IN TOF L_1 C_1

Circle:



C_1 = CIRCLE/CENTRE P_1 RADIUS R

C_2 = CIRCLE/P_1 $P_2 P_3$

Fig. 7.22

Plane:

$ax + by + cz + d = 0$

P_1 = PLANE/$a\ b\ c\ d$

P_2 = PLANE/ P_1 P_2 P_3

Auxiliary Statements

Spindle	SPINDL / ON 500 RPM CCWD
Coolant	COLANT / ON
Feed rate	FEDRAT / 2.0 MMPR

Auxiliary Statements

FROM / $P_1 \rightarrow$ G92

GOTO / $P_2 \rightarrow$ Absolute Prog.

GO DLTA/$P_6 \rightarrow$ Incremental

M02 $\rightarrow$ FINI

GO RGT

GO LFT

GO UP

GO DWN

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8 MACHINE TOOL

8.1 Lathe Machine

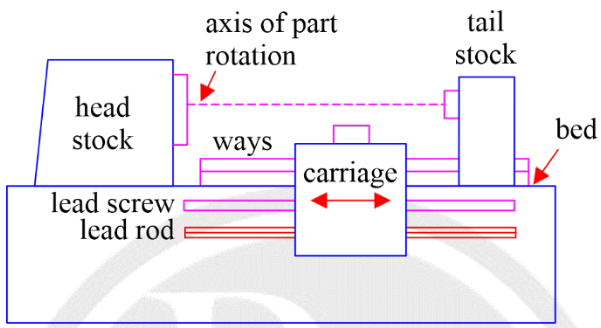


Fig. 8.1 Lathe Machine

- Number of Spindle Speed

  Number of spindle speed is in a **geometric progression.**

  $N_1, N_1r, N_1r^2, N_1r^3, ...N_1r^{n-1}$

  $N_1 = N_{min} \quad and \quad N_1r^{n-1} = N_{max}$

  Therefore, **Step Ratio** $(r) = \left(\frac{N_{max}}{N_{min}}\right)^{\frac{1}{n-1}}$

Where,

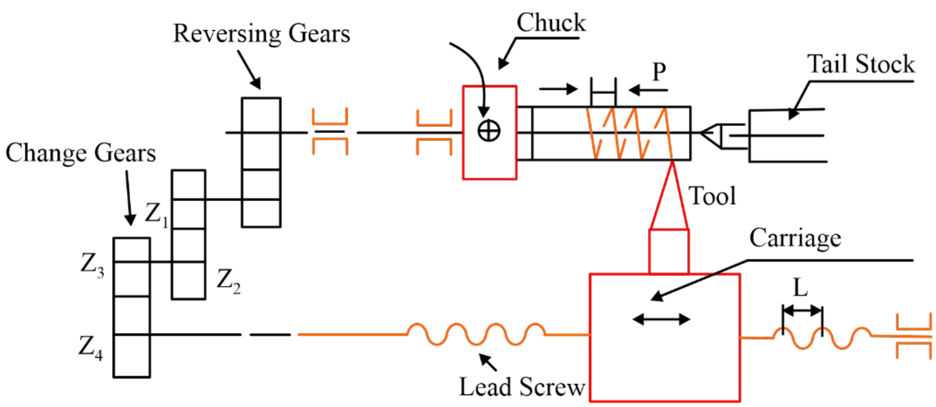
n = number of spindle speed

N_1 = minimum speed

N_2 = maximum speed

8.2 Threading

Threading - The cutting tool is moved quickly cutting threads.



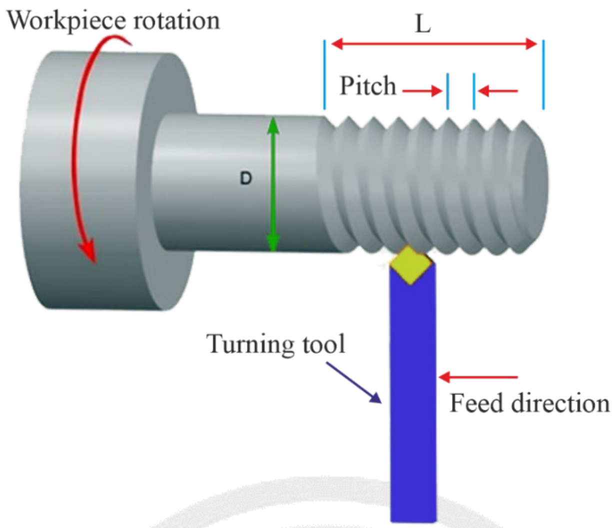


Fig. 8.2 Thread Cutting

In one revolution of the spindle, carriage must travel the pitch of the screw thread to be cut.

$N_s P z_s = N_L L z_L$

P = Pitch of the screw thread to be cut

L = Pitch of the lead screw

z_s = Number of start of the screw thread to be cut

z_L = Number of start of the lead screw

i_{cg} = gear ratio of spindle (N_s) to carriage (N_L) gear train

8.3 Turning

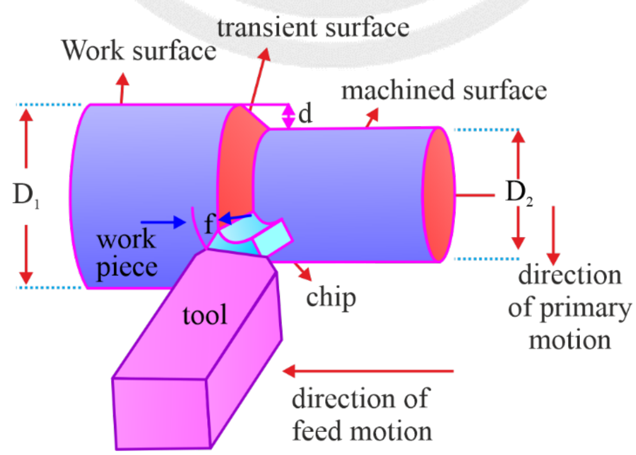


Fig. 8.3 Turning process

Formula for Turning

- Depth of cut, $d = \dfrac{D_1 - D_2}{2}$ mm

- Average diameter of workpiece $D_{avg} = \frac{D_1 + D_2}{2}$ mm
- Cutting Time, $= \frac{L + A + O}{fN}$
- Cutting Speed, $V = \frac{\pi D_1 N}{1000}$, m / min

8.3.1 Facing

Facing is the process of removing metal from the end of a workpiece to produce a flat surface. Most often, the workpiece is cylindrical

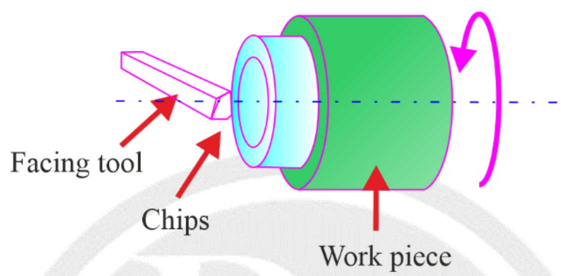


Fig. 8.4 Facing operation

8.3.2 Turning Tapers on Lathes

(a) Using a compound slide,

(b) Using form tools,

(c) Offsetting the tailstock, and

(d) Using taper turning attachment.

Note:

- Compound slide can be employed for turning short internal and external tapers with a large angle of (steep) taper.
- Form tool method is useful for short external tapers

8.3.3 Compound Slide formula

- The angle is determined by $\tan\alpha = \frac{D-d}{2l}$

$\alpha = Half\ taper\ angle$

$D = Diameter\ of\ stock$

$d = smaller\ diameter$

$l = length\ of\ the\ taper$

8.3.4 Offsetting the tailstock formula

- Tailstock offset (h) can be determined by

$$h = \frac{L(D-d)}{2l} \text{ or } h = L\tan\alpha$$

8.4 Drill

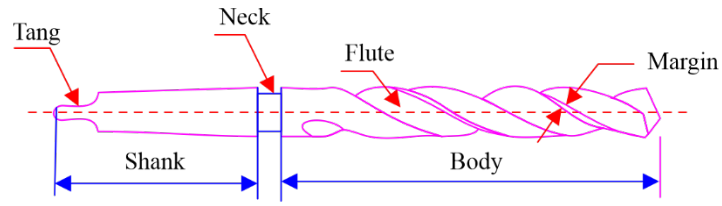


Fig. 8.5 Drill

Note:
- The helical flute in a twist drill provides the necessary Rake angle for the cutting edge and Space for the chip to come out during drilling.
- The rake angle in a twist drill varies from minimum near the dead centre to a maximum value at the periphery.

Cutting Speed (V) in Drilling

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

$$V = \frac{\pi DN}{1000} \text{ m/min}$$

Machining time (T) = $\frac{L}{fN} m/min$

$$MRR = \pi D^2 fN / 4$$

Where

D = Diameter of drill(mm)
N = RPM of drill
f = feed(mm/rev)
MRR = Material removal rate
$L = L_1 + L_2 + L_3 + L_4$
L_1 = Depth of hole
L_2 = Approach length
L_3 = Length of tip
L_4 = Over Travel

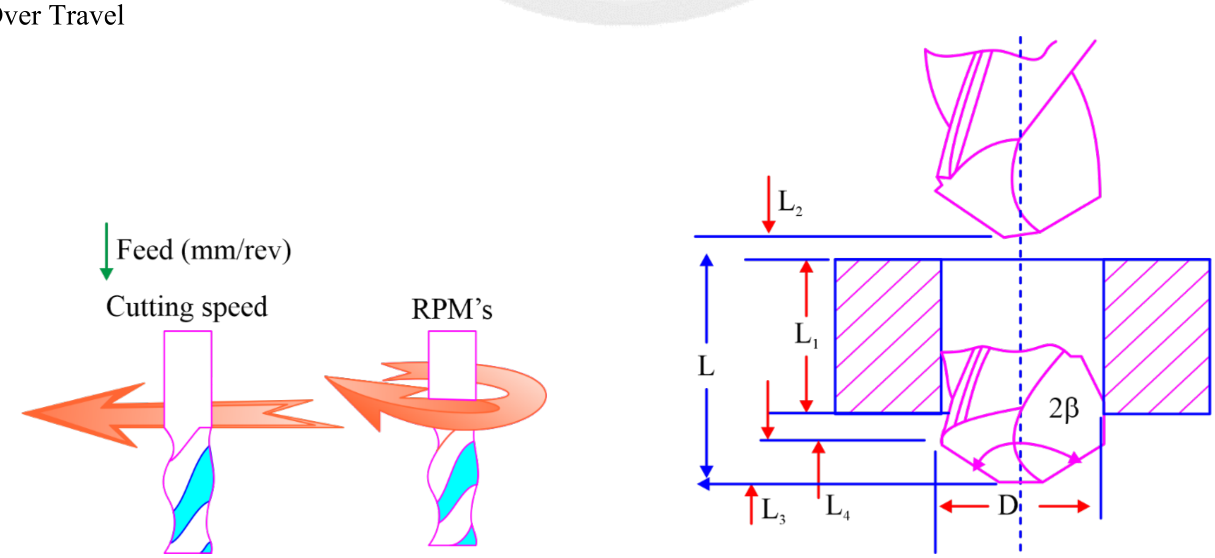


Fig. 8.6 Drilling process

8.5 Milling

Milling is a process performed with a machine in which the cutters rotate to remove the material from the work piece present in the direction of the angle with the tool axis. With the help of the milling machines one can perform many operations and functions starting from small objects to large ones.

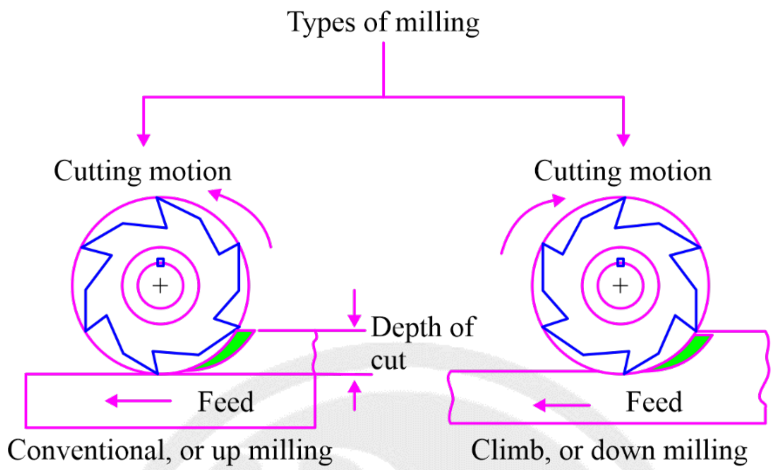


Fig. 8.7 Milling process

Speed of table (mm/min):

feed per tooth = f_z (mm/tooth)

Number of teeth = Z

$$\text{Feed} = f_z Z \frac{\text{-mm}}{\text{tooth}}$$

Speed of table(f) = Feed*N

Milling Velocity (V)

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

Milling Time (T)

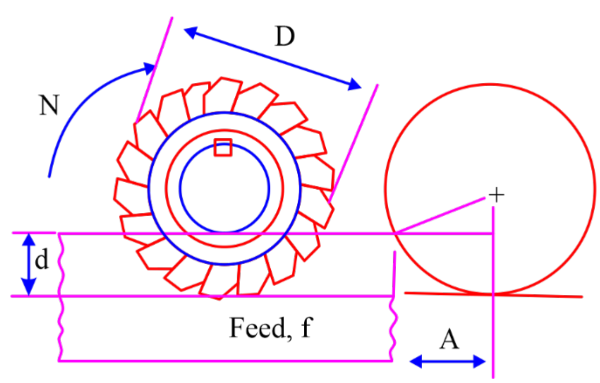


Fig. 8.8

- Time for one pass $= \dfrac{L + 2 \times A}{f_z ZN}$ min
- Approach distance $= A = \sqrt{\left(\dfrac{D}{2}\right)^2 - \left(\dfrac{D}{2} - d\right)^2} = \sqrt{d(D-d)}$

$$f = f_z ZN$$

$$f_z = \frac{f}{ZN}$$

Maximum uncut chip thickness $= \dfrac{2f}{ZN}\sqrt{\dfrac{d}{D}}$

Average uncut chip thickness $= \dfrac{f}{ZN}\sqrt{\dfrac{d}{D}}$

Material removal rate (MRR) in Milling

$MRR = w \times d \times F$

where, w = width of cut, d = depth of cut F = Feed of the table

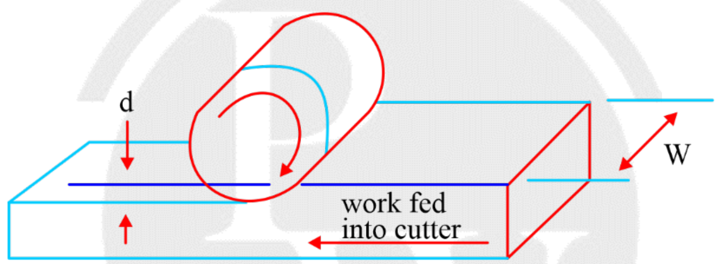


Fig. 8.9

8.6 Grinding

Grinding is an abrasive machining process that uses a grinding wheel or grinder as the cutting tool. Grinding is a subset of cutting, as grinding is a true metal-cutting process

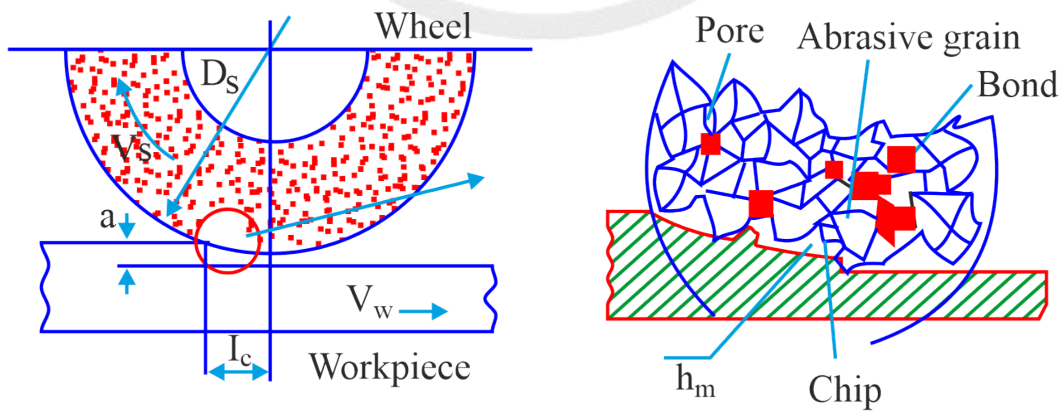


Fig. 8.10 Grinding process

Note:
- Among the conventional machining processes, maximum specific energy is consumed in Grinding
- It is desired to offset the adverse effect of very high negative rake angle of the working grit, to reduce the force per grit as well as the overall grinding force.

(a) G Ratio

The grinding ratio or G ratio is defined as the cubic mm of stock removed divided by the cubic mm of wheel lost.

(b) Parameters for specify a grinding wheel

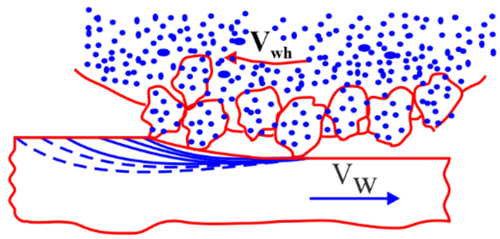


Fig. 8.11

(i) The type of grit material

(ii) The grit sizes

(iii) The bond strength of the wheel, commonly known as wheel hardness

(iv) The structure of the wheel denoting the porosity i.e. the amount of inter grit spacing

(v) The type of bond material

(vi) Other than these parameters, the wheel manufacturer may add their own identification code prefixing or suffixing (or both) the standard code.

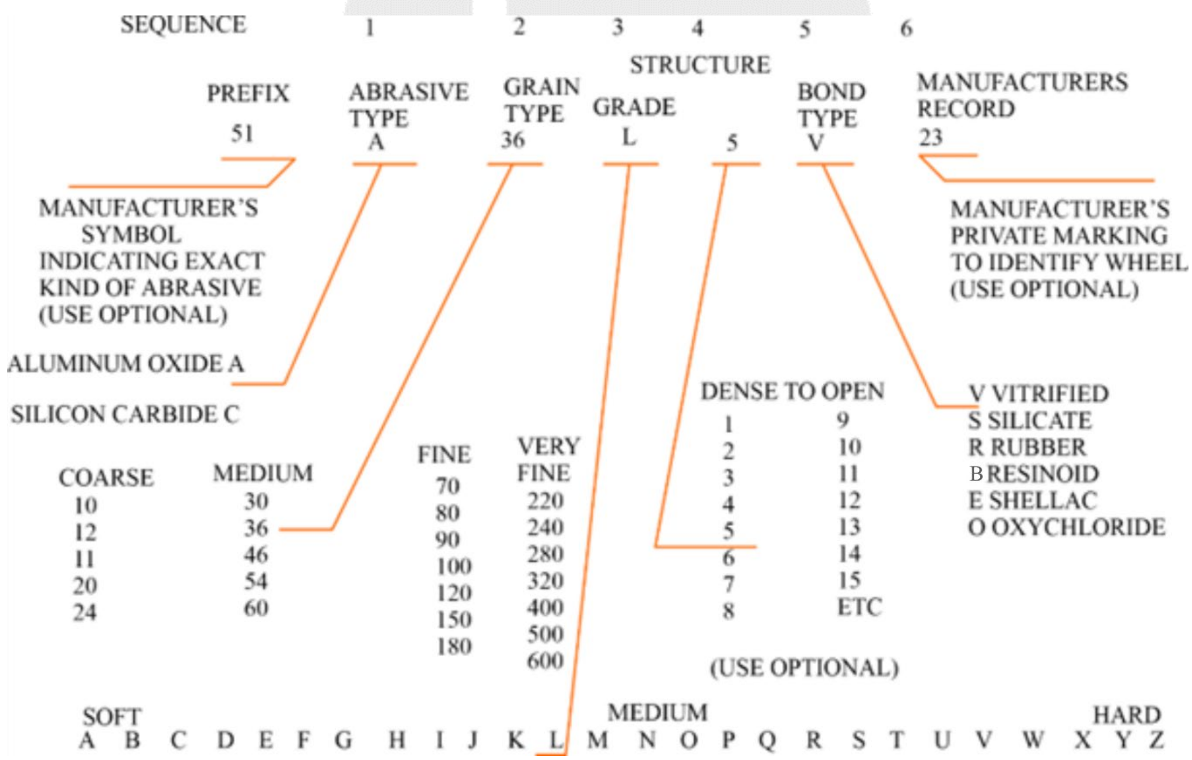


Table 8.1

(c) Creep feed grinding

This machine enables single pass grinding of a surface with a: larger down feed but slower table speed.

8.7 Lapping

- Lapping is basically an abrasive process in which loose abrasives function as cutting points finding momentary support from the laps.

8.8 Honing

- Honing is a finishing process, in which a tool called hone carries out a combined rotary and reciprocating motion while the workpiece does not perform any working motion.

8.9 Buffing

- Buffing is a polishing operation in which the workpiece is brought into contact with a revolving cloth wheel that has been charged with a fine abrasive, such as polishing rough.

Note:
Negligible amount of material is removed in buffing while a very high lustre is generated on the buffed surface.

8.10 Shaper

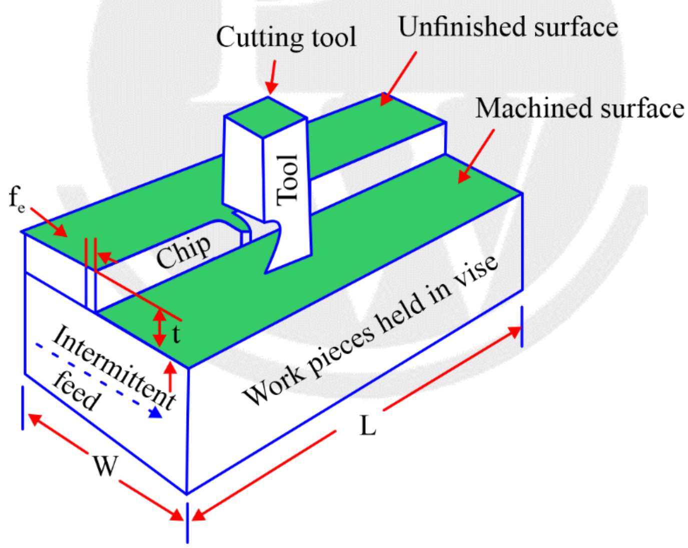


Fig. 8.12 Shaping process

Shaper Machine is a production machine in which the single point cutting tools are attached and the workpiece is fixed and while moving forward the tool cuts the workpiece and in return, there is no cut on the workpiece and used for producing flat and angular surfaces.

Formula

Cutting speed, $V = \dfrac{NL(1+m)}{1000}$

Number of strokes, $N_s = \dfrac{w}{f}$

Time of one stroke, $t = \frac{L(1+m)}{1000V}$ min

Total time, $T = \frac{L(1+m)}{1000v} N_s = \frac{Lw(1+m)}{1000vf}$ min

8.11 Planer

Planning can be used to produce horizontal, vertical, or inclined flat surfaces on workpieces that are too large to be accommodated on shapers.

8.12 Slotter

Slotting machine is basically a vertical axis shaper. Thus, the workpieces, which cannot be conveniently held in shaper, can be machined in a slotter.

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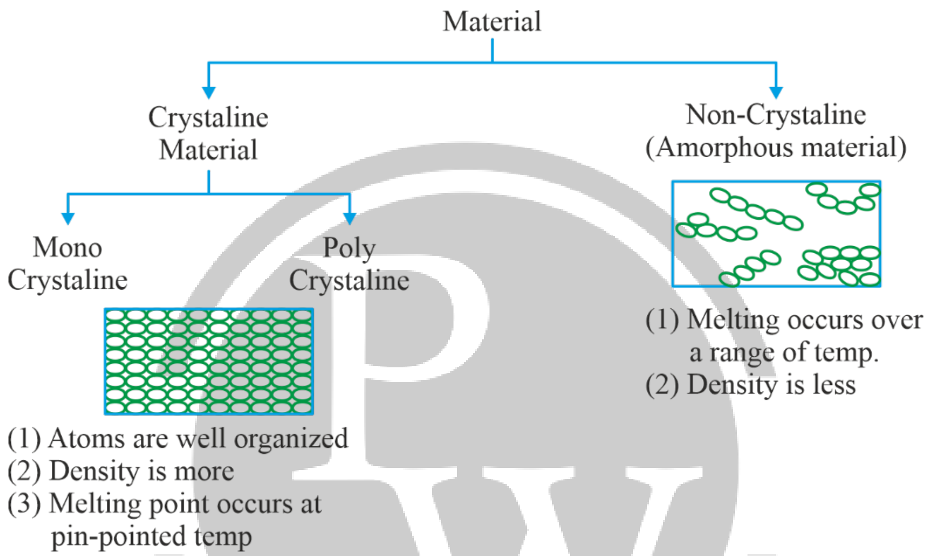
9 MATERIAL SCIENCE

9.1 Crystallography



Important terms:

(a) Unit Cell

A unit cell is defined as the smallest respresentative group of atoms which when repeated in all the crystallography direction for infinity no. of times result in the development of the crystal lattice.

(b) Crystal Lattice

It is a 3D-network of line in space also called as infinity lattice.

(c) Space Latice

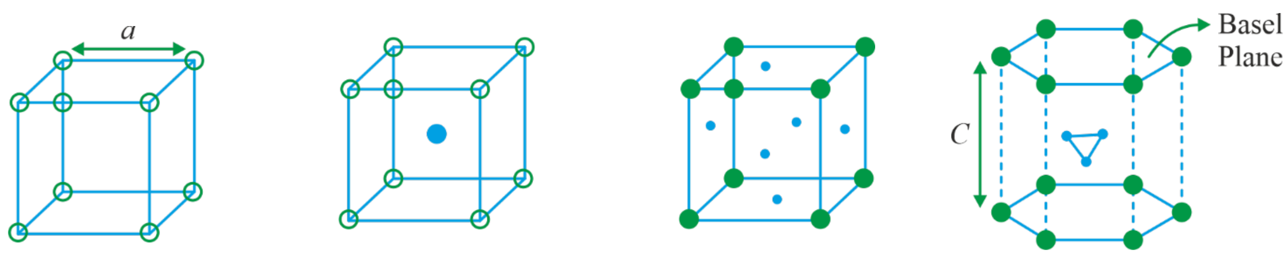
It is a 3-D network of point in space also called at point Latice.

(d) Puimitive Cell

It is smple cubic cell having atoms only at its corners. It is used to define other cubic cell.

(e) Allotropy

The tendency of any material exists in different structure at different temperature and press in known as allotropy of material.



(SSC)	(BCC)	(FCC)	(HCP)
$\text{vol}^w = a^3$	$\text{vol}^w = a^3$	$\text{vol}^w = a^3$	$\text{vol}^w = \frac{3}{2}\sqrt{3}$
$r = \frac{a}{2}$	$r = \frac{\sqrt{3}\,a}{4}$	$r = \frac{\sqrt{2}\,a}{4}$	$r = \frac{a}{2}$
	Ex-Vanadium molybdenum tungsten chromium Iron (910°-1400°C) except	Ex-copper, Al, Pb, Ag, gold, Ni etc	$\frac{C}{a} = 1.63$

Fig. 9.1 Unit Cell

9.2 Crystal System

"7 crystal system which are explained in 14 brains lattice".

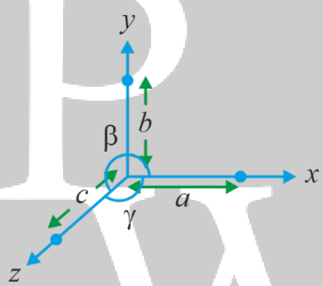


Fig. 9.2 Unit cell angles and length

a, b, c → Interstitial Length

α, β, γ → Interstitial Angle.

	Crystal System	Unit Cell	Nature of Unit Cell
1	Simple cube	SSC, BCC, FCC	$\alpha = \beta = \gamma = 90°$ $a = b = c$
2	Tetragonal	SCC, BCC	$\alpha = \beta = \gamma = 90°$ $a = b \neq c$
3	Ortho-rhombic	SCC, BCC, FCC, HCP	$\alpha = \beta = \gamma = 90°$ $a \neq b \neq c$
4	Monoclinic	SC, BCC	$\alpha = \beta = 90° \neq \gamma$ $a \neq b \neq c$
5	Tri Clinic	SC	$\alpha \neq \beta \neq \gamma \neq 90°$ $a \neq b \neq c$
6.	Rhombohedral (Trigonal)	SC	$\alpha = \beta = \gamma \neq 90°$ $a = b = c$
7	Hexagonal	SC	$\alpha = \beta = 90°,\ \gamma = 120°$ $a = b \neq c$

Table 9.1 Different types of crystal system

9.2.1 No. of Average atoms in a unit cell (N_{avg})

"The no. of atoms originally belonging to unit cell."

$$N_{avg.} = \frac{N_c}{8} + \frac{N_f}{2} + \frac{N_i}{1} \quad \textbf{(Cubic Cell)}$$

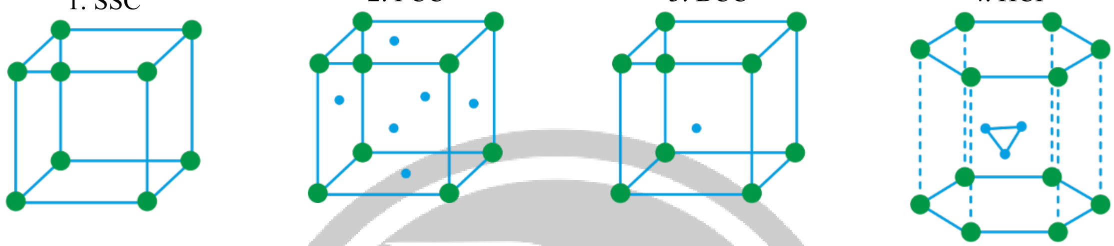
$$N_{avg.} = \frac{N_c}{6} + \frac{N_f}{2} + \frac{N_i}{1} \quad \textbf{(Hexagonal Packing)}$$

$N_C \rightarrow$ No. of atoms at corner.

$N_f \rightarrow$ No. of atoms at face centre

$N_i \rightarrow$ No. of atoms at body centre.

1. SSC 2. FCC 3. BCC 4. HCP



1. SSC: $N_{avg} = \frac{8}{8} = 1$, $N_{avg} = 1$

2. FCC: $N_{avg} = \frac{8}{8} + \frac{6}{2} + \frac{O}{1}$, $N_{avg} = 1 + 3 = 4$

3. BCC: $N_{avg} = \frac{8}{8} + \frac{0}{2} + \frac{1}{1}$, $N_{avg} = 2$

4. HCP: $N_{avg} = \frac{12}{6} + \frac{2}{2} + \frac{3}{1}$, $N_{avg} = \frac{12}{6} + \frac{2}{2} + \frac{3}{1}$, $N_{avg} = 6$

Fig. 9.3 Cubic Cell

9.2.2 Co-ordination No.

"It is defined as no. of nearest and equidistance atoms. surrounded considered atoms".

SCC-6, BCC-8

FCC-12, HCP-12

9.2.3 Atomic Packing factor:

"It is the ratio of volume occupied by avg. No. of atoms to volume of unit cell". "APF is index of density".

S. No.	Properties	SCC	BCC	FCC	HCP
1.	Volume	a^3	a^3	a^3	$\frac{3\sqrt{3}}{2}a^2$
2.	Avg. No. of Atoms	1	2	4	6
3.	Co-ordination No.	6	8	12	12
4.	APF	0.52	0.68	0.74	0.74
5.	Atomic radius	$r = \frac{a}{2}$	$r = \frac{\sqrt{3}}{4}a$	$r = \frac{\sqrt{2}}{4}a$	$r = \frac{a}{2}$

Table 9.2

The tendency of any element to exist in different structure at different pressure and temperature is known as **Allotropy**. In case of most of metals this tendency is thermodynamically reversible. This type of reversible transformation is also called as **polymorphism**.

Allotropic transformation is associated with change in volume and density.

(1) % change in density (BCC-FCC)

$$= \frac{APF_{BCC} - APF_{FCC}}{APF_{BCC}} \times 100$$

$$= \frac{0.68 - 0.74}{0.68} \times 100$$

$$= -8.82\%$$

(2) % change in volume

$$= \frac{2V_{BCC} - V_{FCC}}{2V_{BCC}} \times 100$$

$$= \frac{2 \times a_{BCC}^3 - a_{PCC}^3}{2 \times a_{BCC}^3} \times 100 = \frac{2 \times 2.3^3 - 2.8^3}{2 \times 2.3^3} \times 100$$

$$= 8.14\%$$

9.3 Crystal Plane (Miller Indices)

Miller Indices of a plane is defined as reciprocal of intercepts and written in a bracket without a separating, between them. It is smallest integers.

Steps follows for miller indices:

Step-I $\rightarrow$ Determine Intercepts

Step-II $\rightarrow$ Separate multiplies

Step-III $\rightarrow$ Take reciprocal of multipliers

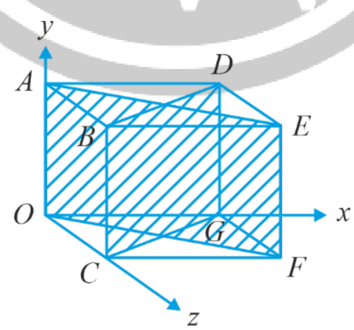
Step-IV $\rightarrow$ Convert it into smallest integer.

Note:

- If miller indices are negative then it is given be bar $(-1, \bar{1})$
- If the plane is passing through origin then, we have to shift the origin.

Plane BEFC (001)

	X	Y	Z
1. Intercepts	∞	∞	I
2. Multiplier	∞	∞	1
3. Reciprocal	$\frac{1}{\infty}$	$\frac{1}{\infty}$	$\frac{1}{1}$
4. Miller	0	0	1

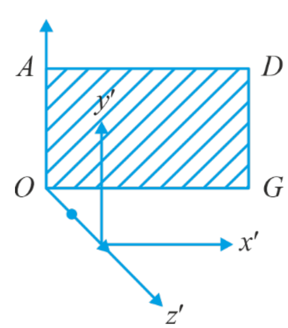


Plane ADGO (001)

x	y	z
∞	∞	-1
$\frac{1}{\infty}$	$\frac{1}{\infty}$	$\frac{-1}{1}$
0	0	$\bar{1}$

Plane BDGC (101)

x	y	z
1	∞	1
$\frac{1}{1}$	$\frac{1}{\infty}$	$\frac{1}{1}$
1	0	1



Plane ADEB (010)

x	y	z
∞	1	∞
$\frac{1}{\infty}$	$\frac{1}{1}$	$\frac{1}{\infty}$
0	1	0

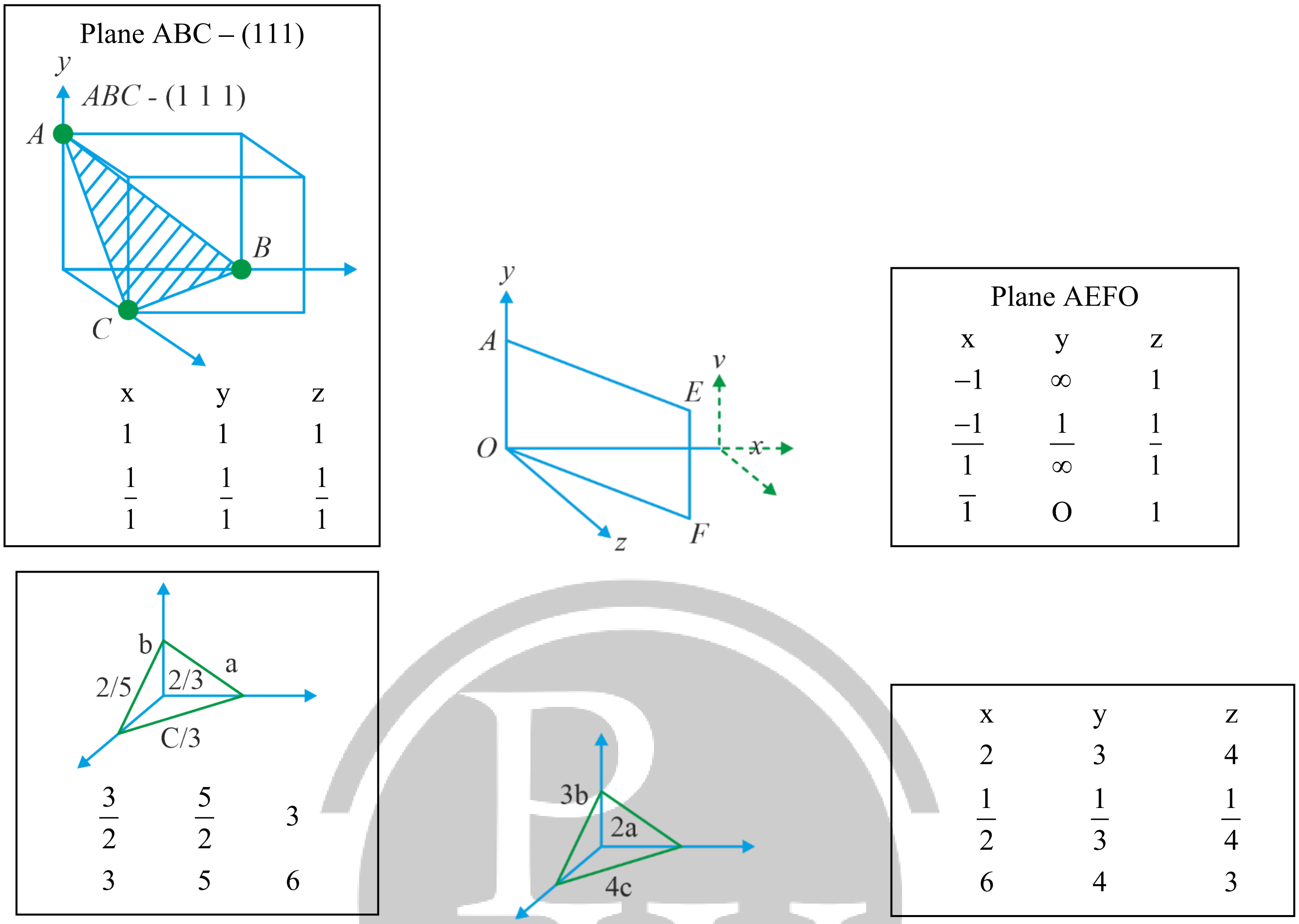


Fig. 9.4 Crystal Plane (Miller Indices)

- Parallel plane will have same Miller Indices Quantitively.
- Only arithmatic sing of non-zero indices will be different.

Interplanar Distance $= \dfrac{a}{\sqrt{h^2 + k^2 + l^2}}$ for miller indices (h, k, l)

Two Plane are inclined:

$(h_1 \;\; k_1 \;\; \ell_1)\;(h_2 \;\; k_2 \;\; \ell_2)$

$$\cos\theta = \frac{h_1h_2 + k_1k_2 + \ell_1\ell_2}{\sqrt{h_1^2 + k_1^2 + \ell_1^2}\cdot\sqrt{h_2^2 + k_2^2 + \ell_2^2}}$$

If two planes are parallel (θ = 90°)

$h_1h_2 + k_1k_2 + \ell_1\ell_2 = 0$

Linear density

$$\frac{\text{Number of atoms on any direction}}{\text{Length of direction}}$$

Simple cubic along $100 = \frac{1}{a}$

$$\text{FCC [110]} = \frac{2}{a\sqrt{2}}, \text{BCC [111]} = \frac{2}{a\sqrt{3}}$$

Family of Direction: $< 100 > = 6 ; < 110 > = 112 ; < 111 > = 8$

Planar Density $= \frac{\text{No. of atoms on a plane}}{\text{Area of plane}}$

$$\text{SC along (100)} = \frac{1}{a^2}, \text{FC along (100)} = \frac{2}{a^2}, \text{BC (110)} = \frac{2}{\sqrt{2}a^2}$$

9.3.1 Slip System

Combination of crystal plane & crystal direction along which dislocation will move with an ease

FCC – 12 – Ductile

BCC – 24 – Strong

HCP – 3 – Brittle [Before dislocation, cracks come out]

With increase in slip system ductility increases but in case of BCC due to less atomic packing factor avg. dist. Between atoms decrease due to which dislocations move very difficult]

∴ BCC is always strong.

9.3.2 Critically Resolved shear stress

$\tau = \sigma \cos \phi \cos\lambda$

↑

Applied stress

ϕ = angle between to slip plane & the applied stress.

λ = angle between slip & stress direction.

9.3.3 Mechanical Tests

Charpy – Toughness
Knoop – Microhardness
Spiral Test – Fluidity
Cupping Test – Formability
Jominy Test – Hardenability

$$\text{gm/atom} = \frac{\text{Atomic wt.(gm/mole)}}{\text{Avogadro's no.(atoms/mole)}}$$

9.4 Defects in Material:

Defects

- Point defect
  - Vacancies
  - Impurities
  - Interstitial
  - Frankel
  - Schottky
- Line defect
  - Edge Dislocation
  - Screw Dislocation
- Surface defect
  - Low tilt angle
  - Low twist angle
  - Twinning
  - Grain boundary
  - Stactcing fault
- Volume Defect

9.4.1 Point Defects

(a) Vacancies:

It occurs when there is an unoccupied atom site in the crysted structure.

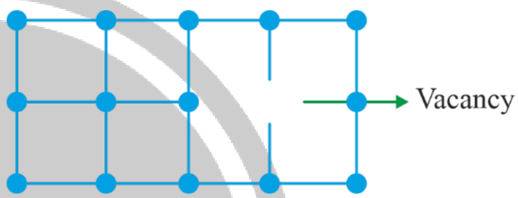


Fig. 9.5 Vacancies Defect

(b) Impurities:

When foreign atoms substitute parent atom in the crystal structure or at interstitial space known as impurities defect.

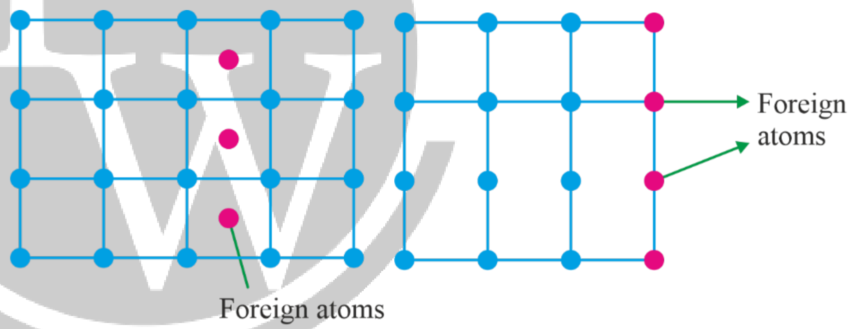


Fig. 9.6 Impurities Defect

(c) Interstitial:

A interstial defect occurs when an atom occupies a definite position in the lattice which is not normally occupied in the ideal crystal.

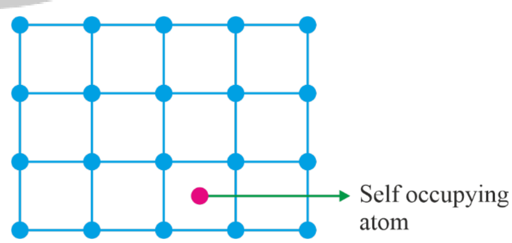


Fig. 9.7 Interstitial Defect

(d) Frankel

When an Ion displace from regular location in crystal lattice to an intertitial location in the crystal lattice. Ionic crystals have two different types of ions which are cation (+ve) and anion (-ve) cations are smaller ions which can easily displaced into the voids in Ionic solid.

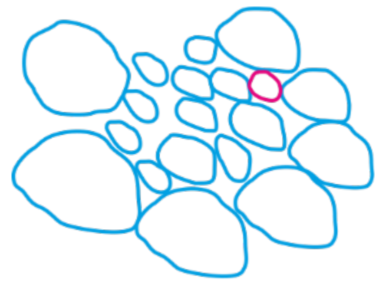


Fig. 9.8

(e) Effect of point defect:

- Strength and hardness can be in or eased due to lattice distortion.
- Electrical resistivity increases
- Phase transfmroation takes places more actively in the presence of point defect.

9.4.2 Line Defect

(a) Edge dislocation:

An edge dislocation is whre an extoal half plane of atoms is introudced midway to the crystal.

Burger Vector:

Burger vector is a vector which characterised the movement of dislocation in practice. Burger vector of ede dislocation is **perpendicular** to edge dislocation line.

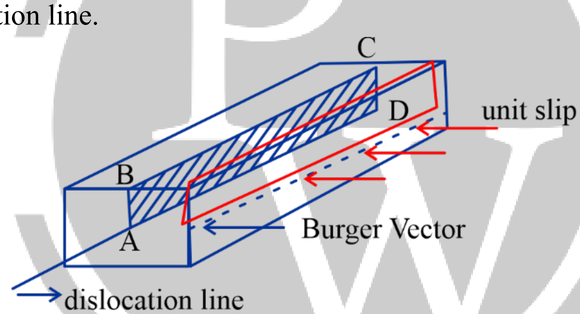
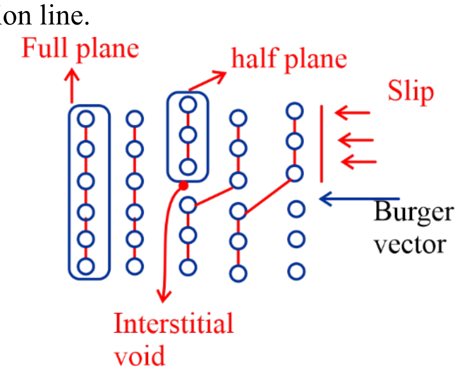


Fig. 9.9 Edge dislocation

(b) Screw dislocation:

It is formed when discreat atomic plane of truly crystaline solid into a surface of solid around dislocation this can be explained by cutting part way through a perfect crystal an then skewing the crystal 1-atom spacing.

Burger vector line **parallel** to dislocation line.



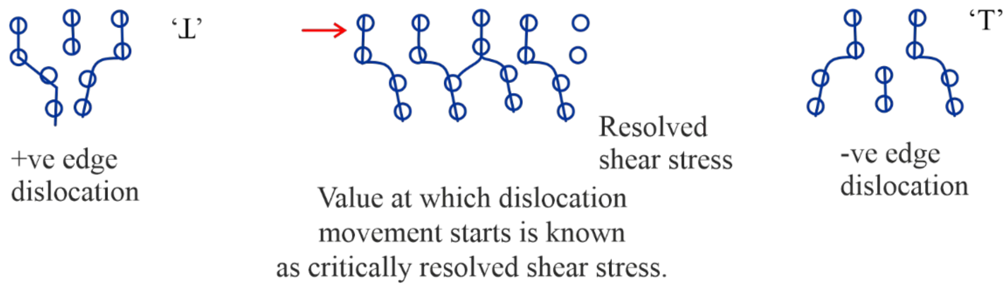


Fig. 9.10 Screw dislocation

(c) Interaction between dislocations:

When two opposite in nature edge dislocation travels towards each other on same slip plane they will attract to each other and combine to become a perfect plane.

When two in similar in nature dislocation travels towares each other on same slip plane they result in repation and due to this strength and hardness of material increases, this is known as **strength hardening**.

9.4.3 Surface Defect

(a) Low tilt angle defect

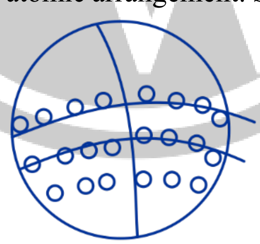
It occurs due to edge dislocaton when two or more than two number of dislocations are exsiting in boundry **one above to another** is results in lattic distortion.

(b) Low twist angle

It occurs due to screw dislocation. When two or more than two number of dislocation one above to other in boundary it results in distortion.

(c) Twinning

Twin boundry is a plane occurs which there is a special minor image disorientation of crystal structure. During anneling process a part of lattice may slipped wrt other of atomic arrangement. Slip part may become mirror image to unslipped part.



Mirror image of grain orientation

Fig. 9.11 Twinning

(d) Grain boundry

Dendride is randomly growing on solid faces. The function between two dendroid randomly is known as grain boundry.Characteristics:Region (High energy, Low melting point, heavy impurity concentrator)

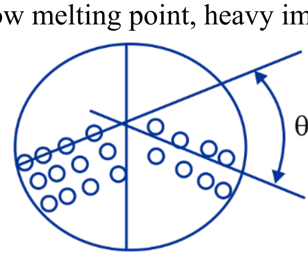


Fig. 9.12 Grain boundry

(e) Stacking

It can be defined as fault in stacking sequence. Stacking fault are surface defect which result in net wise of energy level of lattice.

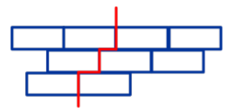


Fig. 9.13 Stacking

9.5 Hume – Rothery Rule

- **Alloy:** Combination of 2 elements whose resulting microstructure reflects the property of individual.
- **Compound:** Resulting product losses the properties of independent element.
- **Intermetallic Inclusions:** Impurities present combines with other element are results into different material with distinct properties.

Before applying this rule crystal structure of both materials should be same. It having 3 conditions:

(i) Difference in atomic radius < 15%

(ii) Valency of both should be same

(iii) Electron negativity (other) & electron affinity (own) should be comparable.

- Alloys have higher strength than the parent metals.

9.5.1 Binary phase Diagram of type– 1: [Isomorphism]

Materials that are completely soluble both in liquid as well as solid state. [Lever Rule only applicable in 2 phase diagram]

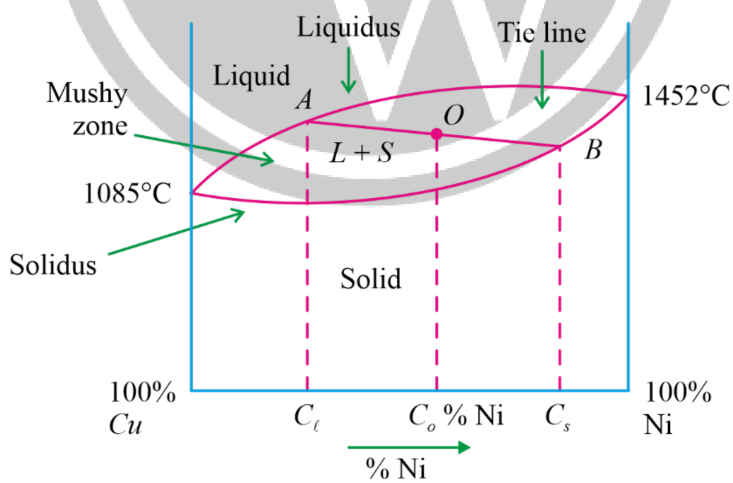


Fig. 9.14 Binary Phase Diagram Type-1

$$m_s = \frac{C_0 - C_l}{C_s - Cl}$$ $$m_2 = \frac{C_S - C_0}{C_s - C_l}$$ $$m_S + m_l = 1$$

- Larger Mushy zone exhibit lesser fluidity and more difficult to cast.

Conclusions drawn from level Rule

(1) As temp. decreases, mass fraction of solid phase increases.

(2) With temp. decrease, % of Nickel in solid also decreases.

- Initially diffusion tries to achieve phase stability, but if phase is stable at various temp. Then it tries to achieve chemical homogeneity.

  Slow cooling enables particular orientation of atoms in solidification front and when different solidification fronts fuse together, the region of orientation mismatch are called grain boundaries.

  They can be easily broken that why atmospheric oxygen attacks grain boundary atoms & material starts corroding.
- **Chromium addition** reacts with oxygen producing Cr_2O_3, which does not allow **oxygen to attack** grain boundaries.
- Nickel is added to **stabilize** the **phase mixture** at room temp.
- 18% Cr & 8% Ni material is called "**stainless steel**".
- **Finer is the grain lesser is corrosion.**
- Materials with completely removed grain boundaries are called "**Superalloy**"
- Thin sheets of super alloy is called "**Whisker**".

Note:
Stainless steels are very difficult to weld.

During welding, higher temp. leads to reaction / combining of chromium with oxygen and it appears on surface, which results in corrosion of that part. This phenomenon is called **weld Decay or sensitization of steel**.

- Due to presence of Mushy zone alloys have range of temp. at which liquification & solidification take place.
- Melting point depends upon composition & phase diagram.
- Rapid cooling results into concentration gradient due to no fine for diffusion higher percentage of Ni at centre and decreasing towards the graph boundary. Hot working of such materials, crack is produced due to early melting of grain boundaries leading to brittle fracture. This phenomenon is coring or Miscibility gaps.

9.5.2 Binary Phase diagram of Type-II

Materials that are completely soluble is liquid state but partially soluble in solid state.

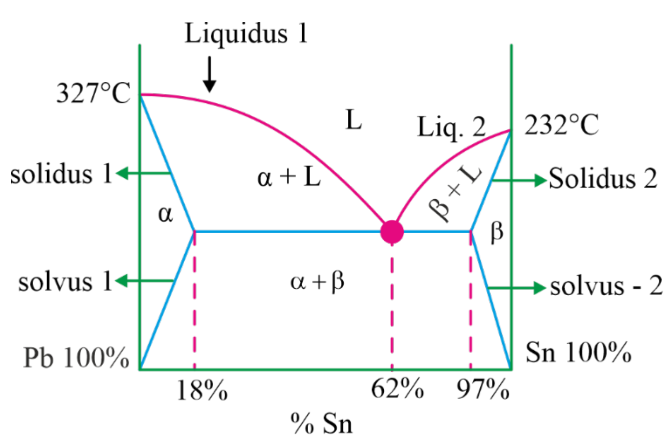


Fig. 9.15 Binary Phase Diagram Type-II

Eutectic Reaction

$$L \underset{62\% Sn}{\overset{183°C}{\rightleftharpoons}} \alpha + \beta$$

Invariant ($F = 0$)

3-phases in equilibrium

9.5.3 Modified Gibbs phase Rule

$$\boxed{P + F = C + 1}$$

Pressure is constant.

Rule of Mixture

$$\boxed{\frac{1}{\rho} = \sum_{i=1}^{n} \frac{x_i}{\rho_i}} \quad \boxed{V_\alpha = \frac{\frac{m_\alpha}{\rho_\alpha}}{\frac{m_\alpha}{\rho_\alpha} + \frac{m_\beta}{\rho_\beta}}}$$

$\therefore$ $$\boxed{V_\alpha + V_\beta = 1}$$

9.5.4 Binary phase diagram of type – III

Materials that are completely soluble in liquid state but completely insoluble in solid state.

Alloy of Bismuth (Bi) shows such characteristics

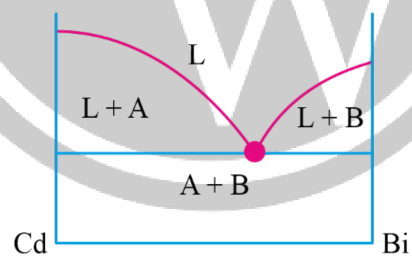


Fig. 9.16 Binary Phase Diagram Type-III

9.6 Cooling Curve of Iron

Phase change is investigated by either change in

(1) Crystal structure

(2) Unit cell size

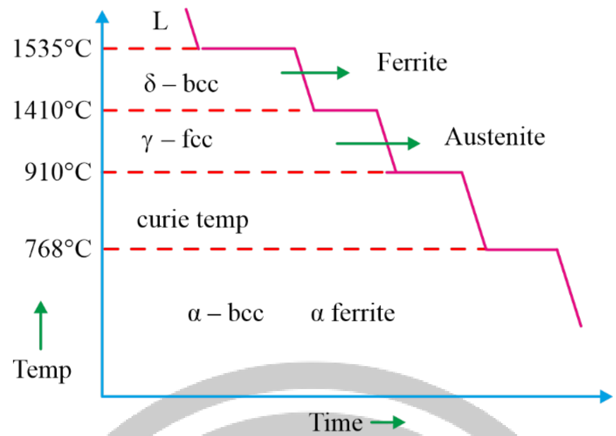
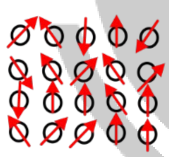


Fig. 9.17 Cooling Curve of Iron

During latent heat transaction at 760°C only magnetic properties are lost.

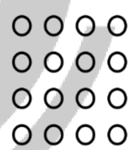
During of periodic table are classified into:

Paramagnetic (Left)



- Randomly oriented dipole
- Soft magnetic material
- Colourful [eg. Cu, Brass, Bronze]

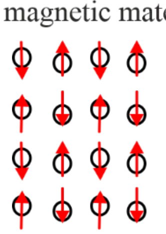
Diamagnetic (Right)



Dipole are exactly opposite to applied field which means all dipoles cancel each other [zero magnetic dipole].

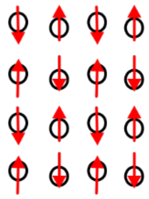
Exception [Ferromagnetic CO, Ni] Iron

- Very strong magnetic dipole
- Hard magnetic material.

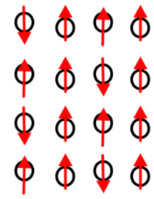


Iron: At room temp. magnetic dipole moments are unidirectional.

Antiferro (Chromium)



Ferrimagnetic



One line of ferro and one line of anti-ferro.

No metals show this behaviour. Only compound exhibit this.

9.7 Iron Carbon Phase Diagram

Fe-Fe₃ C diagram

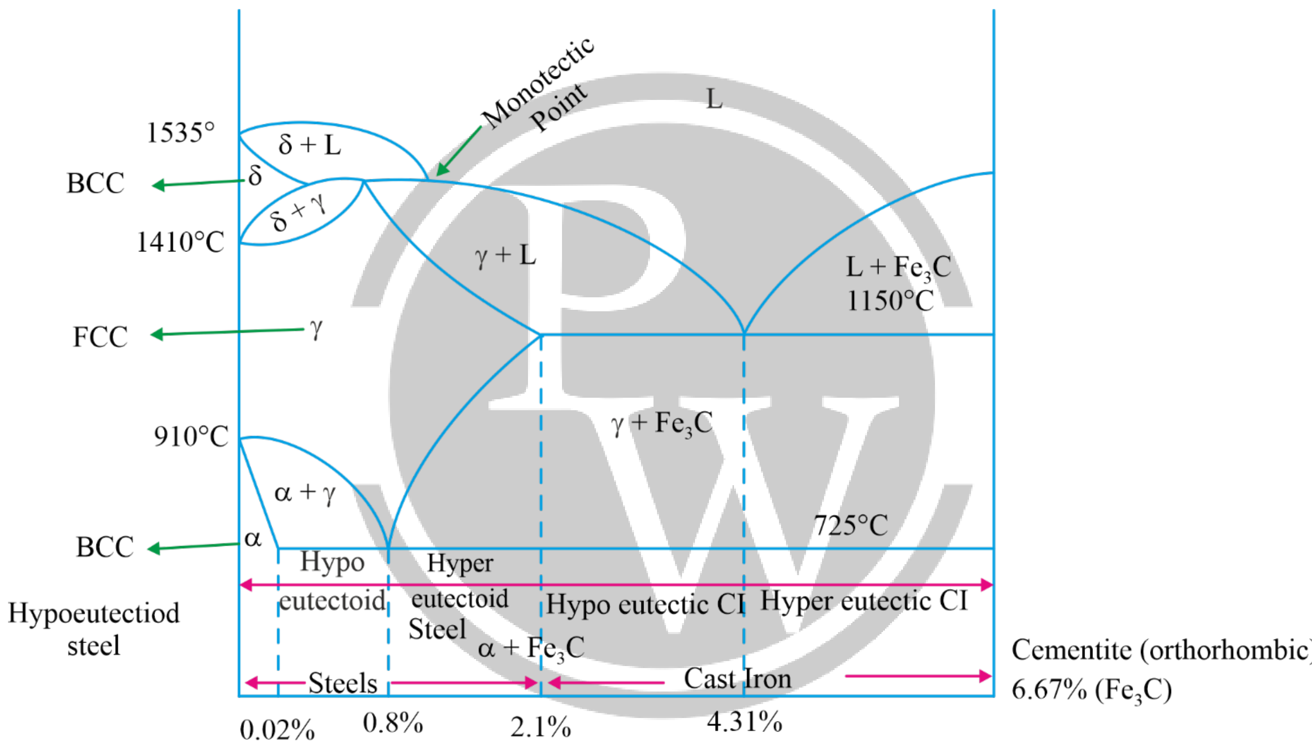


Fig. 9.18 Iron Carbon Diagram

Classification of Carbon

< 0.3% Low C steel (Mild steel)

0.3 – 0.7% Medium steel

> 0.7% High steel

1. $L \underset{4.3\%}{\overset{1150°C}{\rightleftharpoons}} \underbrace{\gamma + Fe_3C}_{\text{Leadburite}}$ [Eutectic Reaction]

2. $\gamma \underset{0.8\% C}{\overset{725°C}{\rightleftharpoons}} \underbrace{\alpha + Fe_3C}_{\text{Pearlite}}$ [Eutectoid Reaction] [γ (Austenite) is not stable in temp below 725°C It becomes Pearlite].

Note:
Pearlite is a phase mixture & is formed purely be diffusion 100% pearlite is formed by eutectoid decomposition.

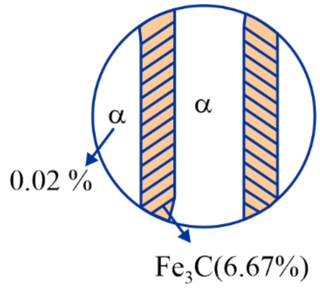


Fig. 9.19 Pearlite Phase

3. $\underset{(s)}{\delta} + \underset{(L)}{L} \underset{0.18\% C}{\overset{1493°C}{\rightleftharpoons}} \underset{(s)}{\gamma}$ [Peritectic Reaction]

It appears where there is large diff. in melting point of 2 elements.

4. Peritectoid reaction $S_1 + S_2 \overset{\text{cooling}}{\rightleftharpoons} S_3$ [Found Cu-alloy phase diag. Not present in Fe–C phase diag.]

9.7.1 Solubility of carbon in various Cases

(i) Maximum solublity of carbon in δ-ferrite phase in 0.1%
(ii) Maximum solubility of carbon in γ-austenite phase is 2.1%
(iii) Maximum solubility of carbon in α-ferrite is 0.025%

9.7.2 Significance of Some Important Line

A_1 Line → (727°C) when Eutectoid steel are heated above A_1, pertite transformation into Austenite.

A_2 line → It is called Curic point temp line. This line signifies magnetic to non-magnetic transformation on heating

* Carbon % has no influence on Curie point temp.

A_3 line → This line is known as upper ctrical temp. line for Hypo Eutectoid steel.

This line signifies complection of Ferrite to Austenite solution.

A(CM) Line → This line is called upper critical temp. line for Hyper eutectoid steel. It signifes completion of cementite to austenite.

9.8 Classification of Cast Iron

(1) **Gray cast Iron:** Flakes are formed due to excess carbon.

(2) **White cast Iron:** Slow cooling results in combined from of carbon with iron is called white cast iron.

(3) **Chilled cast Iron:** Cast iron of such composition in which it will normally freeze as gray but by rapid cooling it is forced to appears white is called chilled cast Iron Extremely brittle.

(4) **Spheroidal cast CI:** Chilled CI heat treated with Mg or Ce addition results into formation of spheroids of carbon. [High Ductile]

(5) **Nodular CI:** If cooling rate during heat treatment is quite high we get Needle shaped carbon.

9.8.1 Effect of Sulphur & Manganese on the Iron

Mg captures S & produces MgS whose Tm is high. So, it overcomes Hot shortness phenomena. It also improves machinability → (Low shear strength).

Hadfield steel – (12% Mg very strong element, used in Bulldozers).

9.8.2 Effect of silicon on steel

Oxygen is used to remove carbon & last trapped oxygen is removed by using silicon inform of sludge. If oxygen removed is complete then it is called killed steel. When removal is partial it is called semi-killed steel.

9.8.3 Effect of silicon on CI

Addition of SI & P shifts the Iron carbon diagram towards left.

Industrially produced gray CI contains carbon percentage 2.4 – 4% sparkles of red not-graphite on liquid iron surface & it sparkles. This phenomenon is called kish.

Equi-cohesion Temperature

Strength of grain boundary becomes uniform & below this temp. material fail in Brittle manner.

9.8.4 Development of Microstructure in Iron-carbon system

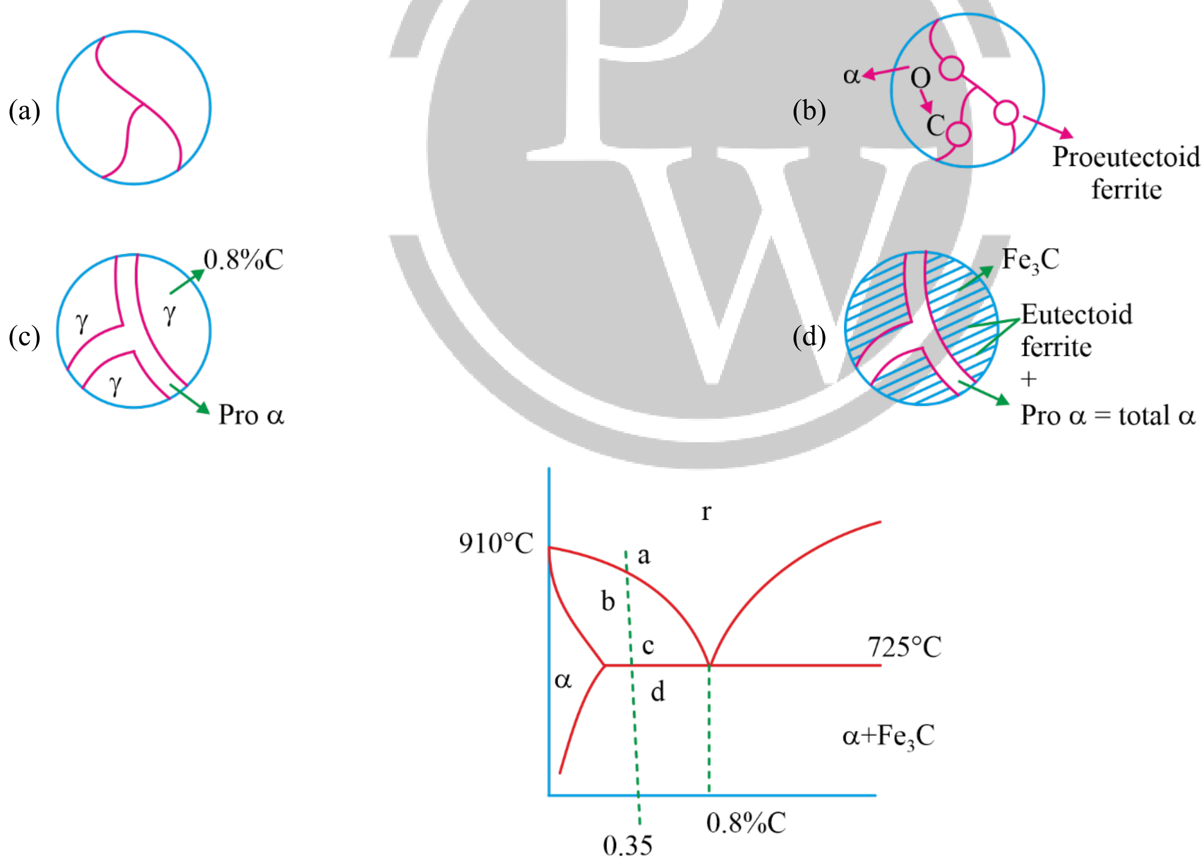


Fig. 9.20 Microstructure of Iron Carbon Diagram

9.9 Yield Point Phenomenon: (YPP)

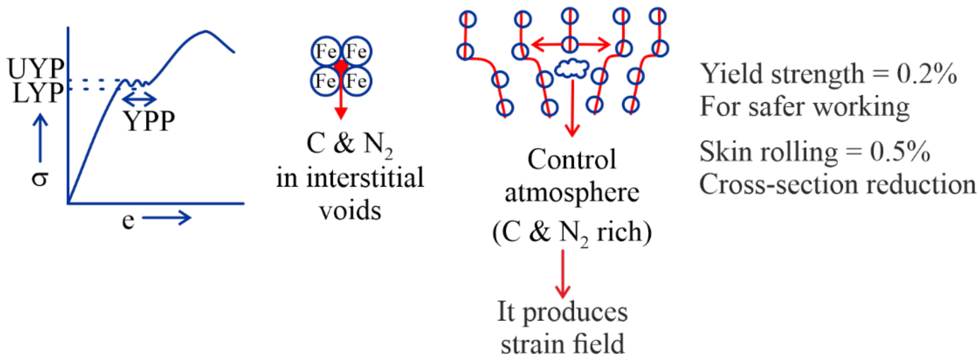


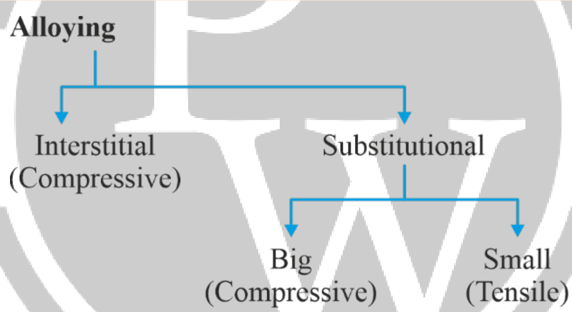
Fig. 9.21 YPP

Time period $[1\frac{1}{2} - 2$ year] depending upon Carbon percentage

No YPP in medium & high carbon steel. [because carbon is not only percent at dislocation site it is everywhere]

9.10 Strengthening Mechanisms

9.10.1 Alloying



Strain fields are created in host atoms and these creates obstacles in dislocation movt. There by increasing strength.

9.10.2 Grain Refinement

$$\text{Grain density} = \frac{\text{No.of grains}}{\text{unit length}}$$

Finer the grain structure better will be the strength.

Hall petch equation $$\sigma_y = \sigma_0 + \frac{k}{\sqrt{d}}$$

k = constant

d = average grain diameter

$n = 2^{G-1}$

n = grain density

G = ASTM number

9.10.3 Work hardening (strain hardening):

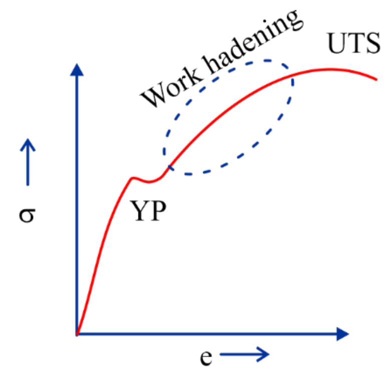


Fig. 9.22 Work Hardening

- Shot blasting
- Sand blasting (Thin section) } Hard Surface
- Shot peening (Odd shapes)

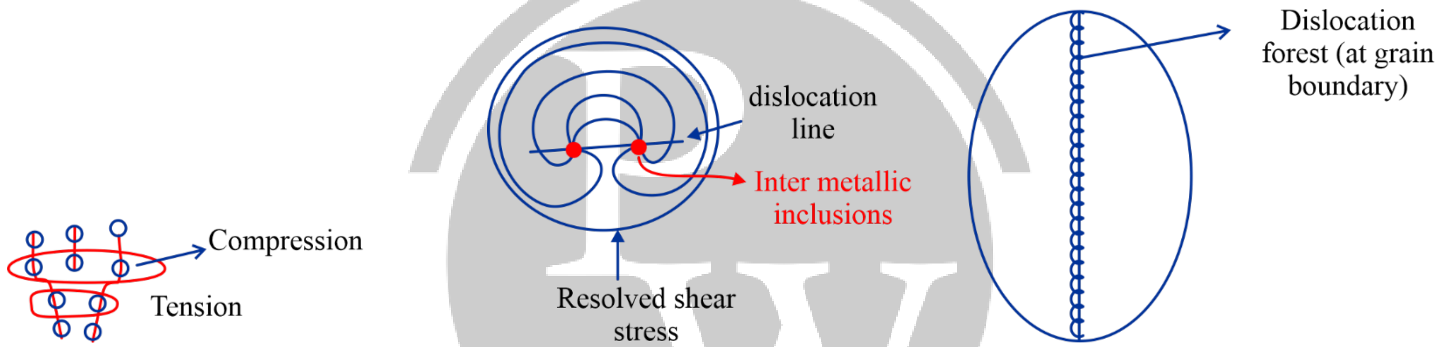


Fig. 9.23

- When more dislocations reach the grain boundary dislocation forest will repel & produces Back stress.
- After unloading from region of work hardening & again reloading yield point will inc. due to back stresses.

9.11 Bauschinger effect

Yield point in compression will appear pre-maturely.

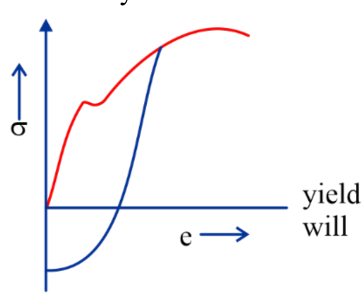


Fig. 9.24 Bauschinger Effect

Nature of stress strain curve in Tension & comp.

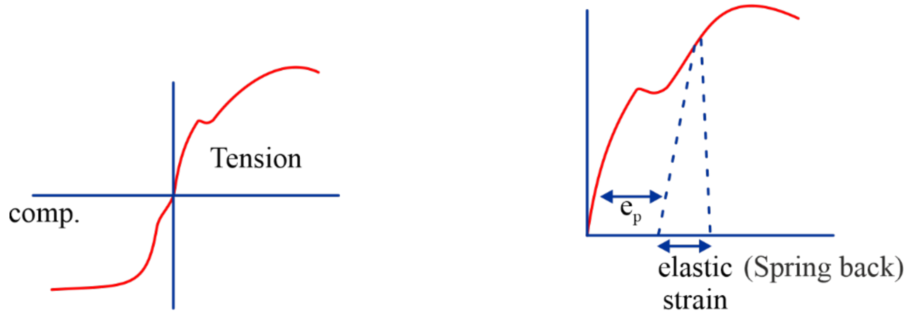


Fig. 9.25 Nature of Stress Strain Curve

Parallel length: Length with uniform cross-section.

Gauge length: Length under observation

Inst. Length & area measured by (Extensometer)

9.12 Various curves with changing strain Rate

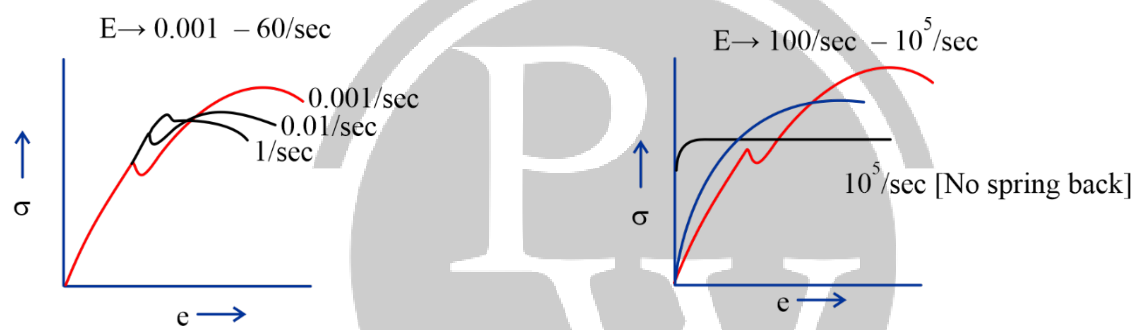


Fig. 9.26 Variation of Strain Rate

- Work hardening decreases due to no time for atoms to respond
- Inc. in yield point
- No elastic region in high strain Rate
- Behave like rigid plastic

9.13 Power Law / Flow curve equation / Holloman equation / Constitutive equation

$\sigma_f = k\varepsilon_T^n$

$\sigma_f \rightarrow$ True stress
k $\rightarrow$ Strength coefficient
$\varepsilon_T \rightarrow$ True strain
n $\rightarrow$ Work hardening exponent

Value of n
for steel = 0.3
for Al = 0.05

$$\sigma_0 = E\in \text{ [Engineering stress \& strain] } \varepsilon = \frac{dl}{\ell_0}$$

$$\sigma_f = K\in_t^n \text{ [True stress \& strain] } \quad \in = \frac{\ell}{\ell_0} = \frac{A_0}{A}$$

$$\sigma_f = \frac{P}{A}[\text{A \& } \ell \text{ inst. Area \& length}]$$

$$\sigma_f = \sigma_0[\in +1] \quad \boxed{\in_t = \ell_n(1+\in)}$$

At UTS

$\boxed{n = \in_t}$

9.14 Age of Precipitation Hardening

Use in air craft (Al – Cu) Duralomin [Cu% -5.5% only]

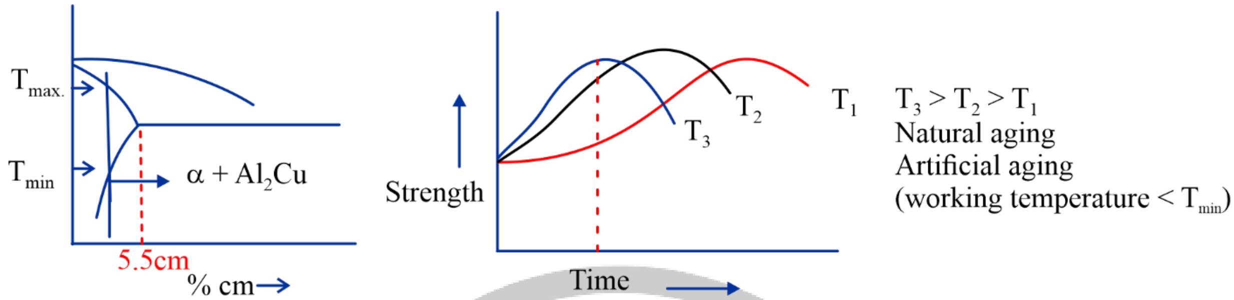


Fig. 9.27

Al – Cu alloy is heated → Then quenched to room temp → microstructure is unstable → slowly with time precipitation occurs creating barriers for dislocation move → strength increases.

Point at which nucleation stops is called peak strength of the material.

9.14.1 Creep

Slow & progressive deformation material over a period of time at constant load or stress at a temp. equal to or greater than recrystallization

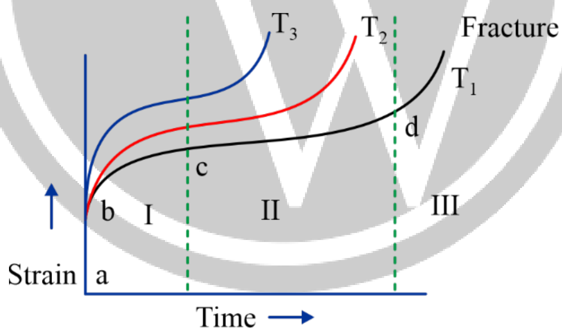


Fig. 9.28

$T_3 > T_2 > T_1$

a – b Instantaneous

b – c transient

c – d steady

d – e accelerated

Region (I) work hardening,

Region (II) Balance b/w work hardening & Recrystallization

Region (III) Recrystallization

- **Tensile Test:** No. of Neck then can appear during tensile test? = 1.
  At what point Neck will appear? = anywhere in parallel length
- **Temp. the transformation curve:** [In equilibrium state] [0.8% C]

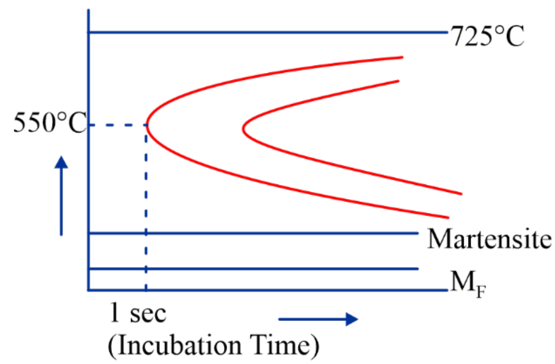
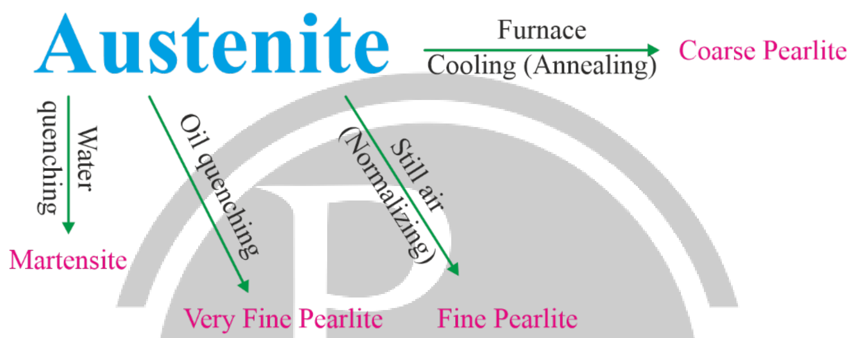


Fig. 9.29

9.15 TTT curve or Bain's curve or S curve or C curve (Non-Equilibrium Diagram)



Hardness Order

(1) Martensite (Max.)
(2) Bainite
(3) Fine Perlite
(4) Coarse Pearlite (Min.)

Period below 725°C during which nothing happens to Austenite is called incubation time.

- Upon decreasing quenching temp. first incubation time decreases, then at 550°C it is 1sec after that it starts increasing.
- Such behaviour is due to
  (a) Driving force
  (b) Diffusion (Atomic Mobility)

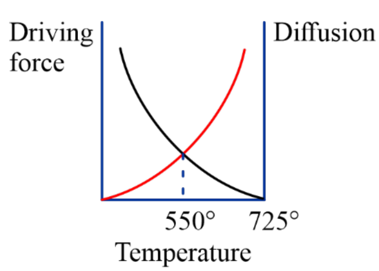


Fig. 9.30

Critical cooling Rate: If cooling rate just touches the nose of TTT diagram is called CCR.

$$CRR = \frac{750 - 550}{1 \text{sec}} = 200°C/sec$$

9.15.1 Formation of Martensite (BCT)

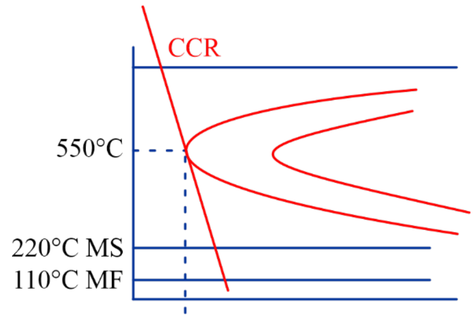


Fig. 9.31

Martensite

- Sub microscopic cementite present in ferrite.
- Hard & most brittle phase of iron
- On TTT curve – Once Austenite converts into same microstructure it never reconverts.

9.15.2 Pearlite

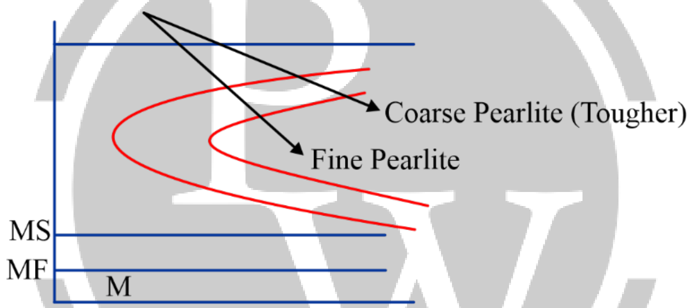


Fig. 9.32 Pearlite

- Low cooling rate allows time for diffusion and result is coarse pearlite.
- Fast cooling rates gives finer Pearlite.
- Generally, with increase in hardness & toughness the ductility decreases [except fine grain].

9.15.3 Austempering

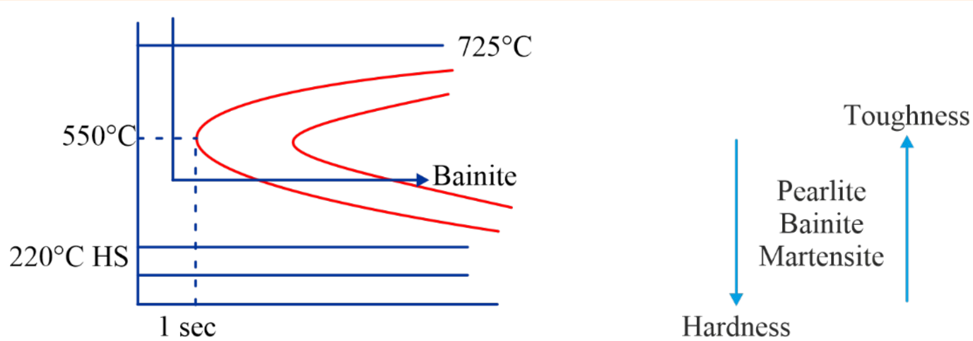


Fig. 9.33

Mech. of formation:

Pearlite – Diffusion

Bainite – Partial (Diffusion + shear)

Martensite – Diffusion less (A thermal)

Bainite has mixed microstructure not uniform like pearlite or Martensite.

9.15.4 TTT diagram for various steels:

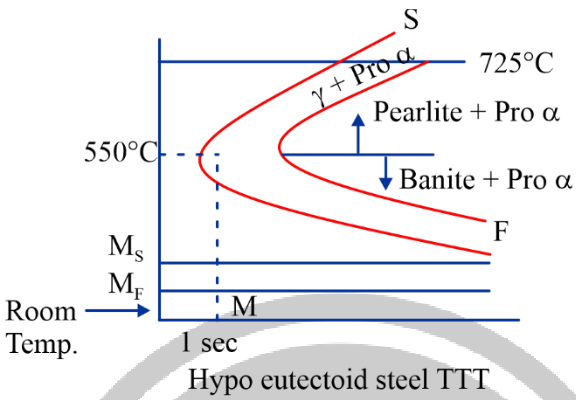


Fig. 9.34

No matter how much percentage carbon is there decomposition line (finish) will be same.

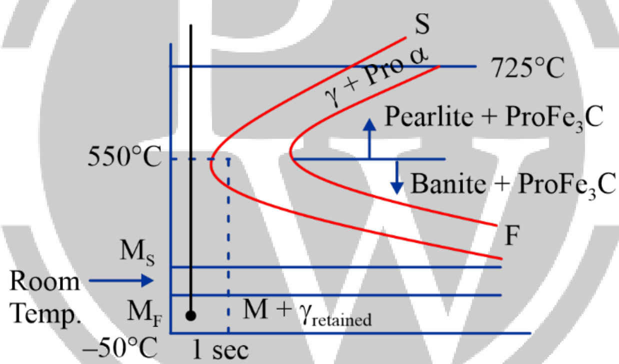


Fig. 9.35 Hyper Eutectoid steel TTT

In Hyper Eutectoid steel TTT diag. we get $\gamma_{retained}$ which is quenched by using Liq. N_2 (77K) i.e. Cryogenic Treatment

9.15.5 Austenitic Stainless steel (ASS)

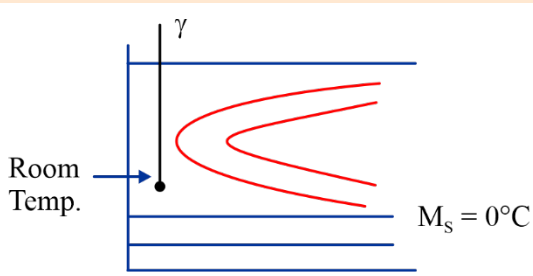


Fig. 9.36

Ni (9%)

Cr (18 – 20%)

In this case to obtain Austenite (stable) we use Nickel & Cr to shift the Martensite start at 0°C.

ASS is used in Nuclear Applications.

- **Maraging steel:** [Used is defence for Missile cover]

  Ni – 17 – 19 %

  Co – 8 – 9 %

  Mo – 3.35 %

  Ti = 0.15 – 0.25%

  Al = 0.05 – 0.15%

  Fe – Balance

9.16 Hardenability – Jominy & Quench Test

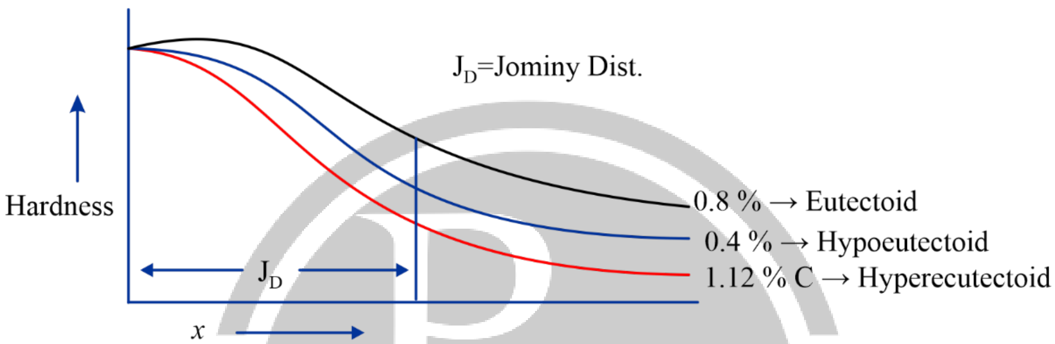


Fig. 9.37

- From bottom to top, there will be variable cooling rate
  At J_D = 50% Pearlite + 50% Martensite
- Hardenability is defined as ease of martensite formation.
- As we deviate from eutectoid comp. hardenability decreases.

9.16.1 Cracks formation on Quenching

During Quenching sample (Austenite) experiences diff temp. at surface & core due to which surface becomes low density (Martensite) & core becomes high density (Austenite). Later when core converts martensite expansion take place & cracks are formed. [Density diff. cause cracks].

Ways to avoid cracks:

(1) Austempering

(2) Martempering (stepped Quenching)

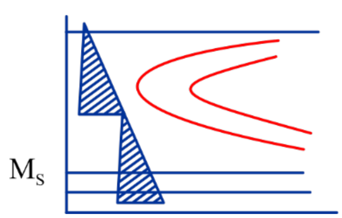


Fig. 9.38

(3) Alloying [Air quenching may produce martensite]

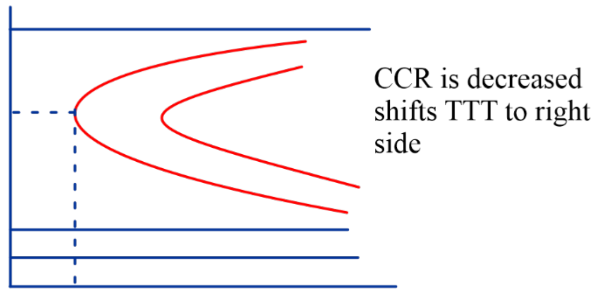


Fig. 9.39

9.17 Heat Treatment Classification

- Annealing
- Normalizing
- Hardening
- Tempering

9.17.1 Annealing

1. Full Annealing:

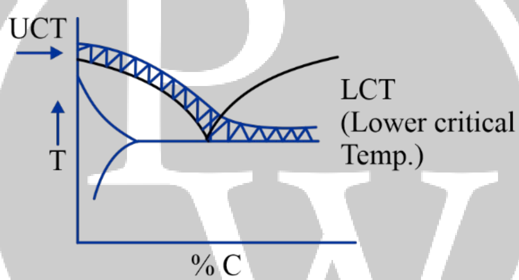


Fig. 9.40 Annealing

- Objective to reduce harness & brittleness & increase ductility
- Result is Coarse pearlite
- Cooling Rate 200°C/hr.

2. Process Annealing:

- Objective stress relieving of low carbon steels.
- Medium & high carbon steels are brittle so they may fracture. Therefore, they are not processed.
- Heated upto Recrystallization Temp. but less than LCT.
- No major change in grain structure [Little finer it becomes]

3. Spheroidize Annealing:

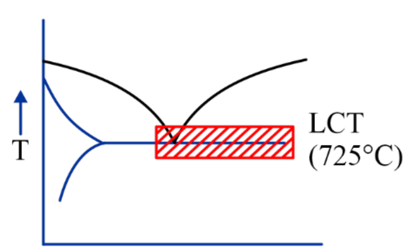


Fig. 9.41

- Cooling rate – 20°C/hr
- Objective to increase machinability of medium & high CS.
- Heated close to lower critical, then cooled slowly in furnace.
- Machinability improves due to formation of spheroids.

4. Diffusion / Homogenizing:

- Performed to make chemical comp. uniform when disturbed by welding.
- Higher temp is used to enable diffusion phenomenon effectively.

9.17.2 Normalizing

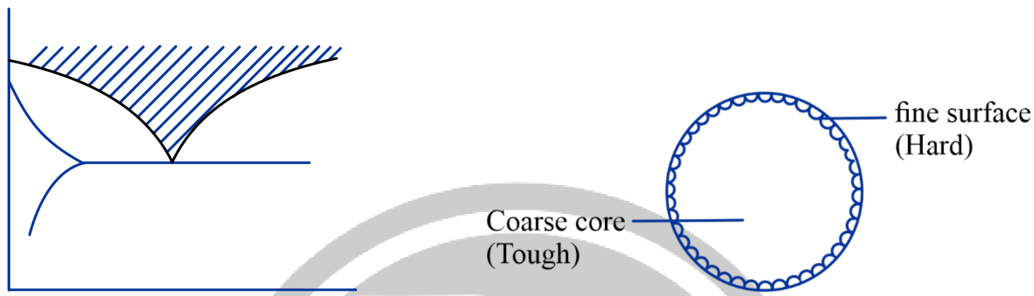


Fig. 9.42

- Air quenched
- Maximum engineering applications
- Considered as the final heat treatment process.

9.17.3 Hardening

Objective: To get martensite structure.

9.18 Quenching Mediums

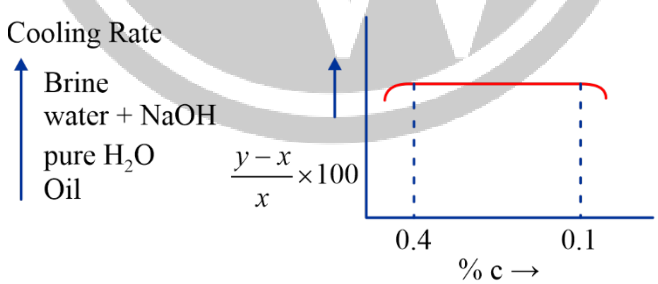


Fig. 9.43

- Water
- 36 % salt (Brine solution)
- Oil baths (Alloy steels)
- Thermoplastic
- Water + NaOH
- Mild steels cannot be treatment by this method as they contain proeutectoid phase [No contribution in Martensite]
- Their strength is increased by Case Hardening.

9.18.1 Case Hardening

Diffusing carbon into MS specimen. Surface is hardened only.

1. Carburizing (Fe_3C)

(a) Pack

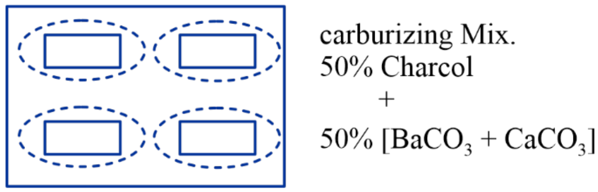


Fig. 9.44

- Cheap & easy to perform
- Poor quality
- Time consuming.

(b) Liquid

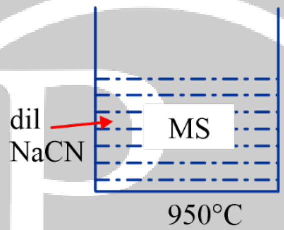


Fig. 9.45

- Good quality cases
- Bath is expensive
- Highly poisonous

(c) Gas carburizing

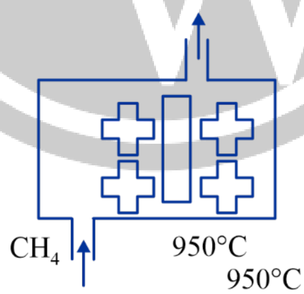


Fig. 9.46

- Thickness of case can be controlled
- Process can be automated.

2. Nitriding

NH_3 + 650°C (extremely brittle)
Mostly it needs further treatment for making tough.

3. Cyaniding

It uses combination of 30% NaCN + NaCl + Na_2CO_3 [at 850°C]

4. Carbo Nitriding (Gas Cyaniding)

$CH_4 + NH_3$ (at temp. 850°C)

- N > CN > C

9.18.2 Flame Hardening

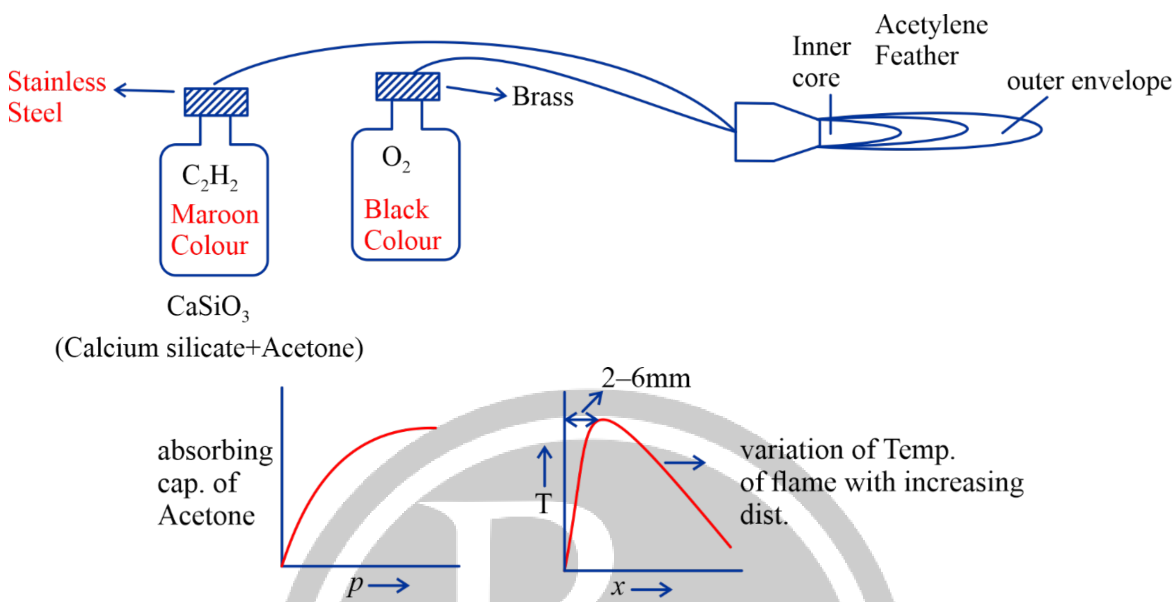


Fig. 9.47 Flame Hardening

1. Carburizing Flame (C)	< 3000°C	Silent	Cast Iron
2. Neutral Flame $C_2H_2 + \frac{5}{2}O_2 \rightarrow 2CO_2 + H_2O$	3150°C	Hissing	Steel
3. Oxidised Flame	3480°C	Roaring	Copper

Flame hardening is used to produce a thin layer of Martensite on surface.

9.18.3 Induction Hardening

[Fastest Method]:

Thickness of case $x = 500\sqrt{\frac{e}{\mu F}}$

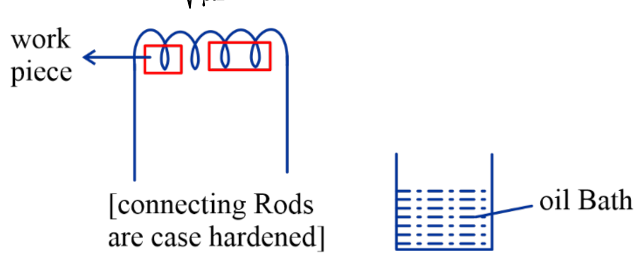


Fig. 9.48

e = electric resistivity

μ = magnetic permeability

f = frequency

9.18.4 Tempering

High temp. Tempering (500 – 600°C)	Medium Temp. (350 – 500°C)	Low Temp. [250°C]
Coarse structure (Tough)	Use for Finer cementite (Springs)	Only stresses are relieved
Sorbite Microstructure	Troostite Microstructure	Used for Agri. tools, Metrology Tools

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