

30.08

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METAL FORMING

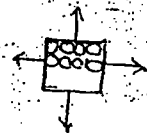
ME by I.E. Pass 1/1/20
PE by R. nam...

Definition: It is a process in which the forces are applied on one material are such that the stresses induced in the material is greater than the yield stress and less than the ultimate stress such that the material is experiencing a plastic and permanent deformation to get the required shape.

$$\sigma_y < \sigma < \sigma_u$$

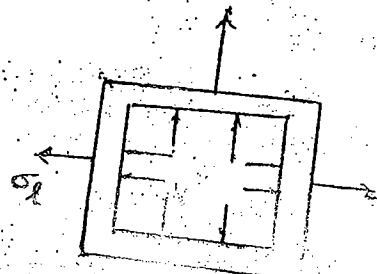
Advantages of M.F. processes:

1. There is no wastage of material. It's only flowing from one place to another but not removed from the workpiece.
2. The grain orientation is possible.
(Isotropic properties are same in all directions)
3. The material can be converted from isotropic to anisotropic properties. (where properties are different in different directions).
(anisotropic = properties are same in 2 directions but different in the third direction)



eg: A pressure vessel experiencing uniform stress

$$\sigma_h = 2\sigma_l$$



eg. Connecting rod of an I.C. engine

Because of Poisson's ratio effect there will be stresses induced in the transverse direction also (30% σ_x). Here isotropic materials are not suited because 70% of energy will be wasted.



eg. Train track

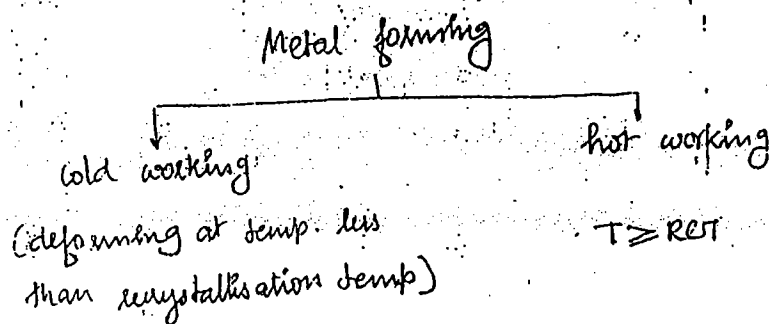
Forces acting is not uniform



14. In some M.F. processes, increase in strength and hardness and in some other process, increase in ductility of the material is possible.

Disadvantages of M.F. processes

1. The forces and energy required for the metal forming process are higher than other manufacturing methods.
2. Only uniform cross section area components can be manufactured (except forging).
3. Components with cross holes are not possible to produce.
4. In some M.F. processes, poor surface finish results.
5. In some M.F. processes, poor dimensional accuracy results.



Recrystallisation temperature

It is the min. temp. at which the formation of new crystals has been completed (whenever behaviour changes, new grains are formed). When a material is getting heated, the energy supplied through it is absorbed by the grains, whenever grains are attaining certain levels of energy, they start changing the behaviour called the starting point of recrystallisation. On further heating, energy levels of grains are increasing. So at some point the energy levels will be crossing the threshold energy and the grains will be showing only new behaviour. called completion of formation of new behaviour. This temp. is called R.C.T.

Beyond R.C.T., additional energy will be utilised for increasing of molecular grain size and further heating at some temp, the grains can no longer exist as solid bodies and get converted into liquids. This temp. is called melting point temp.

R.C.T. is a material property.

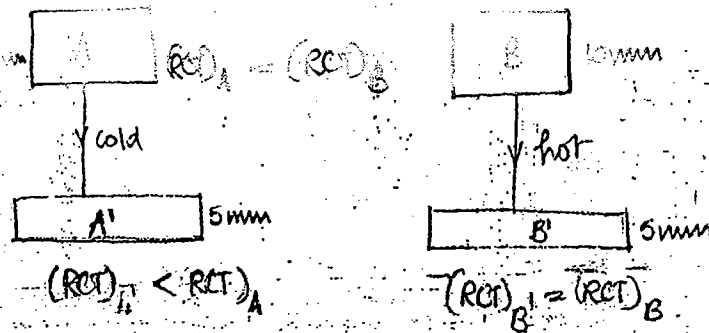
$$R.C.T. = \frac{1}{3} \text{ to } \frac{1}{2} \times M.P.$$

eg. (R.C.T.)_{lead, tin} < room temp.

(R.C.T.)_{zinc, cadmium} $\approx$ room temp.

So the deforming of the above four metals is always considered as hot working process.

But (R.C.T.)_{tungsten} = 1400°C . So deformation of Tungsten even at 1100°C is cold working process.



$\Rightarrow (RCT)_{A'} < (RCT)_{B'}$ because during cold process, some residual stresses are setup inside the material.

In case of hot worked component, whatever the energy required for the changing of behaviour is obtained only through heating process. Whereas in case of cold worked components, energy required is obtained through heating as well as distribution of energy from the energy packets which is in the form of residual stress. Hence, the required threshold level of energy is obtained at a lower temp.

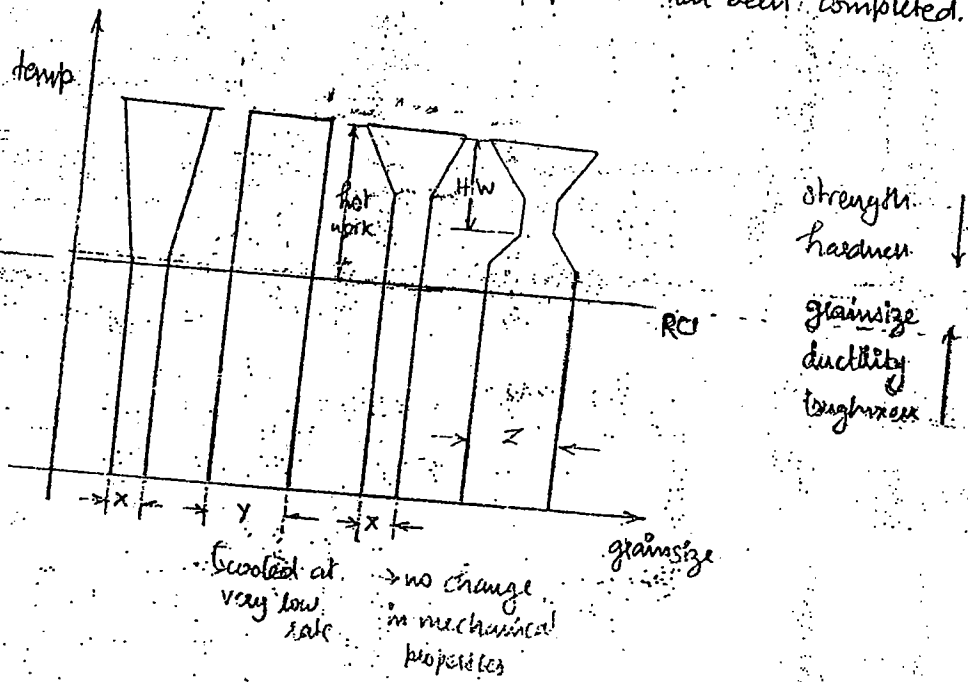
$$\text{So } (RCT)_{\text{cold}} < (RCT)_{\text{hot}}$$

Features of hot and cold working operations

1. For the same amount of deformation to be produced, the force and energy required for cold working is higher than hot.
2. At higher temp, scales or oxides are formed, which is not desirable in case of hot working operations. This produces
 - a) high coeff of friction (0.5 to 0.6) 0.1 to 0.2 for cold working
 - b) very poor surface on components
 - c) poor dimensional accuracy

- But in cold working, close dimensional tolerances are possible.
3. The cold worked components will always have a higher strength and hardness but lower ductility and toughness.

The mechanical properties of materials after hot working greatly depends on the temp. at the process has been completed.



From the above figure, if the hot working is getting completed near RcT, the grain size of the material remains the same as original so is the mechanical properties.

- If the hot working is completed well above the RcT, because of excess energy available, the grain size further increases and at room temp. the grain size becomes greater than the original material grain size hence, coarse grain are obtained giving lower ductility and toughness and lower strength than the original material.

ROLLING OPERATION

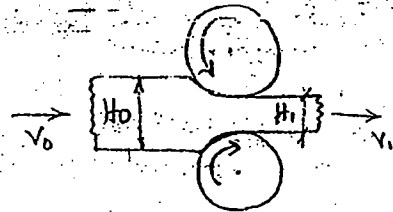
- Here the material is compressed between the 2 rotating rollers such that the thickness of the strip can be reduced from H_0 to H_1 .

- The surface velocity of the roller must be same.

$$\text{i.e., } V_t = V_b$$

$$\pi D_t N_t = \pi D_b N_b$$

$$\boxed{D_t N_t = D_b N_b} \checkmark$$



i.e., the diameter of both the rollers must be same such that the contact area between them on the strip is same which gives equilibrium conditions.

When the roller dia's are same, rpm of the rollers are also same.

Therefore same prime mover can be used for rotating both without any gearbox.

Let D - rollers' dia.

R - radius of rollers.

N - rpm of rollers.

H_0, H_1 - thickness of strip before and after rolling.

ΔH - reduction in thickness.

V_0, V_1 - velocity of strip before and after rolling.

b_0, b_1 - width of strip " " " " " "

- In rolling, the strip is pulled into the rollers because of presence of friction between the rollers and strip only.

Assumptions for rolling operation analysis.

1. Every material which is undergoing the M.R. is always considered as incompressible. i.e., no volumetric change taking place.

$$\text{i.e., } H_0 b_0 L_0 = H_1 b_1 L_1$$

$$\text{or } H_0 b_0 v_0 = H_1 b_1 v_1$$

2. Width of the strip remains constant. i.e., $b_0 = b_1$

i.e., during rolling, whatever the reduction in volume taking place in the thickness direction is simply in the length direction without affecting the width of the strip.

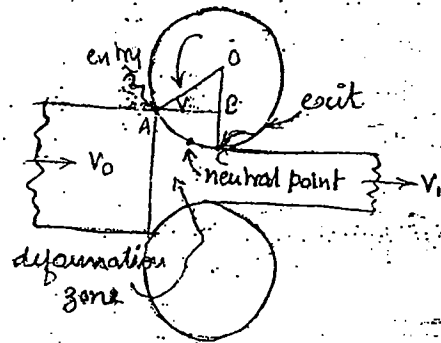
$$\Rightarrow H_0 L_0 = H_1 L_1$$

$$H_0 v_0 = H_1 v_1$$

$$\frac{H_0}{H_1} = \frac{v_1}{v_0} > 1$$

When the rollers are pulling a strip at the entry means then the velocity of the rollers must be greater than the velocity of the strip.

$$V_1 > v_0$$



Along the deformation zone, the velocity of the strip will be increasing, but surface velocity of the rollers remains same. Therefore at some point along the deformation zone, the velocity of the strip becomes equal to the velocity of the rollers. At this point, the stresses induced is exactly equal to the flow stress of the material.

material are increasing the flow of materials becomes easier hence the velocity of the material is further increasing.

The surface velocity of roller is in between the entry and exit velocities of the strip.

The angle made by the deformation zone w.r.t. the centre of the roller is called deformation angle (α) or angle of bite.

$$\cos \alpha = \frac{OB}{OA} = \frac{R - \frac{\Delta H}{2}}{R}$$

$$= R - \frac{\Delta H}{2}$$

$$\text{i.e., } \Delta H = 2R(1 - \cos \alpha)$$

$$\text{or } \boxed{\Delta H = 2R(1 - \cos \alpha)}$$

In the diagram,

$AB = \text{length of deformation zone} = L$

$AC = \text{arc length of def. zone}$

$$= R\alpha$$

$$L = \sqrt{OA^2 - OB^2}$$

$$= \sqrt{R^2 - \left(R - \frac{\Delta H}{2}\right)^2}$$

$$= \sqrt{R^2 - \left(R^2 - R\Delta H + \frac{\Delta H^2}{4}\right)}$$

$$L = \sqrt{R\Delta H - \frac{\Delta H^2}{4}}$$

$$R\Delta H \gg \frac{\Delta H^2}{4}$$

$$AB = L = \boxed{\sqrt{R\Delta H}}$$

From $\triangle OAB$.

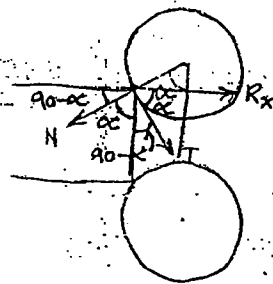
$$\begin{aligned}\tan \alpha &= \frac{AB}{OB} \\ &= \frac{\sqrt{RAH}}{R - AH/a}\end{aligned}$$

$$R \gg \frac{AH}{a}$$

$$\Rightarrow \tan \alpha \approx \frac{\sqrt{RAH}}{R}$$

$$\boxed{\tan \alpha \approx \sqrt{\frac{AH}{R}}}$$

From the figure, R_x is the resultant resolved horizontal component of frictional forces N and T .



$$R_x = T \cos \alpha - N \sin (90 - \alpha)$$

$$= T \cos \alpha - N \sin \alpha$$

$$T = \mu N$$

$$R_x = \mu N \cos \alpha - N \sin \alpha$$

$$= N (\mu \cos \alpha - \sin \alpha)$$

For the ship to be pulled into the roller $R_x \geq 0$

$$N (\mu \cos \alpha - \sin \alpha) \geq 0$$

$$\mu \cos \alpha \geq \sin \alpha$$

$$\mu \geq \tan \alpha$$

$$\tan \beta \geq \tan \alpha$$

$$\Rightarrow \boxed{\beta \geq \alpha}$$

For a given rolling operation, the angle α is β , where β is the angle of the roller.

In a given rolling operation if $\alpha \neq \beta$ the reduction possible in the operation is called maximum possible reduction, corresponding condition is called Coulomb's friction condition.

When $\beta = \alpha$

$$\tan \beta = \tan \alpha = \mu = \sqrt{\Delta H / R}$$

$$\boxed{\Delta H = \mu^2 R} = (\Delta H)_{\max.}$$

⑧ If $H_0 = 180 \text{ mm}$, $H_f = 95 \text{ mm}$, $D = 650 \text{ mm}$, $\mu = 0.2$.

What is the no. of rolling operations required to reduce the thickness?

$$\begin{aligned} \text{No. of pass} &= \frac{(\Delta H)_{\text{total}}}{\Delta H_{\max} / \text{pass}} \\ &= \frac{180 - 95}{\mu^2 R} \\ &= \frac{85}{0.2^2 \times 325} \\ &= 6.5 \\ &\approx 7 \text{ passes} \end{aligned}$$

Let $n = \frac{2\mu H_0}{\Delta H}$

$$(P_x)_{\text{lagging}} = \frac{\sigma_1}{n} \left[(n+1) \left(\frac{H_0}{H_x} \right)^n + 1 \right] - \left(\frac{H_0}{H_x} \right)^n \sigma_1 \quad \checkmark$$

where H_x is the thickness of strip in the lagging zone where the pressure is to be determined.

σ_1 is back tension (auxiliary terminology)

$$(P_x)_{\text{leading}} = \frac{\sigma_2}{n} \left[(n+1) \left(\frac{H_x}{H_1} \right)^n - 1 \right] - \left(\frac{H_x}{H_1} \right)^n \sigma_2 \quad \checkmark$$

where σ_2 - front tension

Thickness of the strip at the neutral point.

$$(P_n)_{\text{lagging}} = (P_n)_{\text{leading}}$$

Here don't use the auxiliary terminologies

$$\Rightarrow \frac{\sigma_1}{n} \left[(n+1) \left(\frac{H_0}{H_n} \right)^n + 1 \right] = \frac{\sigma_2}{n} \left[(n+1) \left(\frac{H_n}{H_1} \right)^n - 1 \right]$$

H_n - thickness of strip at neutral point.

H_n value is very near to H_1

$$\% H_n = H_1 + 20 \text{ to } 30\% \Delta H$$

Q. $H_0 = 200 \text{ mm}$ $H_1 = 214 \text{ mm}$ $\mu = 0.1$, $D = 350 \text{ mm}$ $H_n = ?$

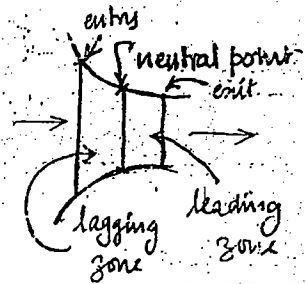
- (a) 13.8 mm (b) 17 mm (c) 15.8 mm (d) 14.2 mm

$$H_n = H_1 + 20\% \Delta H = 214 + 20\% (214 - 200) = 218.8$$

Relative velocity of the strip and the roller along the def. zone.

At entry, the relative velocity is maximum, then reduces along the deformation zone, becomes zero at the neutral point, starts increasing and becomes maximum at the exit.

The neutral point divides the deformation zone into 2 zones: lagging zone and leading zone.



In the lagging zone, the relative velocity is reducing and increasing in leading zone.

Slippage between the roller and strip.

slip $\propto$ relative velocity

slip is max. at entry, reduces to zero at neutral point, then increases

The maximum % slip taking place in the lagging zone is called backward slip.

$$\text{Backward slip} = \frac{v - v_0}{v} = 1 - \frac{v_0}{v}$$

and max. % slip in the leading zone is called forward slip.

$$\text{Forward slip} = \frac{v_1 - v}{v} = \frac{v_1}{v} - 1$$

Variation of pressure along the deformation zone.

Maximum pressure is induced when slip is zero.

i.e., pressure $\propto \frac{1}{\text{slip}}$

Along the def. zone, the pressure is increasing first and then reducing. It is maximum at the neutral point.

By substituting H_n either in the leading zone pressure equation the max. pressure induced in the rolling operation can be determined.

Power required for rotating the rollers $= aT \cdot \omega$
where ω - angular vel. of the rollers.

$$\omega = \frac{2\pi N}{60}$$

T - torque required for rotating the rollers.

$$T = F_{avg} \times a$$

$$a = \lambda L$$

$$\lambda = \text{arm factor} = 0.3 \text{ to } 0.4$$

$$F_{avg} = P_{avg} \times \text{Proj. area}$$

$$P_{avg} = \frac{2}{\sqrt{3}} \sigma_y \left[1 + \frac{Mn}{4H} \right]$$

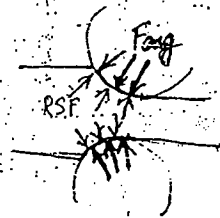
$$H = \frac{H_0 + H_1}{2}$$

$$\text{Proj. area} = b \times L$$

$$\Rightarrow F_{avg} = \frac{2}{\sqrt{3}} \sigma_y b L \left[1 + \frac{Mn}{4H} \right]$$

F_{avg} is the average force acting by the roller on one strip for the rolling to occur.

When F_{avg} is acting by the roller onto the strip, an equal and opposite reaction force produced by one strip is acting on to the rollers. Therefore F_{avg} is also called roll separating force (RSF).



For minimizing the power required or avoiding the separation of the rollers, the RSF or F_{avg} has to be reduced.

The methods of separating RSF are

Reducing σ_y

Due to this, hot rolling is commonly used.

ii.) Reducing the radius of rollers.

As the roller radius is reducing, the strength of load bearing capacity of the roller reduces, therefore the chances of failure of roller increases. This can be eliminated by using backup rollers or supporting rollers.

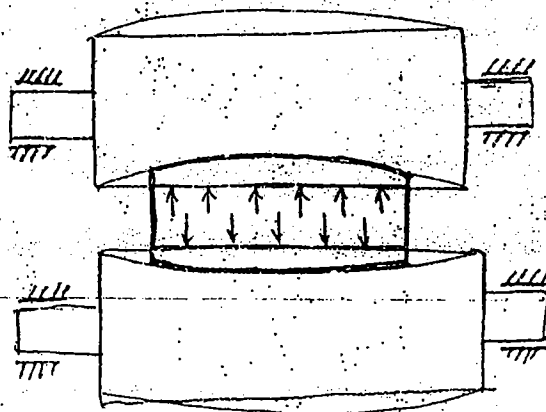
iii.) Reducing the coeff. of friction.

But it can be reduced until $\mu \propto \alpha$.

iv.) By applying back and front tension

When σ_1 and σ_2 are applied, they are acting like a tensile loads in the length direction, due to this, because of the Poisson's ratio effect of the material, the compressive stresses are induced in the thickness direction so that & without the application of the forces on the rollers itself, compressive stresses are induced on the thickness direction. This means that the force acting by the rollers is taken as an additional force for inducing compressive stresses.

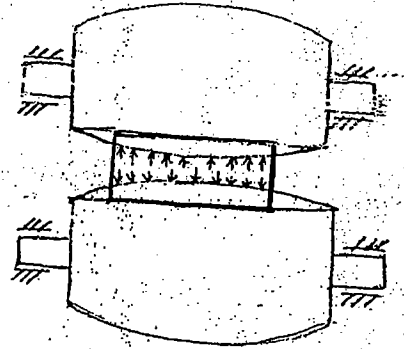
The order of preference of the above methods for reducing σ_y are 1, 2, & 3.



Each roller can be considered as single supported beam with UDL. Due to R.S.F. the rollers are ~~deflecting~~ and producing the strip of non-uniform thickness in the width direction.

This can be resolved by convexing or cambering of the rollers.

i.e., the roller can be made as the larger dia. at centre and small at the two ends.

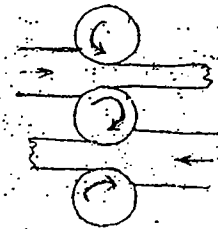


Types of rolling mills:

1) 2 high rolling mills: only 2 rollers are used. But the direction of rotation of the rollers is opposite to each other.

2) 3 high rolling mills: 3 rollers used for producing 2 reductions.

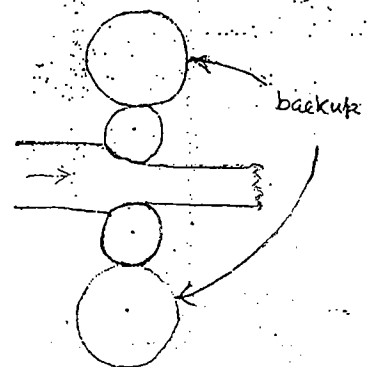
Extreme rollers are rotating in the same direction and the centre roller in opposite direction.



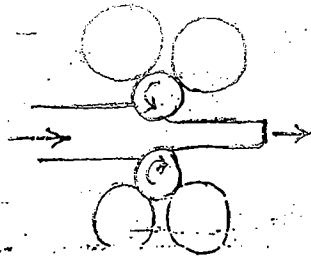
3) 4 high rolling mills:

The backup roller doesn't need the power or energy drawn from the engine. They just support the prime mover.

The limitation of this type is that the centres of all the 4 rollers must lie on a single vertical line.



4) Cluster roller.

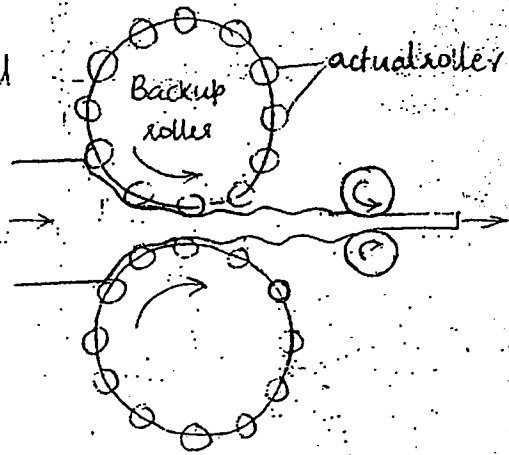


Two rollers are used on each side. The limitations of the high roller is eliminated. There is no increase in power requirement due to the addition of the cluster.

5) Planetary rolling mills.

Whenever the roll separating force is to be reduced to as small as possible by reducing the roller radius, the best method is planetary rolling mill.

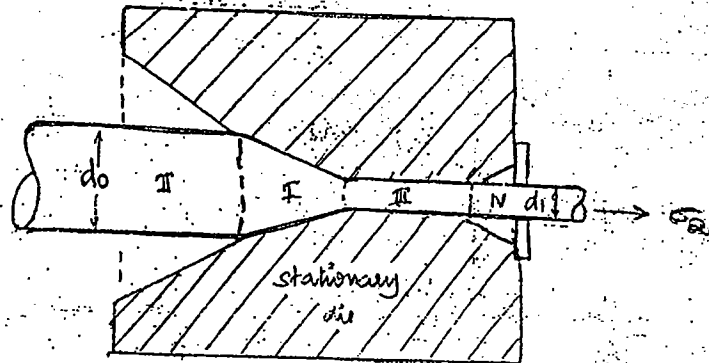
The smaller sized actual rollers are mounted on large size backup rollers. Wave like surface is removed by a set of rollers.



DRAWING OPERATIONS ← wire tube

WIRE DRAWING:

- The method of producing wires from the solid rods by pulling through a stationary die.



- 4 zones:

Zone I - deformation zone: Here the required deformation for converting the rod is obtained in this zone.

The cross section area of the deformation

i) at entry = rod dia

ii) at exit = wire dia.

- Deformation angle or die angle is taken as 2α

2α varies from 12° to 48° .

- For wire drawing of i. hard work piece $2\alpha = 14^\circ$

ii. soft work piece $2\alpha = 48^\circ$

L - die land = length of deformation zone.

- Due to change in cross section

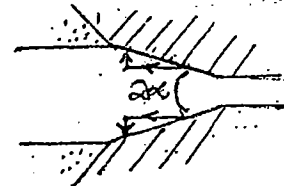
- The frictional force acting on the interface of the die and surface of wire can be resolved into two components.
i.e. horizontal and vertical.

- Effect of horizontal component of frictional force is that it is increases the force applied on the front side of drawing.

- The vertical component of frictional force is trying to fail the die.

- To avoid ^{or reduce} the force required and avoid the failure of die, the friction at the interface has to be reduced. which is possible by using lubricants.

This lubricants can be supplied on the zone II only. So zone II is also called lubricating zone or entry zone.



1. no lub.
2. liquid lub
3. solid powder lub.

- When lubricants are not used, the friction at the interface will be high and so will be the temperature and heat generation. Due to this, the surface of the wire after drawing is observed to be black or burnt.

- The liquid lubricant reduces friction ^{but, a} metallic or dull surface is obtained. It reduces the heat generation and temperature.

- When solid powdery lubricants are used, it reduces the friction, temperature and heat generation and also produces microscopic scratches on the wire surface which make the surface bright shining or silvery appearance.

The commonly used liquid lubricants are mineral oil, SAE oils, vegetable oils, kerosene etc.

The commonly used solid lubricants are
powder, graphite powder carbon powder, glass

Zone III - gaging zone - constant cross section zone. In practice Zone III will be 2 to 5m in length.

Zone IV - exit zone, used for safety. If no lubricant is used, exit zone is not required.

Let A_0 - cross sectional area of rod = $\frac{\pi}{4} d_0^2$

A_1 - " " " wire = $\frac{\pi}{4} d_1^2$

k - coeff. of elongation = $\frac{A_0}{A_1}$ (draft)

$k = 2$ to 8

J - percentage reduction in area $\frac{A_0 - A_1}{A_0} = 1 - \frac{A_1}{A_0}$

σ_2 - drawing stress applied at the front side of the drawing operation.

$$\sigma_2 = \sigma_y \left(\frac{1+B}{B} \right) \left[1 - \left(\frac{A_1}{A_0} \right)^B \right]$$

where σ_y - yield stress

$B = \mu \cot \alpha$

Drawing load = $\sigma_2 \cdot A_1$

Above eq. are used for determining drawing stress and drawing load under ideal conditions only.

If the horizontal component of frictional force is also considered, the drawing stress required at the front side is called total drawing stress.

$$\sigma_2 + \sigma_f = \sigma$$

where R_1 - radius of the wire drawn.
 L - die land.

$$\therefore \text{Total drawing load} = \sigma_d \times A_1$$

Whenever the drawing stress applied at the front side of wire drawing operation is equal to the yield stress of the material, the reduction possible in the wire drawing operation is called maximum possible reduction.

$$\text{We have } \sigma_d = \sigma_y \left(\frac{1+B}{B} \right) \left[1 - \left(\frac{A_1}{A_0} \right)^B \right]$$

For maximum reduction

$$\sigma_d = \sigma_y \Rightarrow \frac{\sigma_d}{\sigma_y} = 1$$

$$\frac{\sigma_d}{\sigma_y} = 1 = \left(\frac{1+B}{B} \right) \left[1 - \left(\frac{A_1}{A_0} \right)^B \right]$$

$$B = \mu \cot \alpha$$

$$\Rightarrow \frac{A_1}{A_0} \text{ can be calculated.}$$

Q. $\mu = 0.1$, $\alpha = 6^\circ$, maximum red = ?

$$B = 0.1 \cot 6$$

$$= 0.95$$

$$k = \frac{A_0}{A_1}$$

$$J = \frac{A_0 - A_1}{A_0}$$

$$\text{For max. red, } \frac{\sigma_d}{\sigma_y} = 1$$

$$= \left(\frac{1+B}{B} \right) \left[1 - \left(\frac{A_1}{A_0} \right)^B \right] = 1$$

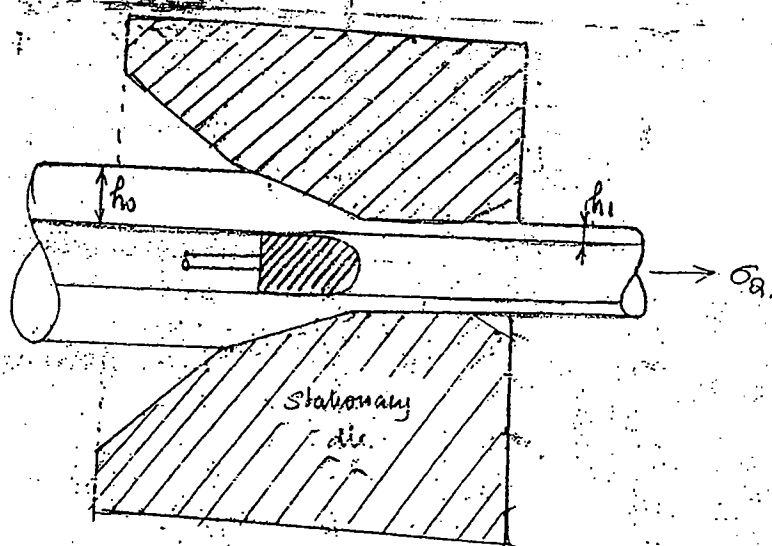
$$\left(\frac{A_1}{A_0} \right)^B = 1 - \frac{B}{1+B}$$

$$\left(\frac{A_1}{A_0} \right)^B = 1 - \frac{0.95}{1.95}$$

$$\frac{A_1}{A_0} = 0.495$$

TUBE DRAWING OPERATION.

- The method of reducing wall thickness of already existing tube by pulling through a stationary die with mandrel so that the inside diameter of the tube may be maintained constant or varied.



The mandrel used may be

1. cylindrical - maintain same inside dia.
2. conical - change inside dia, conical angle α

$$\sigma_d = \sigma_y \left(\frac{1+B}{B} \right) \left[1 - \left(\frac{h_1}{h_0} \right)^B \right]$$

$$\text{where } B = \frac{\mu_1 + \mu_2}{\tan \alpha - \tan \beta}$$

μ_1 - coeff. of friction b/w die and outer surface of tube

μ_2 - coeff. of friction at the interface of mandrel and the inside surface of the tube.

The mandrel based on usage can be divided into 2 types

1. stationary mandrel (ve sign taken)
2. floating or movable mandrel (ve sign taken)



In a floating mandrel, if $\mu_1 = \mu_2 \Rightarrow B \approx 0$.

Substituting, we get $\sigma_{ax} \approx \sigma_y \left(\frac{H_0 B}{B_0} \right) \left[1 - \left(\frac{P_m}{P_0} \right)^B \right]$ $\frac{0}{0}$ form

Applying L'Hospital's rule.

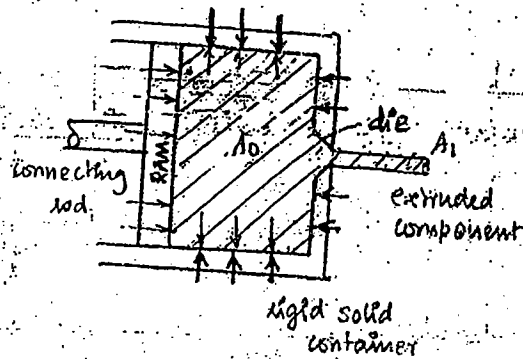
$$\lim_{B \rightarrow 0} \sigma_{ax} \approx \sigma_y \log_0 \left[\frac{1}{\frac{P_m}{P_0} - 1} \right]$$

For maximum reduction,

$$\sigma_{ax} \approx \sigma_y$$

EXTRUSION PROCESS

- Here the material is compressed within a rigid, closed container.



The force applied through the ram pushes the raw material.

Equal and opposite forces are exerted by the container.

The stresses induced is greater than the flow stress, the behaviour of the material will be like liquid.

Hence the material flows through the small opening available in the container taking the size and shape of the die opening.

1. Forward / direct extrusion: direction of ram and product are same.

$$\text{Extrusion ratio} = \frac{A_0}{A_1} = \begin{cases} 140 \text{ to } 50 \text{ general} \\ 1000 \text{ very soft material} \end{cases}$$

(draft)

- The velocity of the extruded component is always much higher than the velocity of ram or raw material.

$$A_0 V_0 = A_1 V_1$$

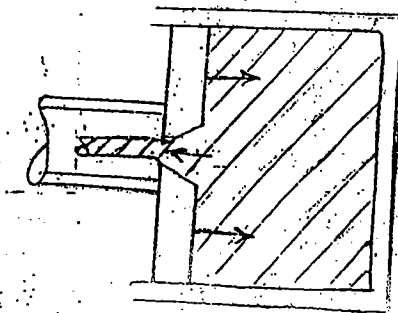
$$\Rightarrow \frac{V_1}{V_0} = 140 \text{ to } 50$$

2. Backward extrusion:

- Here the directions of the ram and the extruded product are opposite.

- In case of forward extrusion, the extruded component is coming out from

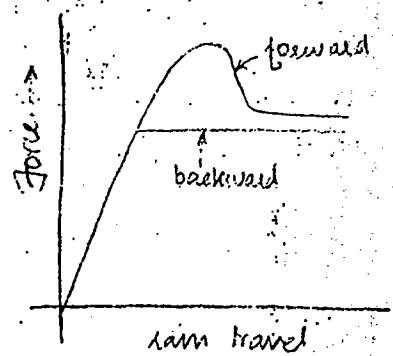
the die into the open environment. In backward extrusion, the extruded component is still inside the die.



— In backward extrusion, the extruded component is going into the connecting rod. Thus its handling is difficult.

— In forward extrusion, the design and manufacturing of ram and die open is easier because they are separate. Whereas in the backward extrusion, it is difficult to design and manufacture the ram and die opening because the axis of ram of die opening must coincide otherwise the failure of the ram will take place due to bending moment.

— In case of forward extrusion, every point on the raw material has to travel against the container wall friction whereas in backward extrusion, the material can be deformed and directly flowing into the die without any movement of the raw material. Hence the force required for forward ^{extrusion greater} is ⁱⁿ than that ⁱⁿ backward extrusion only at the initial portion of extrusion afterwards, the force required is slightly lower than the backward extrusion.



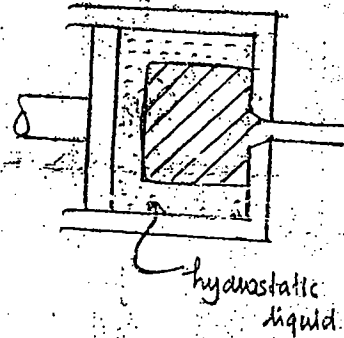
— From the above statements, the most commonly used extrusion is forward type.

— During extrusion of brittle materials, using forward extrusion, because of presence of container wall friction, a lot of cracks are produced on the outer surface of extruded components. Hence such material can be extruded using

backward extrusion

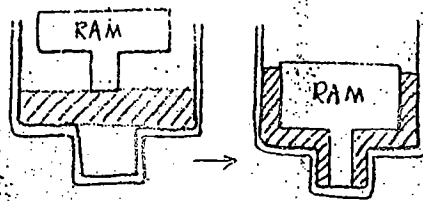
3. Hydrostatic extrusion:

- Here, because of presence of hydrostatic liquid at the interface the container and friction is eliminated completely so that the semi brittle and brittle materials can be extruded easily.
- Because it is similar to forward extrusion, the advantages are same.
- + Hydrostatic ext. is preferable to use for extrusion of semi brittle and brittle materials only, but not for ext. of soft and ductile work pieces. because avoiding the leakage here is difficult.
- The hydrostatic liquids used are
 - i) At room temp. ext. - vegetable oils, glycerine, SAE oils, castor oil, iso pentane.
 - ii) At elevated temp. of ext. - wax, polymers, liquid glass etc.



4. Impact extrusion:

- The method of producing very thin wall tubes from the solid rolls using impact loads is called impact extrusion.
- Impact ext. is applicable only for very soft work pieces like Cu, Al, Ag, or Au etc.
- Used for producing collapsible tubes and seamless tubes.
eg toothpaste tube.



Force required for extrusion

In an extrusion process, the force applied by the ram is mainly acting on the original raw material cross section area.

Therefore the force is calculated based on the A_0

1. $\sigma_0 = \text{extrusion stress}$

$$= \sigma_y \left(\frac{1+B}{B} \right) \left[1 - \left(\frac{A_1}{A_0} \right)^B \right]$$

where $B = \text{material}$

$$\begin{aligned} (\text{Ext. force})_{\text{backward}} &= \sigma_0 \times A_0 \\ &\text{hydrost. ext.} \end{aligned}$$

$$(\text{Ext. force})_{\text{forward ext.}} = (\sigma_0 + P_f) A_0$$

where P_f - pressure required for overcoming the container wall friction.

2. $EF = k A_0 \ln \frac{A_0}{A_1}$

where k - extrusion constant varies with processes.

$\ln \frac{A_0}{A_1}$ - true strain induced in the material.

$$\text{True strain} = \ln(1+e) = \ln \frac{A_0}{A_1}$$

e - engg. strain.

3. $(EF)_{\text{min}} = \sigma_y \times A_0$

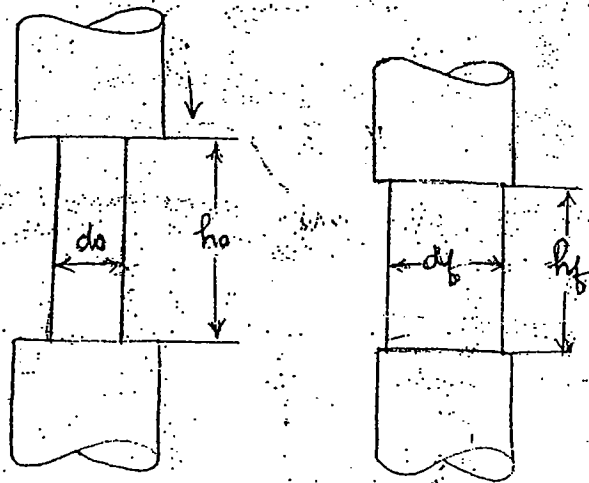
$$(EF)_{\text{actual}} = \frac{(EF)_{\text{min}}}{\eta_{\text{ext.}}}$$

$$\eta_{\text{ext.}} = 0.55 \text{ to } 0.65 \text{ for backward ext.}$$

$$= 0.45 \text{ to } 0.55 \text{ for forward ext.}$$

FORGING OPERATIONS.

- The material is compressed in b/w & dies so that stresses induced in the material is greater than yield and less than the ultimate stress.
- The required shape of the component can be obtained either by using continuous load or by impact load.



- Every material undergoing forging is considered to be incompressible. ($dV = 0$).

$$\Rightarrow \frac{\pi}{4} d_o^2 h_o = \frac{\pi}{4} d_f^2 h_f$$

$$d_f = d_o \sqrt{\frac{h_o}{h_f}}$$

$$h_f = h_o \left(\frac{d_o}{d_f} \right)^2$$

Classification.

1. Based on the method of force application.

a) hand forging - human hand, only impact load.

b) machine forging - mechanical force.

Hand forging

i) drop hammer type

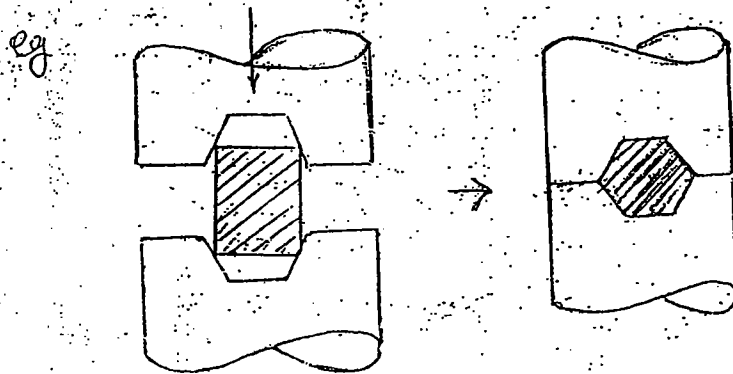
Machine forging

ii) any range of loading

2. Based on method of shape of part obtained.

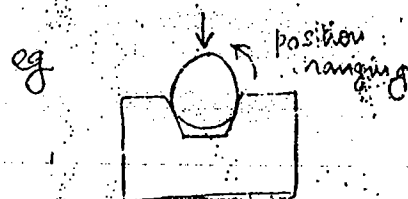
a) Open die forging: required shape and size of the component is obtained by changing the position of the component in b/w the blows. For making it possible to change the position of the component, the force applied in the open die forging is only drop hammer type of blows.

b) Closed die forging / Impression die forging: The required size and shape of the component is same as the size and shape of the dies used.



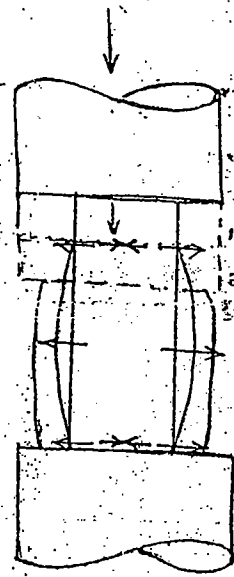
Either continuous or impact load can be used.

c) Semicrosed type forging: The shape and size of the component obtained is same as the half die used. But the required shape of the component can be obtained by changing the position of the component in b/w the blows.



Analysis of the forging operation

- In the forging operation, when the forces are applied on a material, the die is moving so that it induces outward expansion forces and inward frictional forces.
- At the ends, the inward frictional forces are higher than the outward expansion forces. Therefore the material is simply sticking to the surface of the die.
- When it is moving towards the centre of height of the material, the frictional forces gets reducing hence it expands at the centre producing the barrel shape of the component.
- The initial stage of the forging is also called barrelling operation which can be analysed by using sticking friction model.
- On further application of force, by the half die, the outward expansion forces are continuously increasing but the inward frictional forces remains constant. Hence at some point, the outward expansion forces become equal to the inward frictional forces so that the material starts sliding over die surface producing nearly cylindrical shape of the component. This part of the forging operation can be analysed by using sliding friction model.



— The method of force application within the material is similar to that of a pressure vessel of thin cylinder experiencing uniform internal pressure. Therefore the forces inducing forging process is similar to that of a thin cylinder.

$$\text{i.e., } \sigma_h = 2\sigma_l$$

$$e_h = 2e_l$$

$$\epsilon_h = 2\epsilon_l$$

Force required for forging operation

$$(\text{Forging force})_{\text{initial}} = \sigma_y \times A_0$$

$$(\text{FF})_{\text{final}} = \sigma_y \times A_f$$

$$(\text{FF})_{\text{min}} = \frac{F_c + F_f}{2}$$

$$(\text{FF})_{\text{actual}} = \frac{(\text{FF})_{\text{min}}}{\eta_{\text{forging}}}$$

$$\eta_{\text{forging}} = 0.4 \text{ to } 0.6$$

$$(\text{FF})_{\text{actual}} = \sigma_y A_f \left[1 + \frac{2\mu r_f}{3h_f} \right]$$

$$A_f = \frac{\pi}{4} d_f^2, \quad r_f = \text{final radius}, \quad h_f = \text{final height}$$

$$\text{Workdone} = (\text{FF})_{\text{actual}} \times \text{distance}$$

$$= (\text{FF})_{\text{act}} \times (h_0 - h_f)$$

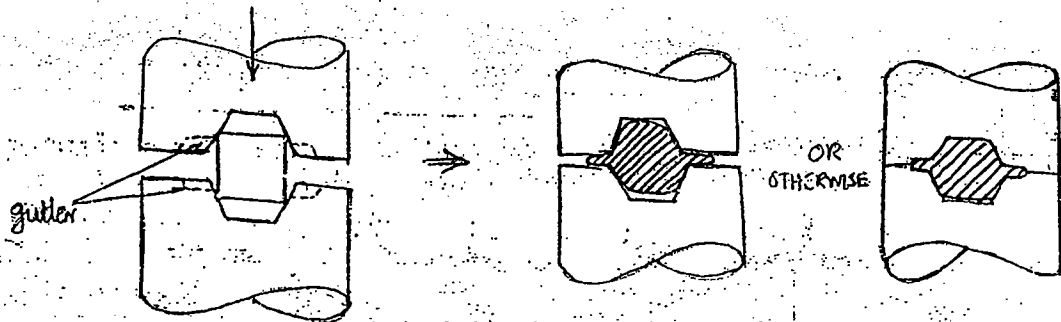
$$= QWH$$

$$H = \frac{WQ}{2W} \quad \text{height from which forging is to be hammered}$$

10/09

In case of open type and semiclosed die forging operation, the volume of raw material ~~remains~~ same as the volume of ~~the~~ finished product.

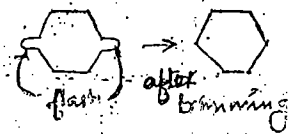
In case of closed type forging, the volume of the raw material is 10-20% higher than that of the final finished components.



In closed die forging operation, it is ensured that the die can be filled completely even though same amount of material is flowing outwards, the excess volume of raw material has to be taken.

To accommodate this excess volume of material, it is necessary to provide some amount of open space in the dies called gutter. Due to the provision of gutter, the excess volume of material is occupied in the gutter producing the projection in the component called flash.

This is an unwanted material which has to be removed by trimming.



i.e. after closed die forging operation, the component must be trimmed.

The performing operations or type of forging operations used to produce a component.

1. Fullering: The method of distributing the material from centre to outwards non uniformly using forging is called fullering. In this process, the length of the component is increasing and cross section is reducing non uniformly.
2. Drawing/drawing out: The method of distributing the material, centre to outwards uniformly by forging is called drawing. In this process, the length of component is increasing and cross section is reducing uniformly.
3. Upsetting: The process of reducing the length and increasing the cross section by forging is called upsetting.
4. Edging/Edging: The method of collecting the material locally using forging is called edging.
5. Flattening: The method of producing flat surfaces using forging is called flattening.
6. Chamfering: Making the sharp edged corners into rounded corners using forging is chamfering.
7. Bending operation: Bending the component into the required angle by forging is called bending operation.
8. Blocking/swaging: Producing approximate size and shape of the component is called blocking.
9. Finishing: The method of producing exact size and shape of the component is called finishing.

10. Trimming: It is the cutting operation used for removing the flash produced in the produced component.

Of the above 10 operations,

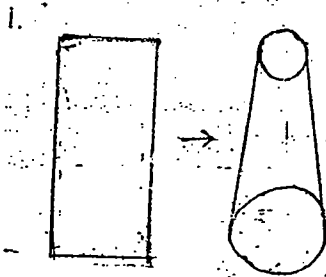
1-6 - open die F. Operations

7-8 - semi closed F.O.

9 - closed F.O.

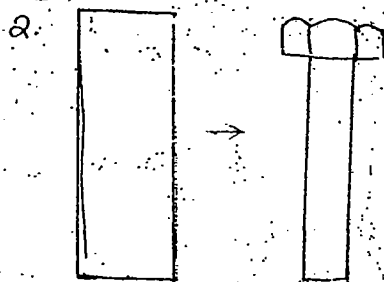
10 - cutting O.

8. Find the operation sequence for the following



1. Fullering

2.



1. Upsetting

2. Flattening

3. Swaging

4. Chamfering

Forgeability:

The ease with which the forging of a given material can be done without producing the defect with minimum amount of force and energy is called forgeability.

eg. ductile materials are easily forgeable than the hard and brittle materials.

→ The commonly used materials in the industry in decreasing order of forgeability are

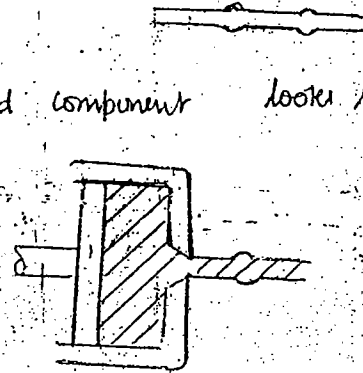
1. Aluminium and its alloys
2. Mg and its alloys
3. Copper " " "
4. Steels
5. Stainless steel
6. Nickel alloys
7. Titanium alloys
8. Iron base super alloys
9. Cobalt base super alloys
10. Columbium alloys
11. Tantalum alloys
12. Molybdenum alloys
13. Nickel base super alloys
14. Tungsten alloys
15. Beryllium

DEFECTS IN M.F. PROCESS

1. Bamboo defect:

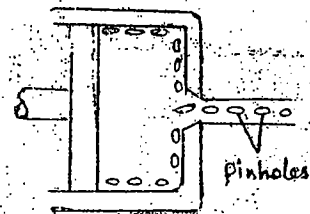
- It is produced in extrusion process.
- The outer surface of an extruded component looks like a bamboo stick.

- This is produced due to non uniform velocity of the ram.



2. Pipe defect (or) Centre burst

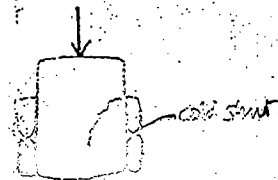
- This is the presence of the pinholes at the centre of extruded components.
- During extrusion process, when a heated raw material is placed inside the container without removing the scales present on the raw materials, which form the central part of the extruded component. They are porous in nature producing pinholes.



- The reason is because of improper cleaning of scale present at the raw material.

3. Cold shut (or) lap defect

- The discontinuity produced in the forged component like a hair like defect.
- This is commonly found in closed die forging but rarely seen in casting also.



The reduction possible in M.E. are.

- Rolling 2 to 10
- Drawing 2 to 6
- Extrusion 100 to 50 and as high as 400
- Forging 2 to 8.

SHEET METAL OPERATIONS

The operation performed on the sheets to get the required shape is called sheet metal operation.

Classification:

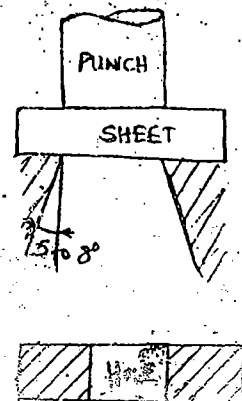
cutting	{	1. Punching (or) piercing	} Major operations
		2. Blanking	
forming	{	3. Deep drawing	
		4. Bending	
	}	5. Perforating	Minor operations.
		6. Notching	
		7. Lancing	
		8. Slitting	
		9. Nibbling	
		10. Trimming	

For both punching and blanking operations are performed by using punch and die. The shape of the punch and die remain same as the component produced.

Inclination of the die is provided for the easy removal of the blank produced.

In punch and die working, the punch size must be always less than the die.

The size of the punch is always less than the die.



and die remain same as the shape of the component produced.

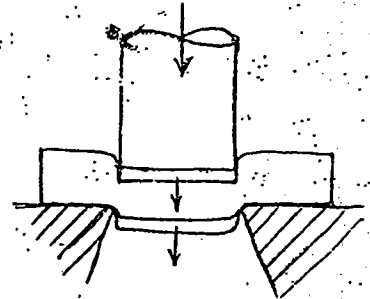
— In punch and die working, if the hole produced in the sheet is useful one, then it is called punching or piercing.

— In punching, the punch size is made equal to the hole size and clearance is provided only on the die. Also, in punching the shear is provided only on the punch.

— In punch and die working operation, if the blank or piece produced is useful one, then it is called blanking operation.

— In blanking, the die size is made equal to blank size and clearance is provided only at the punch. Also, in blanking, the shear is provided only on the die.

— When the force is applied by using the punch and moving the punch, the elastic compression is taking place at the top of the sheet and elastic elongation at the bottom. But the amount



of compression is greater than the elongation. Therefore this difference in compression and elongation is producing shear stresses in the sheet metal present in between the punch and die. On further application of force and moving the punch, the compression and elongation are continuously increasing, the difference between them is also increasing so that the shear stresses induced in the metal also increase and at some point, the shear stresses induced become greater than or equal to the ultimate shear stress of

the sheet metal so that shearing or cracking starts from the edges of punch and die and propagate in their respective directions meeting somewhere in the midtrans section producing the piece or blank leaving a hole in the sheet.

From the above the mechanism by which the cutting of the sheet is taking place due to shearing and tearing actions.

By selecting optimum clearance the punch and die it is possible to ensure that the crack propagations meet or somewhere in the midsection.

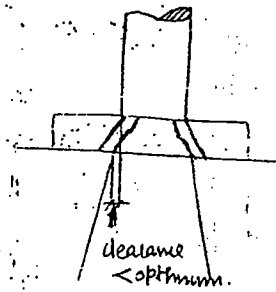
$$\text{Optimum clearance} = \text{radial clearance} \\ = 0.0032 t \sqrt{T_u}$$

where t - thickness of sheet metal in mm

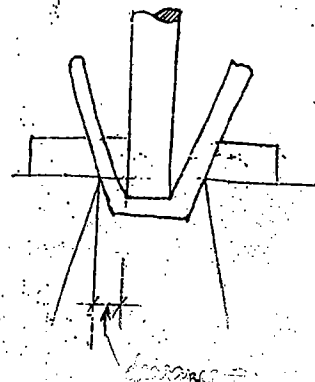
T_u - ultimate shear stress of the sheet metal in MPa

$$\text{Opt. clearance} = 5\% t \quad \text{if } t < 2 \text{ mm} \\ = 10\% t \quad \text{if } t \geq 2 \text{ mm}$$

If the clearance $<$ optimum clearance, the three piece configuration is produced.
i.e., a hole in the sheet, a blank and a hollow component.



If the clearance $>$ optimum clearance, the sheet is pulled into the die without shearing.



- In punching and blanking, the size of punch and die is selected based on the ^b burnishing area produced on the respective useful components.

(The area of the component on which the zig zag edges are getting converted into straight and smooth edges is called burnishing area).

- On the hole, the burnishing area is produced because of the punch and on the blank, the B.A. is due to the die.
- In punching operation, because the hole is the useful component, the B.A. in the hole is produced due to the punch. Hence the size of the punch is exactly equal to the size of hole. Therefore, in punching, punch size = hole size and the clearance is provided on the die.

Q. Hole = $\phi 20 \text{ mm}$

$t = 2 \text{ mm}$

$C = 10\% t$



Punching

$$P.S. = H.S. = \phi 20 \text{ mm}$$

$$D.S. = P.S. + \text{clearance}$$

$$= 20 + 0.2 \times 2$$

$$= \phi 20.4 \text{ mm}$$

Q. Blanking rod = 30 mm

$t = 1 \text{ mm}$

$C = 5\% t = 0.05 \text{ mm}$

$$D.S. = B.S. = 30 \text{ mm radius}$$

$$P.S. = D.S. - \text{clearance}$$

$$= 30 - 0.05$$

$$= 29.95 \text{ mm radius}$$

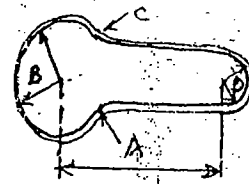


8. Blank.

$t = 1 \text{ mm}$.

$C = 5\% b$

	A	B	C	D
Part	30	20	10	15
P.S	20	19.95	10.05	14.95
R.S	30	20	10	15



11.09

Load estimation in punching and blanking operation.

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

τ_u - ultimate shear stress

A_s - sheared area

$$= p \cdot t$$

$p = \phi d$ for circle

$= 4ea$ square

$= 2(a+b)$ rectangular.

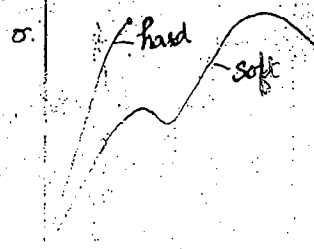
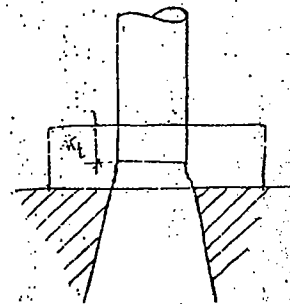
$$\begin{aligned} \text{Work done/energy required} &= \text{Force} \times \text{distance} \\ &= F_{\max} \times \text{dist.} \end{aligned}$$

K_f is the distance to be travelled by the punch for completing shearing action.

It is % penetration required for shearing action completion.

$$K_f = 20 \text{ to } 30\%$$

The higher value of K_f is taken for the soft materials, because before its failure, it experiences large amount of deformation.



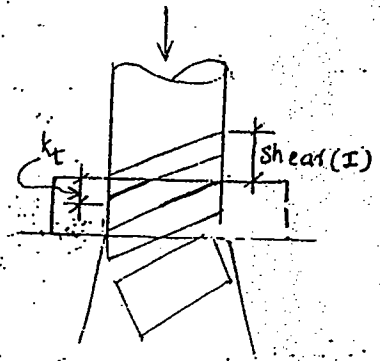
— All the sheet metal operations will always be produced at room temperature only. (Therefore it is not possible to reduce the T_u)

— Normally in punching/blanking, the total sheared area will be cut at a time. But if the sheared area is divided into no. of parts, each and every part of area is cut slowly and continuously until the total area will get cut, so that the force required during any one time will reduce.

Methods to reduce F_{max}

1. By providing shear

— Making the face of punch or die into inclined is called the provision of shear.



— In punching/blanking, the work done or energy required remains constant in respect of the provision of shear on punch or die.

Work done with shear = work done without shear

$$F \times (k_t + I) = F_{max} \cdot k_t$$

$$\Rightarrow F = \frac{F_{max} k_t}{k_t + I}$$

$$I = \frac{F_{max} k_t}{F} - k_t$$

— By providing the shear on the punch, only one produced hole will be useful because the blank may get blind.

— In the punching/blanking, the shear is provided only at one element i.e., either the punch or the die. But it is never provided on both because, doing so both the hole and the piece become useless.

If $K = 0.5$

$$I = \frac{t}{3}$$

$$F = \frac{F_{max} \times 0.5 \times t}{0.5t + t/3} = 0.6 F_{max}$$

If $I = \frac{t}{2}$

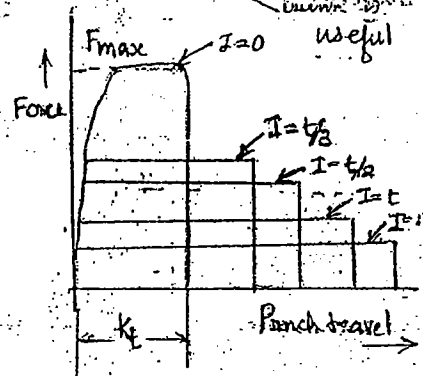
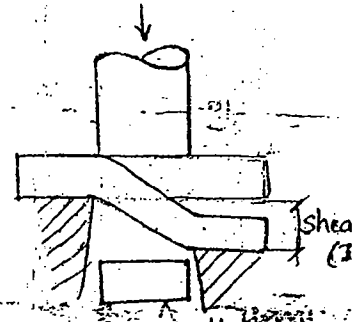
$$F = \frac{F_{max} \times 0.5t}{0.5t + t/2} = 0.5 F_{max}$$

If $I = t$

$$F = F_{max} / 3$$

If $I = 2t$

$$F = F_{max} / 5$$



— The maximum shear provided on the punch/die should be sheet thickness only. Beyond this, the increase in shear produces a little reduction of force but the life of punch will be reduced considerably.

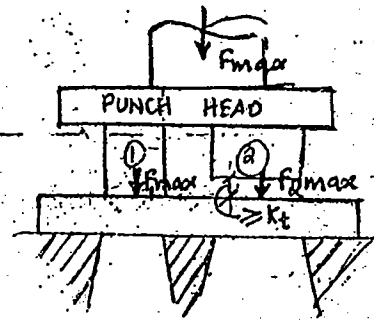
2. By staggering of punches

— This method is possible only when more than one operations is performed in one punch stroke.

— With staggering of punches — at the time, the second punch is

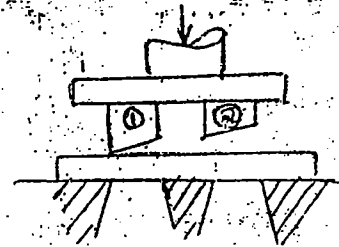
$$(F_{max})_{\text{without staggering}} = F_{max} + F_{max}$$

$$[(F_{max})_{\text{staggering}} = \text{maximum of } F_{max} \text{ or } F_{max}]$$



3. Combination of shear and staggering

— F_{max} can be further reduced.



— During staggering, the balancing of force is very difficult.

— Theoretically, reducing of F_{max} by the third method occurs. But practically it is impossible to balance it.

— While punching, F_{max} is the force applied by using the punch onto the sheet, an equal and opposite reaction force is produced by the sheet is acting onto the punch, induces compressive stress in the punch material.

$$\sigma_{cp} = \frac{F_{max}}{A_{cp}}$$

$$= \frac{4t\tau_u}{\pi d^2}$$

$$\Rightarrow \sigma_{cp} = \frac{4t\tau_u}{d}$$

— During punching operation, as the diameter of hole to be produce is reducing, the compressive stresses induced in the punch material are increasing and at some point comp. stresses in the punch may become greater than allowable

compressive stresses in the punch, so that the punch may ~~fail~~ ^{fail} at any time. To avoid this, it is required to restrict the minimum amount of diameter hole to be produced.

$$\text{I.e., } d_{\min} = \frac{4t\sigma_c}{\sigma_{\text{allowable}}}$$

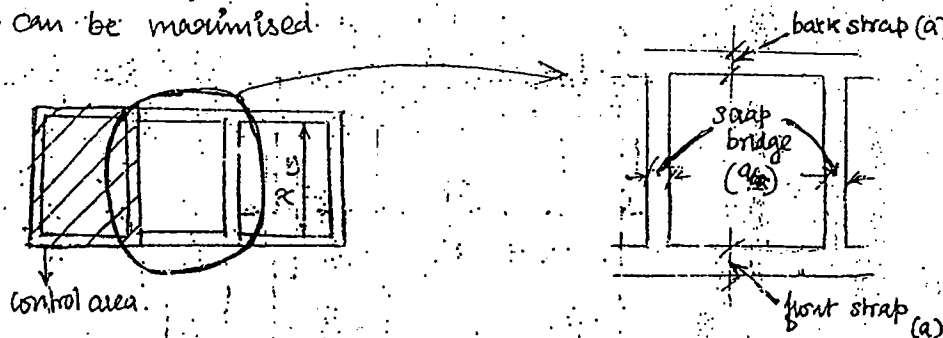
$$\sigma_c = \sigma_{\text{allowable}} \Rightarrow d_{\min} = 4t$$

$$\frac{\sigma_c}{4} = \frac{\sigma_{\text{allowable}}}{4} \Rightarrow d_{\min} = t$$

$d_{\min}$ is applicable only for the punching operation, but not for blanking operation.

Strap strip layout

- It is the layout by which the blanks are produced from the sheets such that the percentage utilisation of the sheet can be maximised.



- Margin is provided to avoid the waviness present on the edge of the rolled sheet and also during transportation there is a possibility of edge damage to occur.

$$\text{Margin} = a$$

$$= 0.8 \text{ mm} \quad \text{if } t < 0.8 \text{ mm}$$

$$= t \quad \text{if } 0.8 < t < 3.0 \text{ mm}$$

$$= 3.0 \text{ mm} \quad \text{if } t > 3.0 \text{ mm}$$

Let L = length of sheet

s = feed of sheet

h = width of sheet

$h = y + 2a$

$s = x + a$

The distance to be travelled by the sheet during one return stroke of the punch is called feed.

$$\text{No. of blanks} = \frac{L-a}{s} \approx \frac{L}{s} \Rightarrow L = ns$$

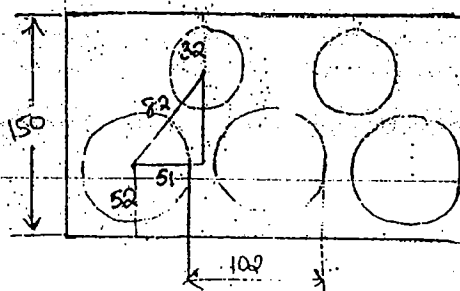
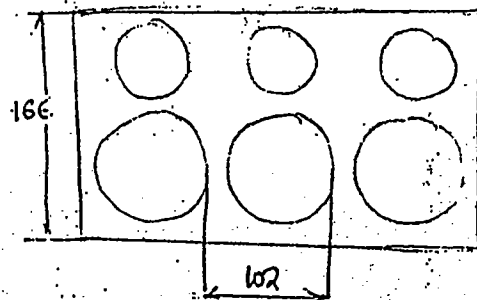
$$\% \text{ utilisation} = \frac{\text{area utilised}}{\text{total area of sheet}}$$

$$= \frac{n(x \cdot y)}{L \times h}$$

$$\text{i.e., } \% \text{ utilisation} = \frac{xy}{\text{control area}} \checkmark$$

Q. Equal no. of circular blanks of dia. 100mm and 60mm. are to be produced from a sheet of thickness 2mm with margin of 2mm. Design a strap-strip layout which is giving maximum % utilisation of the sheet.

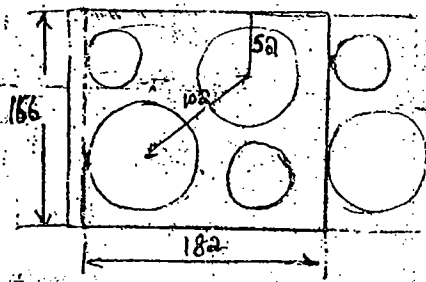
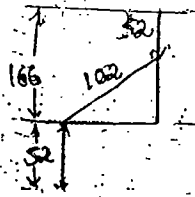
$$\% \text{ utilisation} = \frac{\frac{\pi}{4} (100^2 + 60^2)}{102 \times 166} = 63\%$$



$$\% \text{ utilisation} = \frac{\frac{\pi}{4} (100^2 + 60^2)}{150 \times 102} = 69\%$$

$$\% \text{ ut} = \frac{2 \times \frac{\pi}{4} (100^2 + 60^2)}{166 \times 182}$$

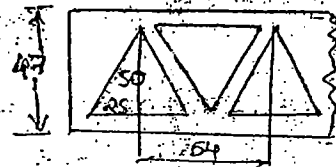
$$= 80.7\%$$



Q. An equilateral triangular blank is to be produced from 50mm side from a sheet of thickness 2mm with a margin 2mm. For this the optimum layout is given below. Determine the % utilisation of the sheet.

$$\% \text{ ut} = \frac{2 \times \frac{\sqrt{3}}{4} (50)^2}{142 \times 54}$$

$$= 85\%$$



→ In punching machine, if the electric motor is used as a prime mover, because of motor supplies energy uniformly throughout, large size of flywheel is required to store and release energy whenever extra energy is needed.

→ In case, an I.C. engine is used as a prime mover, the energy is generated only in the power stroke. So the cutting portion of the punch movement is matched with powerstroke of the engine, the size of the flywheel can be reduced.

→ Within the I.C. engine, if the max. pressure zone of a power stroke is exactly matched with cutting portion of punch movement size of the flywheel can be reduced to as much as possible.

1. In case of SI engine, max pressure occurs at $5-15^\circ$ rotation of the crank after TDC. If it is matched with the cutting portion of the punch movement, flywheel size can be reduced.
2. In case of CI engines, 8 to 20° rotation of crank after TDC has max. pressure.

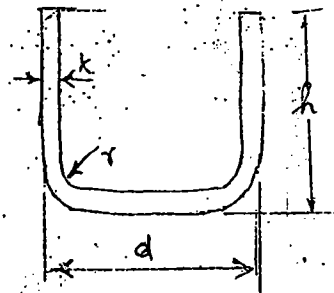
DEEP DRAWING OPERATIONS

- The method of producing cup-shaped components from the flat blanks is called deep drawing. It is a forming process in which the forces are applied on the material such that the stresses induced is greater than yield and less than the ultimate stress so that the plastic deformation of the material is taking place to change the shape.

$$\sigma_y < \sigma < \sigma_u$$

$$\text{If } \frac{h}{d} < 0.5 - \text{shallow drawing}$$

$$\frac{h}{d} \geq 0.5 - \text{deep drawing}$$



eg. All the utensils used in the

kitchen are produced by deep drawing.

- Usually the final finished components dimensions are known, but it is produced from a dia. D . Hence it is required to determine the dia.

r = corner radius

- If r is negligible, one side surface area blank is equal to one side surface area part

$$\frac{\pi}{4} D^2 = \frac{\pi}{4} d^2 + \pi d h$$

$$D = \sqrt{d^2 + 4dh}, \text{ when } \frac{d}{r} > 20.$$

$$= \sqrt{d^2 + 4dh} - \frac{r}{2}, \text{ when } \frac{d}{r} = 15 \text{ to } 20.$$

$$= \sqrt{d^2 + 4dh} - r, \text{ when } \frac{d}{r} = 10 \text{ to } 15$$

If $\frac{d}{r} < 10$, for D, use total area equalisation.

Q. Determine the blank size for the given component.

1. Equalising the areas

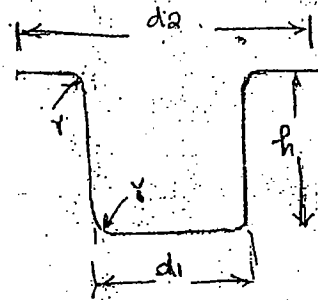
$$\frac{\pi}{4} D^2 = \frac{\pi}{4} d_1^2 + \pi d_1 h + \frac{\pi}{4} (d_2^2 - d_1^2)$$

$$D^2 = d_1^2 + 4d_1 h + d_2^2 - d_1^2$$

$$\rightarrow D = \sqrt{d_2^2 + 4d_1 h}, \frac{d}{r} > 20.$$

$$- \frac{r}{2}, \frac{d}{r} = 15 \text{ to } 20$$

$$- r, \frac{d}{r} = 10 \text{ to } 15$$



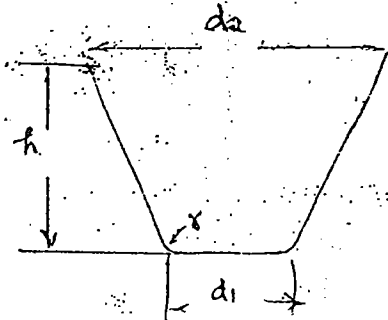
Assuming r is negligible,

$$2. \frac{\pi}{4} D^2 = \frac{\pi}{4} d_1^2 + \pi d_1 h$$

$$= \frac{\pi}{4} d_1^2 + \pi \frac{(d_2 + d_1) h}{2}$$

$$D^2 = d_1^2 + 2(d_1 + d_2)h$$

$$D = \sqrt{d_1^2 + 2h(d_1 + d_2)}$$

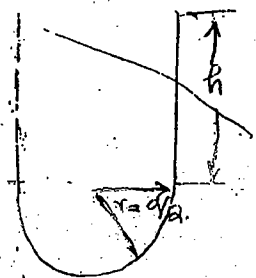


3.

$$\frac{\pi}{4} D^2 = \pi d h + \frac{\pi d^2}{2}$$

$$D^2 = 4dh + d^2$$

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



8. A hemispherical cup of 200 mm radius is to be produced from a blank. The radius of the blank required is _____

$$\frac{\pi}{16} D^2 = \frac{4\pi r^2}{2}$$

$$D^2 = 8r^2$$

$$D = 2\sqrt{2}r$$

$$= 565 \text{ mm}$$

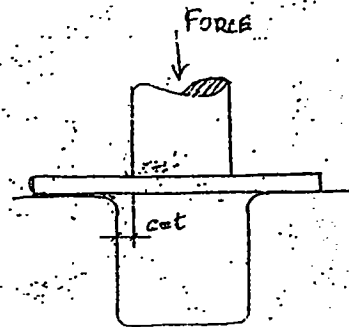
$$R = 282 \text{ mm}$$

12.09

— In deep drawing also, punch and die combination is used

as tool for producing the component.

But the clearance b/w the punch and die is equal to the sheet thickness which is greater than the optimum clearance, hence when the force is applied by the punch, the blank will be pulled in to the die without any shearing action.



— During deep drawing, when the forces are applied by using the punch, the average stresses induced in the sheet is greater than the yield and less than the ultimate stress

$$\sigma_y < \sigma < \sigma_u$$

But in some local areas of a sheet, the stresses induced may become greater than ultimate. In such areas the cracking of the material will be taking place, which leads to leakage during the usage of the component.

- To avoid this problem, it is always preferable to perform the deep drawing operation in more than one stage or draw.

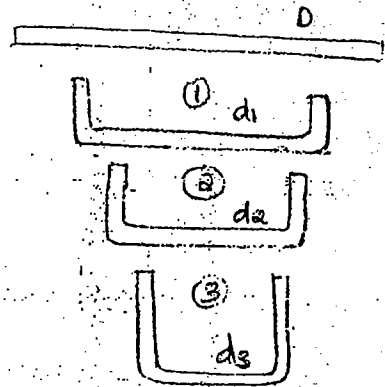
Drawing load (P)

$$P = \pi d t \sigma_y \left(\frac{D}{d} - c \right)$$

$$P_1 = \pi d_1 t \sigma_y \left(\frac{D}{d_1} - c \right)$$

$$P_2 = \pi d_2 t \sigma_y \left(\frac{d_1}{d_2} - c \right)$$

$$P_3 = \pi d_3 t \sigma_y \left(\frac{d_2}{d_3} - c \right)$$



- For this, separate punches (varying dia's) are used.

d_1, d_2, d_3 - dia's of the blank at different stages

t - thickness of the blank

σ_y - yield stress of the material

D - diameter of the blank

c - constant to cover friction, bending and corner radius etc

$$c = 0.6 \text{ to } 0.7$$

- In a given deep drawing operation, if corner radius is negligible, and bending is also negligible i.e., $c=0$

$$c=0 \Rightarrow P_3 = \pi d_3 t \sigma_y$$

$$\text{Work done} = P_1 \times h_1$$

$$W.D_2 = P_2 (h_2 - h_1)$$

$$W.D_3 = P_3 (h_3 - h_2)$$

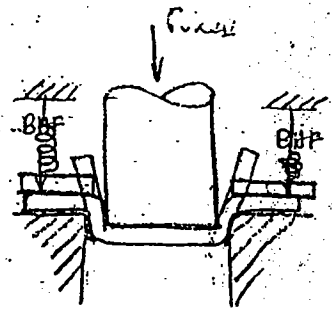
h_1, h_2, h_3 can be calculated using

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

$$= \sqrt{d_1^2 + 4ct_1 h_1}$$

$$= \sqrt{d_2^2 + 4ct_2 h_2}$$

- When the force are applied onto the blank by punch, the edge of the blank lifts creating the wrinkles or folding on the component and make the appearance very bad. To avoid this wrinkles, it is required to avoid the lifting of edge. It is possible by applying some amount of force onto the blank called blank holder force (BHF)



$$BHF < P$$

$$= \frac{1}{3} P \quad \text{avoid the lifting of edge}$$

$$BHF_d = \frac{P_d}{3}, \quad BHF_s = \frac{P_s}{3}$$

eg Spring loaded stripping plate is used for providing blank holder force (BHF)

By adjusting the compression of the spring, the amount of blank holder force can be varied.

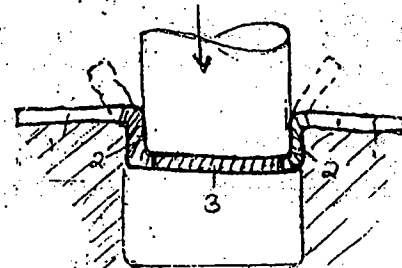
08/12/2010 — The BHF applied by using spring loaded stripper plate can be maintained until the punch is completely withdrawn from the deep drawing component.

- Partially deep drawn component can be divided into 3 zones:

Zone 1: Bottom of the punch

Zone 2: deformation zone

Zone 3: Flange portion.



At the bottom (Zone 1), stress is induced

without BHF — no stress

with BHF — tensile

At zone-2,

without B.H.F.
with B.H.F.

purely tensile; and the compressive stresses induced will be negligible and this tensile

stresses only will be responsible for changing the shape of component.

At zone-3,

without B.H.F. - tensile in 2 directions and comp. in the third.

with B.H.F. - tensile stresses

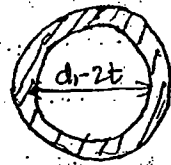
Because the stresses induced in zone 2 is only responsible for changing of the shape of the component, it is required to determine the magnitude of stresses induced in zone 2 in different stages. Stresses induced in zone 2 must be greater than yield and less

Let σ_{2n} - stress induced in zone 2 of stage 1. than ultimate.

$$\sigma_{21} = \frac{P_1}{\frac{\pi}{4} \{d_1^2 - (d_1 - 2t)^2\}}$$

$$\sigma_{22} = \frac{P_2}{\frac{\pi}{4} \{d_2^2 - (d_2 - 2t)^2\}}$$

and so on.



$\sigma_y < \sigma_{2n} < \sigma_u \Rightarrow$ possible

$\sigma_{2n} < \sigma_y \Rightarrow$ impossible

$\sigma_{2n} > \sigma_u \Rightarrow$ failure

$$\sigma_{2n} = \frac{P_n}{\frac{\pi}{4} \{d_n^2 - (d_n - 2t)^2\}}$$

$\sigma_y < \sigma_{2n} < \sigma_u$
 $n=1, 2, 3, \dots$

No. of draws (or) stages.

1. Draw ratio method:

$$DR = \frac{d_{a, \text{ before drawing}}}{d_{a, \text{ after drawing}}}$$

$$DR_1 = \frac{D}{d_1} \quad DR_2 = \frac{d_1}{d_2} \quad DR_3 = \frac{d_2}{d_3} \quad \text{and so on}$$

$$\sigma_y < \sigma < \sigma_u$$

For this, limiting draw ratio

$$LDR = DR_1 = DR_2 = DR_3$$

= 1.6 to 2 hard materials

= 2 to 3 soft materials

$$\text{If } d_1 = \frac{D}{DR_1} \leq d_f \text{ then } n=1$$

if not, $d_2 = \frac{D}{DR_2} \leq d_f$ then $n=2$, and so on.

Whenever the dia of the draw before is less than or equal to the final dia.

Q. Cup of dia = 30mm.

$h = 150 \text{ mm}$ $n = ?$

$DR = 1.7$

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

$$= \sqrt{30^2 + 4 \times 30 \times 150}$$

$$= 137.4 \text{ mm}$$

$$d_1 = \frac{D}{DR_1} = \frac{137.4}{1.7} = 80 > 30$$

$$d_2 = \frac{80}{1.7} = 47 > 30$$

$$d_3 = \frac{47}{1.7} = 27 < 30 \quad n=3$$

2. Draw reduction ratio method.

$$DRR = \frac{\text{dia. reduced}}{\text{dia. before.}}$$

$$DRR_1 = \frac{D - d_1}{D}$$

$$DRR_2 = \frac{d_1 - d_2}{d_1}$$

$$DRR_3 = \frac{d_2 - d_3}{d_2}$$

$$DRR_1 = 45 \text{ to } 50\%$$

$$DRR_2 = 30 \text{ to } 35\%$$

$$DRR_3 = 20 \text{ to } 25\%$$

$$DRR_4 \text{ and above} = 16\%$$

$$\Rightarrow d_1 = D(1 - DRR_1) \leq d_f, n=1$$

$$\text{if not } d_2 = d_1(1 - DRR_2) \leq d_f, n=2$$

$$\text{if not } d_3 = d_2(1 - DRR_3) \leq d_f, n=3 \text{ and so on}$$

Q. Cup. of dia. = 30 mm

$$h = 150 \text{ mm}$$

$$\text{DRR}_1 = 40\%$$

$$\text{DDR}_2 \text{ and above} = 55\%$$

$$D = 137.4 \text{ mm}$$

$$d_1 = 137.4 (1 - 0.4) = 82.44 > 30$$

$$d_2 = 82.44 (1 - 0.4) = 49.46 > 30$$

$$d_3 = 49.46 (1 - 0.4) = 29.68 > 30$$

$$d_4 = 29.68 (1 - 0.4) = 17.81 > 30$$

$$d_5 = 17.81 (1 - 0.4) = 10.69 < 30 \quad n = 5$$

Note: for doing problems $\Rightarrow$ In the problem, if LDR value is given, use draw ratio method for determining the no. of draws. If DRR value is given, use draw reduction ratio method. In case, both the values are not given, use draw ratio method with $\text{LDR} \approx 2$ to det. the no. of draws.

Q. Cup. of dia. = 12 mm, height = 30 mm. Determine the no. of draws from a sheet of 1 mm thickness.

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

$$= 140 \text{ mm}$$

$$d_1 = \frac{D}{2} = 70 \text{ mm}$$

$$d_2 = \frac{d_1}{2} = 35 \text{ mm} < 12 \quad n = 2$$

DEFECTS IN DEEP DRAWING

- The method of producing wrinkles or folding in a deep drawn component is called wrinkling.
- It can be reduced by

a. Providing B.H.P.

b. Ironing effect: In deep drawing operation, the clearance b/w the punch and die is made slightly less than sheet thickness.

i.e., clearance = 90 to 95% sheet thickness

When the sheet is flowing through the gap, the material is squeezed out and removes the wrinkles present in the component. This is called ironing effect.

c. By providing draw bead.

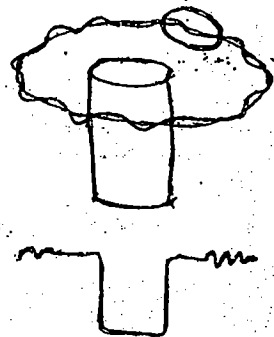
a. Earing:

- The method of producing wrinkles on the flange edge of deep drawing component or waviness present in it is called earing defect.

[It is produced mainly due to anisotropic properties of blank material.]

- Even though, initial blank used in deep drawing operation is having isotropic properties, during deep drawing when the stresses are induced of different magnitude or diff. places,

[At the inside surfaces of workpiece compressive stress are induced, on the outer



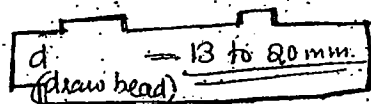
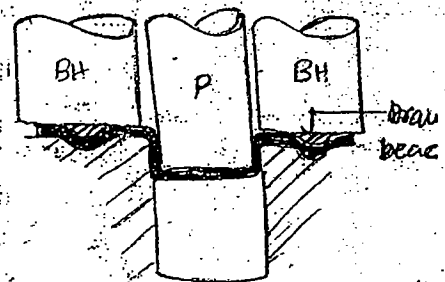
different amounts/magnitudes of strain hardening or work hardening takes place making the material anisotropic and producing earing defect

$$\text{No. of ears} = 2^n$$

n is an integer = 1, 2, 3, ...

— Complete elimination of earing is not possible. But it can be minimised by providing draw beads.

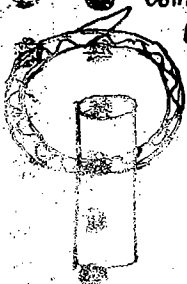
A semi-circular strip provided around the circumference of the blank holder is called draw bead.



Using drawbead, the blank will be experiencing comp. and tensile stresses on both the sides at different locations. Hence the mechanical properties of material is becoming nearly uniform. Hence the earing defect is minimised.

- The effects of using draw bead are
1. It eliminates the wrinkles completely.
 2. Minimises the earing defect.
 3. Reducing the blank holder force.
 4. Increasing drawing force required.

trimmed portion



— Because, earing is not completely eliminated, it can be removed by trimming or edge trimming. But due to trimming, size of the component will be reducing. To maintain the size, original blank diameter must be increased.

Dr. D. S. S. S. S.

BENDING OPERATION.

- Bending a sheet into the required angle by applying the force such that the stresses induced is greater than yield stress and less than ultimate stress.

$$\sigma_y < \sigma < \sigma_u$$

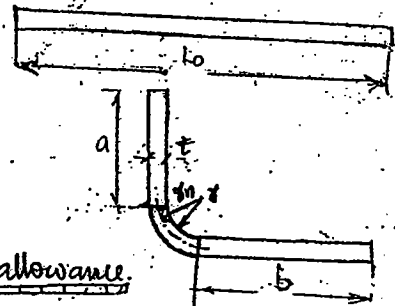
eg. window frames, drawing board clip, fan wings etc.

L_0 = length of original flat

starting strip

= developed length.

= $a + b + B$ where B = bend allowance



- B is the length of the strip required for the bend portion of a component.

$$\text{Bend allowance} = \pi r_n \times \theta$$

r_n - radius of the neutral axis

θ - angle of bending in radians

We know, during bending,

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R_n}$$

$$R = r_n = (r + kt)$$

r - inside radius of bend.

k - stretch factor or bend factor

t - thickness.

$$k = \frac{1}{3} \text{ if } t < 0.075$$

$$k = \frac{1}{2} \text{ if } t \geq 0.075$$

eg. Drawing board clp.

$$L_0 = a + b + c + \alpha B_1 + B_2 + B_3$$

Bending allowance, $B_1 = (r_1 + kt)\theta_1$

$$B_2 = (r_2 + kt)\theta_2$$

$$B_3 = (r_3 + kt)\theta_3$$

$$\text{Bending force} = F_b = c \frac{L_0 \sigma_y t^2}{W} \text{ N}$$

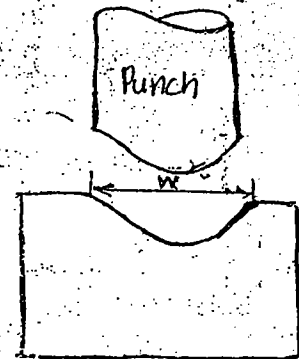
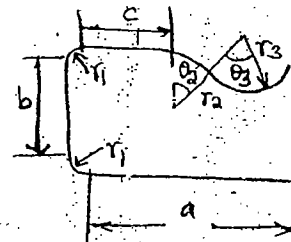
Where L_0 - developed length

σ_y - yield stress

t - thickness of sheet

W - width of die opening

$W = 8t$ or $16t$



Here also, punch and die combination is used.

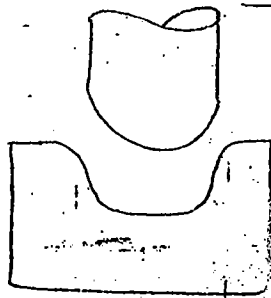
C = die opening factor

≈ 1.2 if $W = 16t$

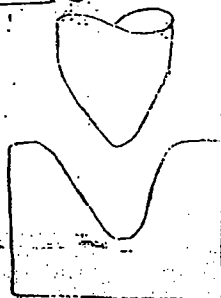
≈ 1.33 if $W = 8t$

Larger the die opening easier is bending operation, hence low values of opening factor required. In general, the bending operation will be done in

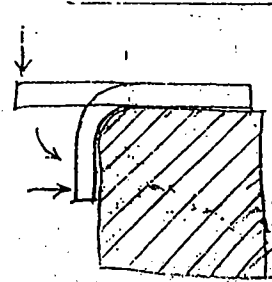
3 methods - U bending, V bending, edge bending



U bending



V bending



Edge Bending

— If a component is produced by all the 3 methods of bending, the force required will be

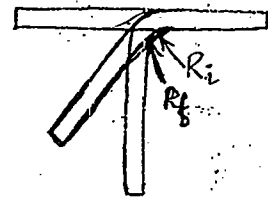


$$U:V:Ed = 2:1:0.5$$

— On bending operation, even though the material is stressed into the plastic deformation zone, some amount of elastic deformation is still present. Due to this, some amount of regaining of the shape ~~of~~ will be taking place called spring back in bending.

The ratio between R_f and R_i is used to indicate spring back

$$\frac{R_f}{R_i} \Rightarrow \text{spring back}$$



$$\text{If } \frac{R_f}{R_i} < 1, \text{ spring back} = 0.$$

As $\frac{R_f}{R_i}$ increases, spring back also increases

$$\left(\frac{R_f}{R_i} \right) = 1 + \left(\frac{R_i \sigma_y}{E t} \right)^2 - 3 \left(\frac{R_i}{E t} \right) + 1$$

In bending operation, it is always preferred to have the lowest spring back. It can be reduced by

- reducing $\frac{R_i}{t}$
 - reducing σ_y
 - increasing E
- } Spring back in yield.

— r_{min} is the min. radius to which the sheet can be bent without producing cracks on the outer surface of a bent component.

Eg Whenever the sharp end components are to be produced, the radius to which the sheet has to be bent is zero

$$r_{\min} = t \left[\frac{50}{a} - 1 \right]$$

where a = % reduction of area of material on the time of fracture during tensile test.

$a_{\max} = 50\%$ (very soft materials; MS, Cu, Silver etc.)

i.e., materials having $a_{\max}$ can be bent to a $r_{\min} = 0$.

For Titanium, $a = 14.5\%$

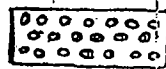
$$r_{\min} = t \left[\frac{50}{14.5} - 1 \right] \\ = 2.5t$$

MINOR OPERATIONS ON SHEET

1. Perforating

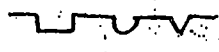
— Method of producing many no. of smallest size of holes in a sheet is called perforating.

eg. sheave.



2. Notching

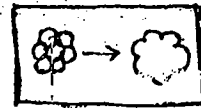
— It is the removing of a piece of a material from the edge of a sheet to produce a notch.

eg. 

3. Lancing: is the method of producing an incomplete hole or incomplete blank in the centre of the sheet.

4. Slitting: method of producing an incomplete hole or blank at the edge of the sheet.

5. Nibbling: is the method of producing a large sized hole using a small size punch in many no. of repetitive strokes.

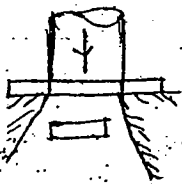


6. Trimming: The method of removing a piece of material from the complete circumference of the sheet is called trimming.

19.09

TYPES OF DIES.

1. Simple die:



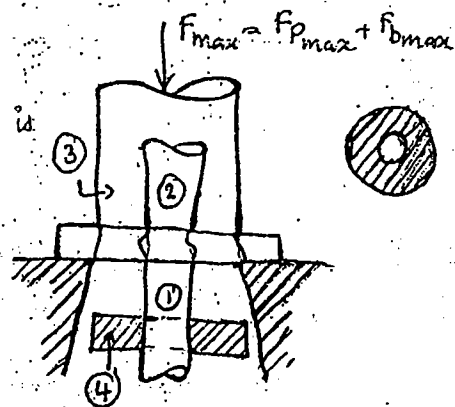
If only one operation is performed in one stage at one time is called a simple

2. Compound die:

If more than one cutting operation is performed in one stroke in one stage is called compound die.

eg production of a washer.

The advantage of compound die is that one component can be produced per stroke therefore production rate is high.



Both ~~though~~ the method of reducing

the punch force cannot be used in compound die. So the force required will be very high.

If the no. of operation to be performed is greater than 3 it is difficult to manufacture using a compound die.

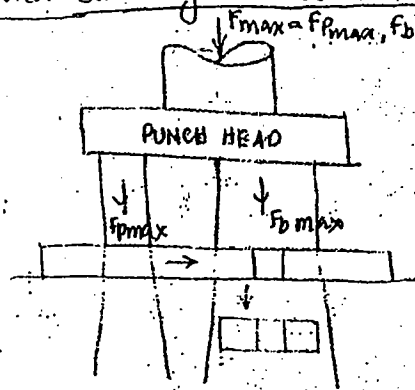
3. Progressive die

Here more than one cutting operation is performed in one stroke but at different stages so that the punched out sheet is moving from one stage to another and blanking will be the last operation.

eg production of washer.

The advantages of progressive die are:

- The production remains same as compound die. i.e., one component per stroke can be produced.



- Either by providing shear or by staggering, the force required can be reduced.

- Design and manufacturing of punch and die is easier, whatever may be the no. of operations.

The only difficulty facing here is the balancing of punch and die.

4. Transfer die

Here, more than one cutting operation can be performed in one stroke at different stages. But blanking will be the first operation.

So that the blank produced is moving to the next stage for completing the remaining punching operation.

Among progressive and transfer dies, the progressive die is preferable because once the sheet is set, it easy to travel one stage to another without any further setting.

Whereas in a transfer die, in every stage, the blank has to be set.

5. Combination die:

If cutting operations are combined with forming operation and performed at one stroke in one stage, it is called a combination die. i.e., the punching ^{or} ~~and~~ blanking is combined with deep drawing or bending operations.

6. Multiple die:

In the above dies, only one component is produced per stroke.

But if more than one component is to be produced per stroke, more than one of the above dies are kept in parallel.

eg. To produce, 10 washers per strokes, 10 compound dies or 10 progressive dies are kept in parallel.

- Metal cutting - Redford & Boothroyd - Machine Tool Engg - Nagpal
- Sen & Bhattacharya - Tumeja & Sherkar

METAL CUTTING

- Experimental investigation in metal cutting - V.C. Venkatesh

20.09

The method of analysing metal removal process for determining force and ~~power~~ ^{power} consumption during machining, temperatures induced during machining, tool life, surface finish etc is called metal cutting or machining process.

By doing the machining analysis and determining the different parameters, it is possible to decide the rigidity requirements of the machine, the capacity of the prime mover required, selection of the cutting tool material, selection of process parameters during machining etc.

Hot hardness temp is the min temperature at which increase in temp. causes considerable reduction in the hardness of the tool material.

Rockwell hardness

eg For H.C. steel tool $RT(30^{\circ}C) \rightarrow RC\ 65$

$100^{\circ}C \rightarrow RC\ 64$

$200^{\circ}C \rightarrow RC\ 63$

$250^{\circ}C \rightarrow RC\ 62$

$260^{\circ}C \rightarrow RC\ 61$

$\Rightarrow$ hot hardness temp of H.C. steel is $250^{\circ}C$

HSS $\rightarrow 600^{\circ}C$

Diamond

2. The metal removed from the work piece can be done by using
you can use cutting tools.

1. Single point cutting tool : only one cutting edge is used for
removing the metal from the workpiece.

eg. lathe, shaping, tools.

2. Multi point cutting tool : more than one cutting edge is
available for removing the metal from the workpiece.

eg. milling cutter, drill bits, etc.

Factors influencing the machining operations

1. Mechanical properties of work material

With increase of hardness of W.M. force and power consumption
are increasing, heat generation is increasing, temperature is
increasing and tool life is reducing.

2. Tool geometry

The geometric properties of single point cutting tool like
back rake angle (when back rake angle, force and power
consumption are reducing and so is heat generation and
temperature but increases tool life).

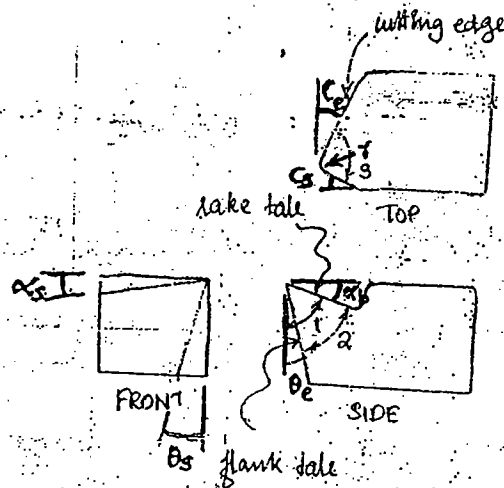
3. Interaction b/w tool and work piece (process parameters in machining)

The speed, feed and depth of cut are taken as process
parameters of machining.

eg. With increase of speed, Power $\uparrow$;

↑ Feed and depth $\Rightarrow$ ↑ Force

TOOL GEOMETRY



α_b - back rake angle

α_s - side rake angle

θ_e - end relief angle

θ_s - side relief angle

C_e - end cutting edge

C_s - side cutting edge

r - nose radius

- 1 - cutting angle $= 90^\circ - \alpha_b$
- 2 - lip angle $= 90^\circ - \alpha_b - \theta_e$
- 3 - nose angle

For easy understanding and identifying the geometric properties of a single point cutting tool, a standard method must be used for indicating the geometric properties called tool designation or tool signature.

1. ASA system: (American Standards Association system)

$$\alpha_b - \alpha_s - \theta_e - \theta_s - C_e - C_s - r$$

The advantages of ASA system are

i. Because all the geometric parameters used in the designation can be seen in 3 views of a single point cutting tool.

Hence it is easy to understand.

ii. Whenever the angle used in the designation, are

measured with respect to the cutting direction.

Measurements of the angles are given

— Limitation

1. During machining operations, the formation of the shear plane, flow behaviour of the chip etc. is taking place w.r.t. cutting edge of the tool. Therefore if different geometric properties of a single point cutting tool are measured w.r.t. cutting edge of the tool, the analysis of the machining process become easier.

Whereas in AS system, since the angles are measured w.r.t. to planes, analysis of machining process becomes difficult.

2. O.R.S. (Orthogonal Rake system)

$$\underline{i} - \underline{\alpha} - \underline{\theta_s'} - \underline{\theta_e'} - \underline{C_e} - \underline{\lambda} - \underline{r}$$

i - inclination angle

α - side rake angle or effective rake or orthogonal rake angle.

θ_s' - side relief angle

θ_e' - end relief angle

C_e - end cutting edge angle

λ - approach/entering or principal cutting edge angle.

r - nose radius.

Whatever the six angles used in the designation, are measured w.r.t. cutting edge of the tool. Therefore the analysis of machining will be easier.

- Understanding of the angle in ORS designation and their measurement is difficult.
- The most commonly used designation in the industry is ASA system of designation.
- If nothing is specified at the place of designation, it is assumed that the given designation is an ASA system.
- Both the designations of a cutting tool can be used for the designation of one tool itself. The relationship between them is given by

$$\begin{bmatrix} \tan i \\ \tan \alpha \end{bmatrix} = \begin{bmatrix} \sin \lambda & -\cos \lambda \\ \cos \lambda & \sin \lambda \end{bmatrix} \begin{bmatrix} \tan \alpha_b \\ \tan \alpha_s \end{bmatrix}$$

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

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

$$\text{And } \begin{bmatrix} \tan \alpha_b \\ \tan \alpha_s \end{bmatrix} = \begin{bmatrix} \sin \lambda & \cos \lambda \\ -\cos \lambda & \sin \lambda \end{bmatrix} \begin{bmatrix} \tan i \\ \tan \alpha \end{bmatrix}$$

$$\text{Ify } \begin{bmatrix} \cot \theta_s \\ \cot \theta_e \end{bmatrix} = \begin{bmatrix} \sin \lambda & -\cos \lambda \\ \cos \lambda & \sin \lambda \end{bmatrix} \begin{bmatrix} \cot \theta_s' \\ \tan \theta_e' \end{bmatrix}$$

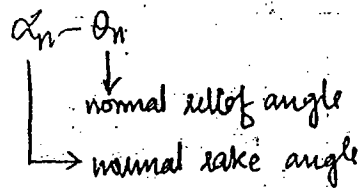
$$\begin{bmatrix} \cot \theta_s' \\ \tan \theta_e' \end{bmatrix} = \begin{bmatrix} \sin \lambda & \cos \lambda \\ -\cos \lambda & \sin \lambda \end{bmatrix} \begin{bmatrix} \cot \theta_s \\ \cot \theta_e \end{bmatrix}$$

C_e = remain same

$C_s = 90 - \lambda$ or $\lambda = 90 - C_s$

γ = remain same.

3. N.R.S. (Normal Rake System)



$$\tan \alpha_n = \tan \phi_n (\tan \alpha \cot \phi)$$

$$\phi_n = \tan^{-1} \left(\frac{\tan \alpha \sin \phi}{\cos \phi} \right)$$

Effect of tool geometry on machining

1. Back rake angle (α_b)

— With increase in (α_b) the area available for cutting

the force is decreasing.

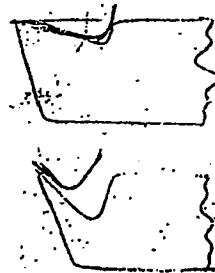
Thus the strength of the tool decreases

— With increase of α_b , force and power consumption will be reducing.

— The length of the contact of tool and workpiece decreases, so energy wasted.

— The wear land (contact area b/w the tool and work piece)

(Tool is considered to be failed if wear land $\geq 3 \text{ mm}^2$)



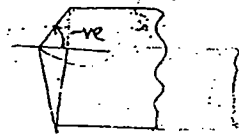
— The back rake angles can be used as $-ve$, 0 , $+ve$ values. Positive back rake angle is the most commonly used one, the maximum value of which is 45° beyond which the strength of the tool reduces drastically. Hence the tool will fail ~~when~~ ^{as soon as} the machining starts.

— The zero α_b is used during machining of Brass work pieces and also during thread cutting operations. $\alpha_b = 0$

— During Brass work piece machining, the surface obtained is very good with zero α_b .

— During thread cutting, if $+ve$ α_b is used, the chip may flow side wards trying to shear off the thread. ~~Therefore~~, When zero α_b is used, the chip will flow straight upwards.

— Usage of $-ve$ α_b has been started with the introduction of the carbide tipped tools because, carbide tools are very weak in tension.



— The maximum $-ve$ α_b used is 10° only beyond which ^{there} increase in $-ve$ α_b increases the forces and power consumption drastically, reducing the tool life.

2. Side rake angle (α_s)

$\uparrow \alpha_s$ strength $\downarrow$

- With the increase of α_s the amount of chip bending in width direction reduces.

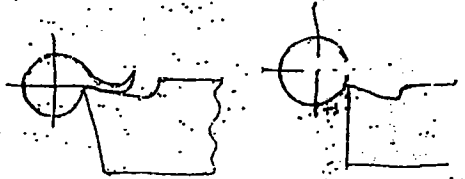
Force & power $\downarrow$ slightly
tool life $\uparrow$

- α_s can take only two values, the nominal value of α_s are 5° to 15° .

3. End and side relief angles [θ_e, θ_s]

- The relief or clearance angles are mainly provided to avoid the rubbing action b/w the tool and work piece.

- When relief angles $= 0$, the tool is simply rubbing under the work piece without doing any machining.



$\uparrow \theta_e, \theta_s \Rightarrow$ strength $\downarrow$
Force & power $\downarrow$ slightly
tool life $\uparrow$ slightly.

- The nominal value of relief angle are 5° to 15° .

4. End and side cutting edge angles

- Cutting edge angles are mainly influencing the surface finish produced on the work piece.

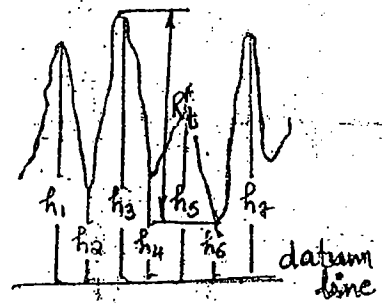
$$\left[\frac{R_t - \text{max. peak to valley height}}{f} \right] = \frac{f}{\tan \phi + \cot \phi_e}$$

f - feed in mm/rev.

- As the value of R_t is increasing,
the surface finish of a component
is becoming poor.

$$R_t = \frac{1}{\tan C_e \cot C_s}$$

$\Rightarrow \uparrow C_s \rightarrow R_t \downarrow \Rightarrow$ better finish
and $\uparrow C_e \rightarrow R_t \uparrow \Rightarrow$ poor finish.



Page 3, Q24

Q. 8.

$$R_{t1} = \frac{1}{\tan 25^\circ \cot 5^\circ} = 0.08 \text{ } \checkmark$$

$$R_{t2} = \frac{1}{\tan 30^\circ \cot 7^\circ} = 0.1146 \text{ } \checkmark$$

- The nominal values of C_e and C_s are

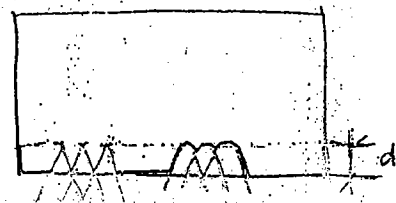
$$\begin{aligned} C_e &= 8^\circ \text{ to } 15^\circ \\ C_s &= 0^\circ \text{ to } 90^\circ \end{aligned}$$

Nose radius:

- It influences the surface produced on the work piece

$$R_t = \frac{16}{8r}$$

$\Rightarrow \uparrow r \rightarrow R_t \downarrow \Rightarrow$ better finish.



— With increase of nose radius, the contact area b/w tool and workpiece increases, therefore force in machining, increases the vibration and chattering and make the surface finish poor.

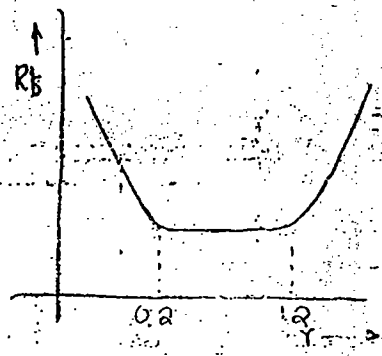
— The nominal value of nose radius

is

$$0.2 < r < 1.2$$

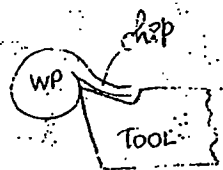
$$\frac{L^2}{8f}$$

$$\frac{1}{\epsilon \mu C_s} + \frac{101 C_e}{\mu} \frac{1}{\mu} \frac{1}{\mu}$$

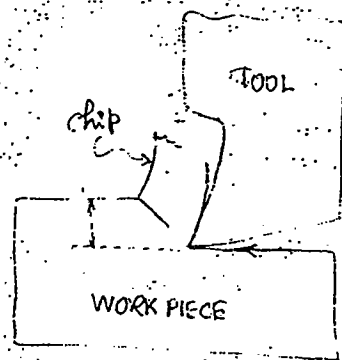


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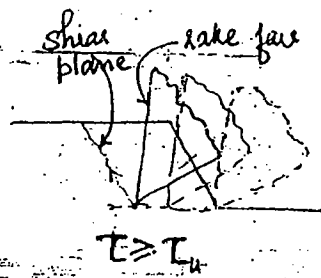
MECHANISM OF CHIP FORMATION



90°



— When the force is applied by using the tip of the tool on to the layer of w.p, material is deforming plastically and sliding over the rake face of the tool, producing shear stresses on the layer of work material. On further application of force by using the tool tip, the shear stresses induced in the layer of work material is increasing, at some point, the shear stresses may become greater than or equal to the ultimate shear stress of work material.



Hence the shearing or cracking starts at the tip of the tool and propagates towards the surface producing shear plane.

- From the above, the mechanism of chip formation is by shearing and tearing action.
- During machining of soft work piece, continuous chip are produced, while for hard work pieces, it is discontinuous.
- During machining of soft work pieces, because of higher toughness, the crack propagation (energy wave propagation) will get absorbed by the work material and it disappears somewhere in the middle which maintains the continuity of the chip at the top side. Hence continuous chips are produced.
- During machining of hard W.P.s, because of lower toughness, the energy or crack waves can propagate upto the surface very easily which separates the chip from the W.P. Hence discontinuous chips are produced.
- Always during machining, whether the types of chips produced is continuous or not, some amount of vibrations or powdered particles are produced. When these particles are removed, high temp. during machining, they will get removed.

welded on to the rake face of the tool called built-up-edge (BUE) formation.

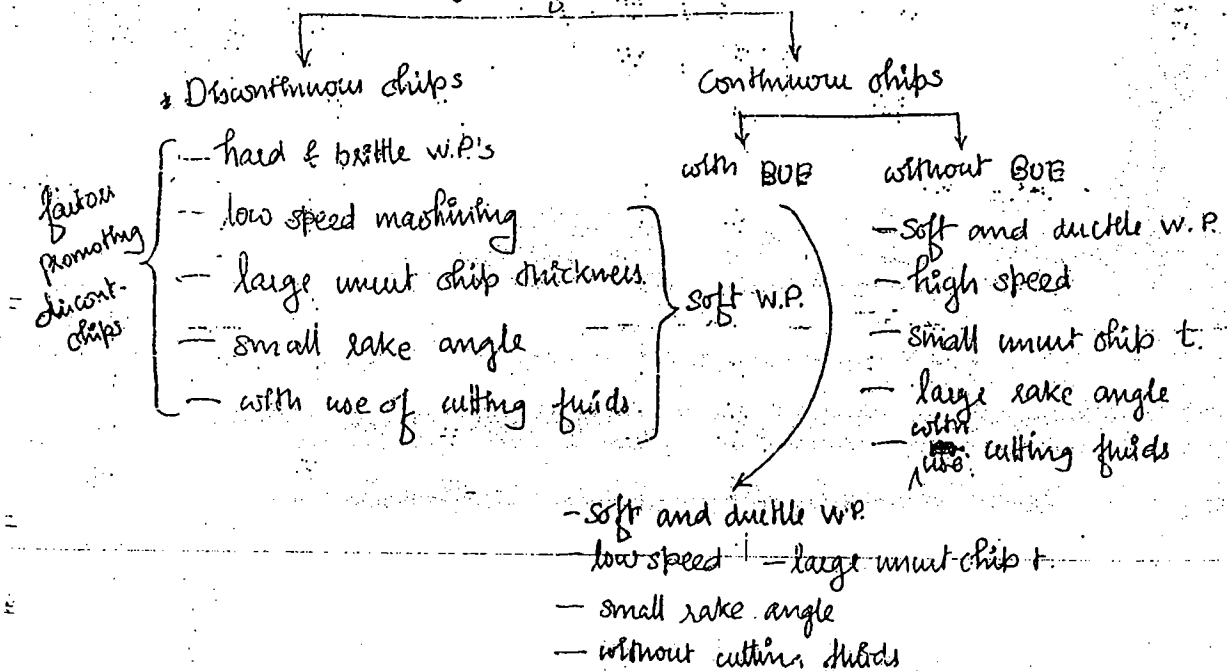
— BUE formation is taking place only with continuous chips.

because, in case of discontinuous chips, as soon as the chip is forming, it is immediately thrown away from the machining zone so that the microchips also will get thrown away. Hence no chance of adhering ^{for} it to the rake face.

— During BUE formation, whatever the wear and tear to be Adv taken place on the rake face of the tool is only the built-up-edge will get wear out, hence the tool life increases.

— But with BUE formation, the surface finish of rake face of the Disadv tool will get damaged which increases the friction and frictional energy losses, hence the required power for machining increases.

Types of chips.



- During low speed machining, the time available for the cutting of the chip is high allowing the chip to bend a which will allow the propagate the existing cracks producing discontinuous chips.

- [During the removal large thickness of the material, the force to be applied by the chip of the tool is increasing which increases the magnitude of the energy wave propagation hence the chances of propagating the energy waves upto the surface is high.

- By reducing the rake angle, the force and power consumption increases which increases the magnitude of energy wave propagation.

- During machining, when the heat is generated the temp. of the chip is high due to this, the chip is getting expanding.

If the cutting fluid is poured, the heat is carried away by it which reduces the temp. of the chip so that the chip is getting contracting. i.e., in short duration, the chip is expanding and contracting so that any cracks present in the chip will get propagated converting the chip into discontinuous.

- For high speed machining, the time available for microchip adhering is very less. ^{heat generated} and power consumption

- With small uncut chip t, the force to be applied by the tool is reducing hence the chances of adhering a chip is eliminated.

— With use of cutting fluids, the heat generated is completely carried away by ~~the~~ it, hence there is no chance of adhering of microchips as there is no little heat generation.

Q. During face turning of a soft w.p. material with optimum cutting velocity from surface towards the centre, the type of chip produced is _____

- a) continuous throughout
- ✓ b) continuous at beginning and discont. throughout to end.
- c) discontinuous throughout
- d) discontn. at beginning and continuous throughout to end

$$V_s = \frac{80N}{1000}$$

As the turning progresses,
the dia of w.p. reduces
reducing the cutting velocity

NOTE:

1. In a given machining operation, it is always preferable to have discontinuous chips only because, it is always easy to dispose.

2. In certain machining, it is compulsory that chip produced are continuous. To convert the continuous into discontinuous chips, the chip breaker can be used.

The principle by which the cont. chip is

converted into discont. using chip breaker is by bending

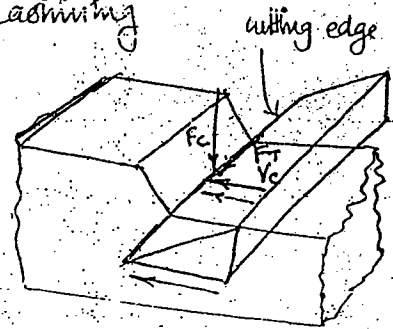


METHODS OF MACHINING

1. Orthogonal machining
2. Oblique machining

— If the cutting edge of the tool is $\perp$ to the cutting velocity vector then it is called orthogonal machining

— If the cutting edge is not $\perp$ to the cutting velocity vector, then oblique machining.



eg. Jack plane, operation in carpentry
parting off in turning, sawing, broaching etc. (orthogonal)

eg. turning, drilling, milling, shaping, grinding etc. (oblique)

— The force acting parallel to the cutting edge - F_t
and which acting $\perp$ to cutting edge - F_c

— When $\theta = 90^\circ$, only 2 components of forces (F_c and F_t) are acting. Therefore it is also called 2D machining.

— In oblique machining, because $\theta \neq 90^\circ$, the horizontal comp. of force F_t is divided into 2 components of forces

$$F_t \begin{cases} F_a = F_t \cos \theta \text{ (axial component)} \\ F_r = F_t \sin \theta \text{ (radial component)} \end{cases}$$

Here, since 3 components of force are acting, it is called 3D machining.

So cutting

— Since there is no direct methods are available for analysing oblique machining problem, it is converted into orthogonal mac. and analysed as orthogonal.

ANALYSIS OF ORTHOGONAL MACHINING

Let t_1 = uncut chip thickness

t_2 = chip thickness

$\alpha = \alpha_b$ (ASA) or α (OES)

$\frac{t_1}{t_2} = r$ chip thickness ratio
chip equivalent

$k = \frac{1}{r}$ chip reduction coeff.

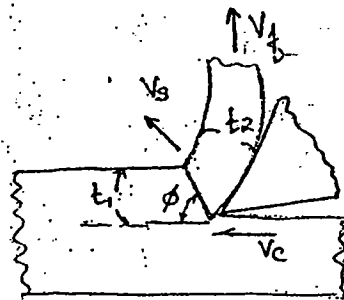
b_1, b_2 - width of the chip before
and after machining

L_1, L_2 - length of chip per revolution before and after machining

$V_c = V$ cutting velocity or velocity of the chip tool relative to the workpiece

V_f chip flow velocity or velocity of the chip relative to tool

V_s shear plane velocity or velocity of chip relative to w.p



For machining operation analysis, there are 2 basic assumptions.

1. Any material which is undergoing the machining operation is considered as incompressible i.e., volumetric change is zero.
2. Width of the chip remains constant before and after machining $b_1 = b_2$

— The force applied by using tip of the tool onto the layer of work material is acting like a compressive force in the length direction. Therefore the length of chip after machining is always less than before. $L_2 > L_1$

— When length of the chip is reducing, the volume of the chip is reducing in the length direction, but it has to be increased in thickness or width direction. But thickness of the chip is very small as compared to the length of the chip. Therefore whatever the volume change in the length direction is increasing only in the width direction. $t_2 > t_1$

$$r_2 \frac{t_1}{t_2} < 1 \quad (\text{OR})$$

Volume before = volume after

$$t_1 b L_1 = t_2 b L_2$$

$$\frac{L_2}{L_1} = \frac{t_1}{t_2} = r < 1$$

Volume per revolution

$$t_1 b V_c = t_2 b V_f$$

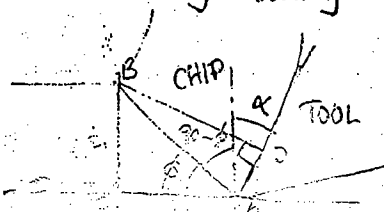
$$\frac{t_1}{t_2} = \frac{V_f}{V_c} = r$$

$$r = \frac{t_1}{t_2} = \frac{L_2}{L_1} = \frac{V_f}{V_c}$$

— The angle made by the shear plane with the cutting velocity vector is called shear angle (ϕ)

$$\sin \phi = \frac{Be}{AB}$$

$$\sin \phi$$



ΔABD

$$\sin(90 - (\phi - \alpha)) = \frac{BD}{AB}$$

$$AB = \frac{t_1}{\cos(\phi - \alpha)} \quad (a)$$

$$(1) = (2) \Rightarrow \frac{t_1}{\sin \phi} = \frac{t_2}{\cos(\phi - \alpha)}$$

$$\Rightarrow r = \frac{t_1}{t_2} = \frac{\sin \phi}{\cos(\phi - \alpha)}$$

$$= \frac{\sin \phi}{\cos \phi \cos \alpha + \sin \phi \sin \alpha}$$

$$= \frac{\sin \phi}{\cos \phi \cos \alpha + \sin \phi \sin \alpha} \left(\frac{\cos \phi}{\cos \phi} \right)$$

$$r = \frac{\tan \phi}{\cos \alpha + \sin \alpha \tan \phi}$$

$$\Rightarrow r \cos \alpha + r \tan \phi \sin \alpha = \tan \phi$$

$$\tan \phi (1 - r \sin \alpha) = r \cos \alpha$$

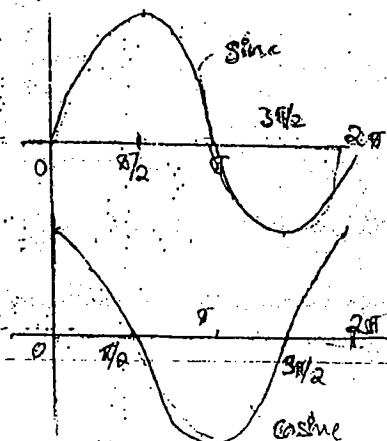
$$\boxed{\tan \phi = \frac{r \cos \alpha}{1 - r \sin \alpha}}$$

$\Rightarrow$ The shear angle depends on the chip thickness ratio, r and the rake angle, α

$$\phi = f(r, \alpha)$$

$$r \uparrow \phi \uparrow$$

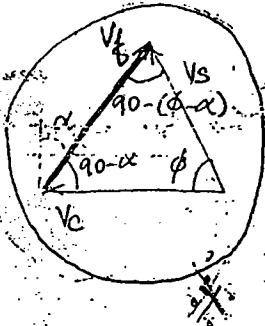
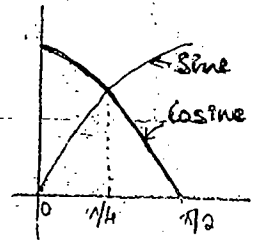
$$\alpha \uparrow \phi \uparrow$$



$$\alpha_{\max} = 45^\circ$$

Upto 45° , sine curve is almost linear

but cosine curve is reducing its value very gradually rapidly



$$\frac{V_f}{\sin \phi} = \frac{V_s}{\sin (90 - \alpha)} = \frac{V_c}{\sin (90 - (\phi - \alpha))}$$

$$\frac{V_f}{\sin \phi} = \frac{V_s}{\cos \alpha} = \frac{V_c}{\cos (\phi - \alpha)}$$

Forces in machining operation

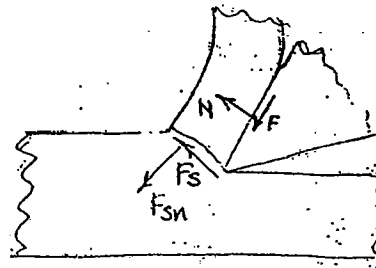
F, N, F_s, F_{sn} - actual forces

Let F be the frictional force acting between the chip and tool.

N be the force normal to F .

F_s shear force acting along the shear plane.

F_{sn} force normal to the shear force, F_s .



measurable (defined based on actual machining) forces

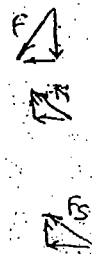
All the above actual forces are acting in the dynamic environment, therefore it is not possible to measure them.

The above 4 actual forces can be resolved into horizontal and vertical forces.

F_H - algebraic sum of horizontal comp.

$$F_H = F_T$$

F_V - alg. sum of vertical comp. forces



— The horizontal and vertical comp. of force can be measured by using either dynamometer or by spring balance.

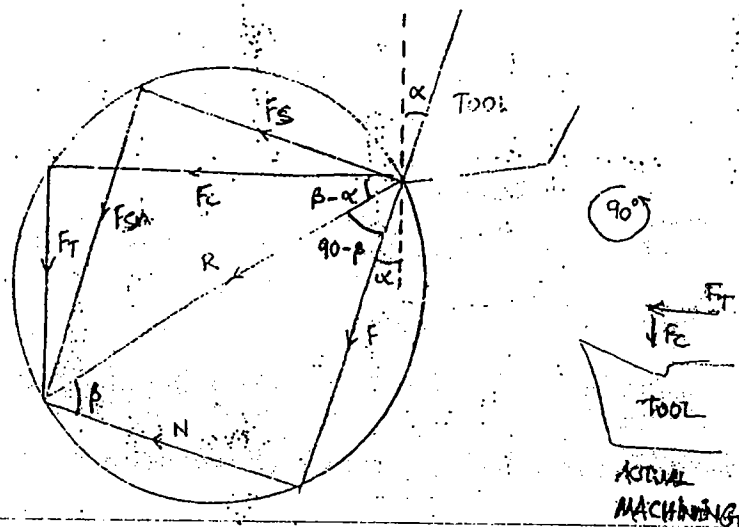
— From the above, the actual force used in the analysis of machining cannot be measurable.

The force which are measurable in the machining process cannot be used in the analysis. Therefore it is necessary to establish the relationship b/w the actual and measurable processes so that using dynamometer, the measurable force can be measured and from actual force can also be calculated. And using this the machining process can be analysed.

— For establishing the relationship b/w actual and measurable process, the Merchant's circle can be used.

$$\text{Resultant, } R = \sqrt{F_C^2 + F_T^2}$$

Using R as dia., draw a circle.



— From the Merchant's circle it is found that, there are 3 right angled triangles present all of which are possessing common hypotenuse. Using this as a basis, the relation b/w the measurable and actual forces can be established.

Q7.09

$$\cos \beta = \frac{N}{R}$$

$$\Rightarrow R = \frac{N}{\cos \beta} = \frac{F}{\sin \beta}$$

$$= \frac{F_c}{\cos(\beta - \alpha)} = \frac{F_T}{\sin(\beta - \alpha)}$$

$$= \frac{F_s}{\cos(\phi + \beta - \alpha)} = \frac{F_{sn}}{\sin(\phi + \beta - \alpha)}$$

Coefficient of friction

Now $\tan(\beta - \alpha) = \frac{F_T}{F_c}$

$$\beta = \alpha + \tan^{-1}\left(\frac{F_T}{F_c}\right) \checkmark$$

Coeff. of friction, $\mu = \tan \beta$

$$\tan(\beta - \alpha) = \frac{F_T}{F_c}$$

$$\frac{\tan \beta - \tan \alpha}{1 + \tan \beta \tan \alpha} = \frac{F_T}{F_c}$$

$$F_c \tan \beta - F_c \tan \alpha = F_T + F_T \tan \beta \tan \alpha$$

$$F_c \tan \beta - F_T \tan \beta \tan \alpha = F_T + F_c \tan \alpha$$

$$F_c - F_c \tan \alpha = F_T + F_T \tan \alpha$$

In general, $\mu < 1$

$F_T > F_C$ (normally)

But in broaching, face turning etc,

$$F_T > F_C$$

For grinding, $\frac{F_T}{F_C} \approx 2.5$

— Whenever, ~~$F_T > F_C$~~ thrust force is greater than cutting force, the value of μ will become greater than 1. In such cases, classical friction theorem can be used, for determining μ value.

(According to classical friction theorem,

$$\mu = \frac{\ln(r)}{\tan \alpha} \quad \checkmark \quad \text{where } r - \text{chip thickness ratio} \\ \alpha - \text{rake angle.}$$

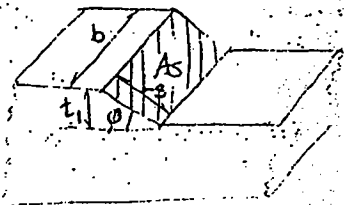
— Let τ = shear stresses induced in the layer of work material.

$$\tau = \frac{F_s}{A_s} \quad \text{where } A_s - \text{shear plane area.}$$

$$\tau = \frac{F_s}{A_0} \times \sin \phi$$

A_0 - cross section area of the uncut chip.

$$A_0 = k_1 \times b$$



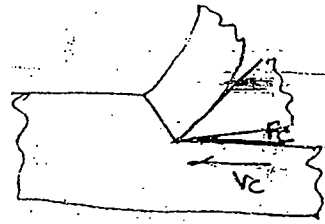
$$\tau \geq \tau_u$$

$$\sigma = \frac{F_{on}}{A_s} \quad \text{normal stresses to shear plane.}$$

$$= \frac{F_{on}}{A_0} \times \sin \phi$$

Workdone/energy required in machining

$$\begin{aligned} W.D &= F_c \times \text{velocity} + F_T \times \text{velocity} \\ &= F_c \times V_c + F_T \times \text{feed velocity} \end{aligned}$$



$$\text{Feed vel} = \text{feed} \times \text{rpm} = f \times N$$

$$W.D = F_c \times V_c$$

= W.D. in shearing

+ W.D. in friction overcoming

$$= F_s \times V_s + F_f \times V_f$$

$$\text{feed vel} = 0.1 \text{ to } 0.5 \times \frac{\text{mm}}{\text{rev}} \times \text{rpm}$$

$$= 0.1 \times 500$$

$$= 50 \text{ mm/min}$$

$$= \frac{50 \times 10^{-3}}{60} \text{ m/s}$$

$$= 0.00083$$

So $F_T \times \text{feed vel}$ can be negligible

— As for a given process conditioning, the shear stress induced in machining can be varied by varying the shear angle in machining (ϕ)

For effective utilization of energy supplied the shear stress induced in the material must be exactly equal to the ultimate shear stress of work material so the energy supplied will become minimum energy. For this, the optimum value of shear angle to be used has to be calculated.

$$W.D = F_c \times V_c$$

$$= \frac{F_s}{\cos(\phi + \beta - \alpha)} \times V_c$$

$$= \frac{F_s}{\cos \phi} \times \frac{1}{\cos(\beta - \alpha)}$$

$$\cos \phi$$

$$T = \frac{F_s}{\cos \phi}$$

$$F_s = \frac{T \cos \phi}{\cos(\beta - \alpha)}$$

For minimum work done,

$$\tau = \tau_u$$

$$\text{So } W.D. = \frac{\tau_u \times A_0}{\sin \phi} \cdot \frac{\cos(\beta - \alpha)}{\cos(\phi + \beta - \alpha)} \quad \text{V.C.}$$

→ Let's check

J. parallel F. = constant

min. work done

In case of experiment

$\phi = 90^\circ$

For min. work done,

$$\frac{d(W.D.)}{d\phi} = 0$$

→ Since

$$\phi + \beta - \alpha = 90^\circ$$

$$\phi + \beta - \alpha = 90^\circ$$

$$\boxed{\phi = \frac{90 - \beta + \alpha}{2}}$$

called as optimum shear angle relation

for min. work done criteria OR

optimum ϕ for min. energy criteria OR

Merchant's shear angle relation

— Let C_m be the machining / Merchant's constant

$$C_m = 2\phi + \beta - \alpha$$

$$\text{If } C_m = 90^\circ, \quad \tau = \tau_u, \quad \eta_{\text{energy}} = 100\% \text{ utilisation}$$

$$\text{If } C_m > 90^\circ, \quad \tau < \tau_u, \quad \eta_{\text{EU}} > 100\%$$

i.e., when $C_m > 90^\circ$, the machining process is taken as impossible process of machining

$$\text{If } C_m < 90^\circ, \quad \tau > \tau_u, \quad \eta_{\text{EU}} < 100\% \text{ (actual process)}$$

✓ For every one degree reduction in the machining constant from 90° , nearly 1% reduction in the η_{EU} occurs.

$$\text{eg } C_m = 85^\circ, \quad \eta_{\text{EU}} = 95\% \quad \text{or } \eta_{\text{EU}} = C_m - 10$$

Specific cutting energy: is the energy required for removing a unit volume of material from the work piece.

$$\text{Sp. cutting energy} = \frac{W.D.}{M.R.R.} = \frac{F_c \times V_c}{t_b V_c}$$

$$= \frac{F_c}{A_0} \quad \text{N/mm}^2 \text{ or } \text{J/mm}^3$$

- Since the units of sp. cutting energy is same as the pressure units, it is also called specific cutting pressure.

- It is used for indicating the machinability of the material i.e., high the sp. cutting energy, poor the machinability.

Shear strain

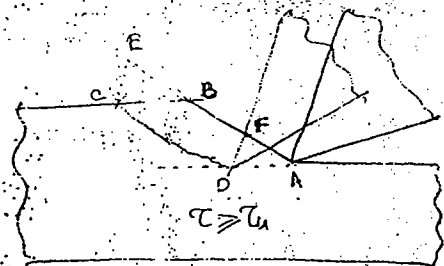
Shear strain = $\frac{\text{deformation in chip just before shearing}}{\text{shortest distance in the shear plane}}$

$$= \frac{AF}{DG}$$

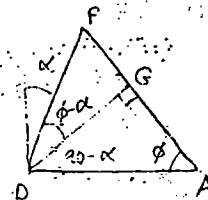
$$= \frac{AG}{DG} + \frac{FG}{DG}$$

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

$$\boxed{\text{Shear strain} = \cot \phi + \tan(\phi - \alpha)}$$



ABCD initial chip
CDEF final chip



- For a given tool, the rake angle (α) is constant.

Therefore the shear strain depends on the shear angle (ϕ).

- To minimise the shear strain induced in the chip, differentiate the shear strain w.r.t. ϕ and equate it to zero.

$$\frac{\partial}{\partial \phi} (\cot \phi + \tan(\phi - \alpha)) = 0$$

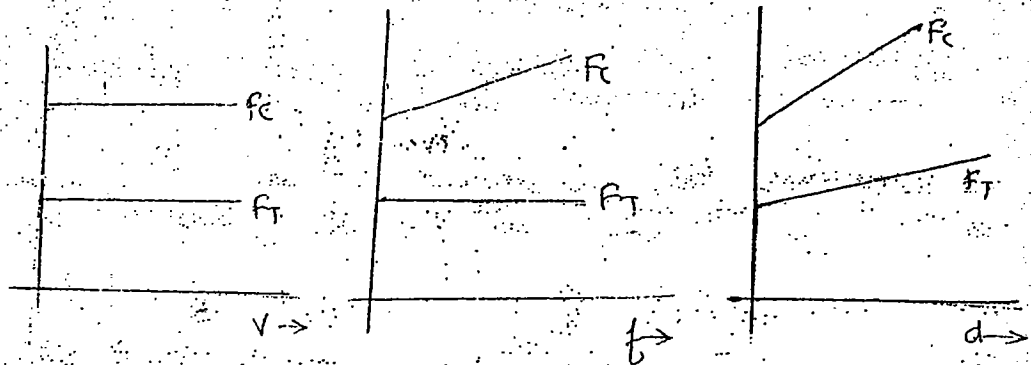
$$2\phi - \alpha = 90^\circ$$

$$\phi = \frac{90 + \alpha}{2}$$

$$\sec^2(\phi - \alpha) = \frac{1}{\cos^2(\phi - \alpha)}$$

Factors influencing the forces induced during machining

1. Process parameters



2. Back rake angle (α_b)

With increase in α_b , the forces induced during machining will decrease.

(For every 1° increase in α_b , nearly 10% reduction in the forces for cutting occurs)

3. Cutting fluids:

With its use, the forces induced will reduce, because the cutting fluids are mainly for carrying away the heat generated during machining and to act as a lubricant in the friction zone.

(With use of cutting fluids, the forces are reduced nearly

25% to 40%)

✓ In orthogonal machining,

$$F_C = 67\% \text{ and } \text{---}$$

$$F_T = 63\%.$$

$$\text{So } F_C : F_T = 2:1$$

✓ In oblique machining,

$$F_C = 67\%$$

$$F_T = \begin{cases} F_{T1} = 27\% \\ F_{T2} = 6\% \end{cases}$$

$$\text{So } F_C : F_{T1} : F_{T2} = 11:4:5:1$$

HEAT GENERATION

— The machining operation is also taking place according to the first law of thermodynamics.

i.e., whatever the energy supplied for machining, is simply converted to heat energy.

$$\phi W = \phi E$$

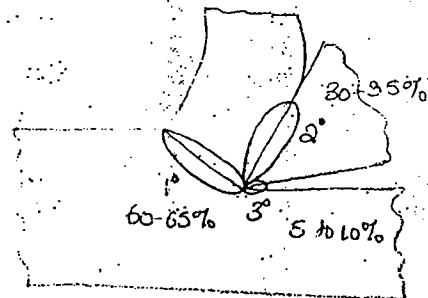
$$\text{Heat generated in machining} = \text{work done} = F_C \times V_c$$

— The heat generation takes place

in 3 zones

1. Primary H.Z (shear zone)
2. Secondary H.Z
3. Tertiary H.Z

} friction zone



— In primary heat zone, the energy is supplied for breaking the atomic bonds b/w the atoms of the material, during which the atoms are releasing the energy in the form of heat energy. Hence heat is generated in the primary heat zone.

- Maximum amount of heat is carried away by the chip and a small amount is transferred to the workpiece.
- In secondary heat zone, whatever the energy required for overcoming the friction is converted into heat energy because of friction. i.e., the heat generation here is taking place due to the presence of friction at the chip-tool interface. Out of the heat generated in secondary zone, maximum is carried away by the chip, and a small amount is transferred to the tool.
- In tertiary heat zone, heat is generated due to the friction between the tool and workpiece. Out of heat generated, maximum heat is carried by the work piece and a small amount by the tool.

- Heat carried amount ^{depends}
 $\text{chip} > \text{work piece} > \text{environment} > \text{tool}$

By assuming the heat transferred to the surroundings by convection and radiation as very small and negligible, whatever the heat generated, is simply carried by the 3 elements (i.e., chip, work and tool in the decreasing order)

$\text{chip} > \text{W.P} > \text{tool}$
 70-75% 15 to 20% 5 to 10%

Neglecting the heat carried by the tool,

$$H.G. = H.C. \text{ by } (chip + W.P.)$$

$$H.C. \text{ by } chip = W \cdot a - H.C. \text{ by } W.P.$$

$$= W - aW$$

$$= W(1-a)$$

$$\therefore a = 0.15 \text{ to } 0.2$$

$$H.C. \text{ by } chip = W(1-a)$$

$$mC_p \Delta T = W(1-a)$$

$$\Delta T = \frac{W(1-a)}{mC_p} = \frac{F_c \times V_c (1-a)}{V_0 \times P \times C_p}$$

$$= \frac{F_c \times V_c (1-a)}{A_0 \times V_c \times P \times C_p}$$

$$\text{i.e., } \Delta T = \frac{F_c (1-a)}{A_0 \cdot P \cdot C_p} \quad (\text{rise in temp. of the chip})$$

$$T_{chip} = \Delta T + R.T.$$

— By knowing the temp. of chip during machining, the chip temp. must be less than the work material melting point.

If the temp. of chip is going near to the melting point of the work material, adjust the process parameters such that the chip temp. can be reduced.

— From the machining zone diag., all the three heat zones are meeting at one junction called the tip of the tool.

Therefore, the tip of the tool is experiencing very high temp.

If the temp. of the tool chip is going beyond the hot hardness temp. of tool material, the reduction in hardness

of the tool becomes considerable. Therefore, the tool temp.

lost due to plastic deformation.

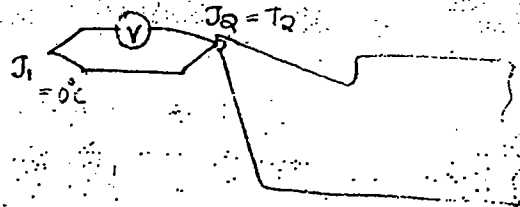
- For adjusting the process parameters during machining or for selecting the cutting tool material which has hot hardness temp. greater than the temp. at the tip of the tool, it is necessary to measure the temp. at the tool tip.

Methods of measurement of tool tip temperature:

1. Tool work thermocouple:

$$\text{emf} \propto T_2 - T_1$$

$$\text{emf} \propto T_2$$



- The limitations of tool work thermocouple are

- i) They can be used for the measurement of temp. upto 800°C beyond which the accuracy is very poor.
- ii) It can be used only for stationary tools but not for moving or rotating tools.

2. Optical pyrometer (non contact type)

- higher temp. can be measured.

3. Calorimetric setup

- used for measurement of temp. of tip of rotating or moving tools.

TOOL FAILURE

- Whenever the tool is not performing the machining operation satisfactorily, the tool is said to be failed.
- The parameters used for measuring the satisfactoriness of machining ^{are}
 - 1. Surface finish produced on the work piece.

- At the beginning of the machining operation, the machined surface will have very good mirror like surface. After some machining, some lines will be found on the next machined part which indicates that the machining is not satisfactory and the tool is said to fail.

2. Forces induced during machining

The forces induced can be measured using dynamometer.

Whenever the forces increases to greater than 15% of the initial value, tool is said to be failed.

wear land $\uparrow$ contact area $\uparrow$ force $\uparrow$

3. Power consumption

By connecting Ammeter to the input of the electric motor, the power drawn by the motor can be estimated.

$$\text{Power} = P = VI$$

Whenever the increase in current is more than 50% of the initial value, it is said to fail.

Losses in the chip

Losses in the chip

Power is not all used for cutting. Some is lost in the form of heat, sound, etc.

because of increased forces, heat and temperature increases and the colour of the chip turns out to be black.

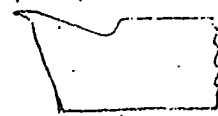
5. During machining of high carbon workpieces, whenever white coloured gases are formed, the tool is said to fail because, at high temperature formed due to tool failure, the carbon present in the surface of the workpiece, easily combine with oxygen in the atmosphere and produce carbon dioxide which is observed as ~~white~~ white coloured gas.

Modes of tool failure

Failure through plastic deformation

- During machining, when the temp. at the tip of the tool is greater than hot hardness temp. of the tool material, the hardness of the tool is reduced considerably and tool tip is deforming plastically. This is called plastic deformation failure.

- This is mainly due to the wrong selection of the process parameters or wrong selection of cutting tool material, but the failure duration is not repeatable. Therefore it is considered as an abnormal failure of the tool.

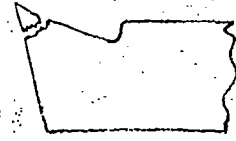


2. Failure through mechanical breakage.

— During initial machining operation, the tool performs the machining satisfactorily.

After some time, the tool tip breaks

suddenly. This is called mechanical breakage failure.



— The mechanical breakage failure is taking place due to the impact loads caused by blowholes or hot inclusions in the workpiece. Whenever a tool is exposed to such defects, the forces on the tool suddenly increases and acts as impact loads on the tool leading to breakage.

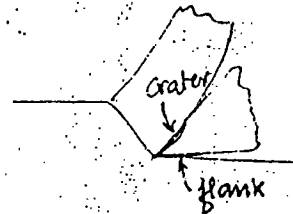
— The failure duration is not repeatable as blowholes are not present everywhere. Therefore it is considered as an abnormal fail.

3. Gradual wear failure.

— During machining operation, the tool is getting worn out slowly. Whenever the wear of the tool becomes considerable, the tool cannot perform the machining satisfactorily. Thus it is taken as tool failure.

It is considered as normal failure.

— The gradual wear failure is mainly due to
1. crater wear
2. flank wear.



— The wearing takes place on the rake face of the tool.

Reasons for crater wear:

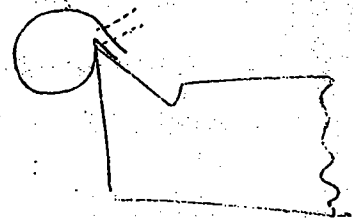
1. Friction at chip-tool interface.
2. Abrasive action of the microchips present at C-T interface.
3. Abrasive action of fragments of built up edge.
4. Diffusion wear.

— In certain cases of machining, the atoms of the tool may be attracted by atoms of the work material. Due to this, the atoms of the tool diffuse into the work material. This is called diffusion wear. This mainly occurs during the machining of ferrous work piece using diamond cutting tool.

— During machining, the crater wear always takes place at some distance away from the tool tip because,

1. during machining, the force applied by the tool is in upward direction, the chip produced is lifting upwards directly, but because of the self weight of the chip, it is falling back onto the rake face of the tool. In the process of lifting upwards and falling back, no direct contact is present between the chip and tool near the tool tip.

Hence no friction, no abrasive action and no diffusion takes place

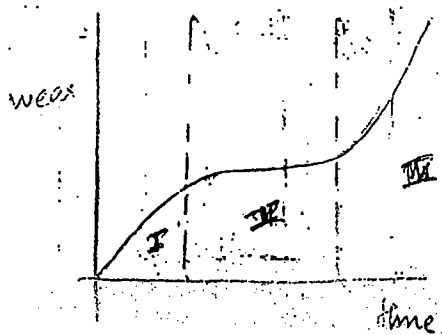


2. When the chip is lifting upward and falling back, it is trying to connect with the rake face at some distance away from the tip. At this point, the friction and temperatures are high and mechanical properties of tool are deteriorated. Hence the tool wear is high at some distance away from the tip, this produces the wear, crater like.

Reasons of flank wear (the wear taking place on the flank face of the tool)

1. Friction at the tool work interface.
2. Abrasive action of microchips at the tool work interface.
3. Diffusion wear.

— As long as the process parameters and tool work combination are kept same, the tool failure duration remains constant. Therefore it is considered as a normal failure of the tool.



Rapid wear in
I and III

Stage I: rapid wear takes place because of very high sharpness of the cutting tool.

Stage III: rapid wear takes place because of high temperature between the tool and work.

TOOL LIFE

- The actual machining time between two successive regrinds of the tool is called tool life. It is generally specified in minutes and also in terms of the no. of pieces produced b/w 2 successive regrinds. This specification is used for mass production.
- It is also specified in terms of the volume of the material removed b/w 2 successive regrinds. This criterion is used for rough machining.

Factors influencing tool life

1. Properties of work piece material

- During machining of hard work pieces, the forces involved are higher, tool wear is high and tool life is low, whereas during machining of soft work pieces, is just opposite.

2. Tool geometry: with increase of back rake angle, side rake and relief angles, the tool life increases.

3. Use of cutting fluids: CF is used mainly for carrying away the heat generated during machining and acting as a lubricant at the chip tool interface. Therefore, the forces are reducing, the tool wear is reducing and tool life increases. With the use of CF the tool life increases by 25 to 400%.

4. Process parameters (speed, feed and depth of cut).

- The process parameters are unique i.e., their values are made constant.

- Taylor has assumed that, out of the three, the cutting velocity is the one that has highest influence of the tool life. He gave a relationship between the tool life and cutting velocity, popularly called Taylor's tool life equation

$$\boxed{VT^n = C} \quad \text{where } V - \text{cutting velocity m/minute}$$

T - tool life in minutes or no. of pieces machined or volume of material removed.

C - Taylor's constant.

= cutting velocity for 1 minute tool life.

n - Taylor's exponent.

The value of n depends on the type of cutting tool material used.

$n \approx 0.05$ to 0.1 for high carbon steel

≈ 0.1 to 0.2 for HSS

≈ 0.2 to 0.4 for carbide tool

≈ 0.4 to 0.6 for ceramic tool

≈ 0.7 to 0.9 for diamond/carborundum.

$n < 1$

Modified Taylor's tool life equation.

$$VT^n f^p d^q = C$$

where f - feed mm/revolution

d - depth of cut in mm.

p, q - constants < 1

$p > q$

$v > f > d$. (decreasing order of influence of process parameters on the tool life).

MACHINABILITY

— The ease with which the machining of a given work piece can be done is called machinability.

— It is measured using the following parameters.

1. Surface finish: Under similar conditions of machining, the workpiece on which the better surface finish can be produced is said to be easily machinable.

2. Tool life: Under similar conditions of machining, the workpiece on which higher tool life is obtained is said to be easily machinable.

3. Lower the force and power consumption, better machinability.

4. Higher the shear angle, higher is the machinability.

5. Higher material removal rate, higher machinability.

6. Lower specific cutting energy better machinability

7. Type of chips produced: Under similar conditions of machining, the work piece, on which discontinuous chips are produced is said to have high machinability.

— The above criteria are used when more than one work piece are given. By conducting the machining experiment, it is possible to identify the easily machinable work piece.

— If only one work piece is given, its machinability can be compared with a standard work piece and the parameter called machinability index can be defined.

$$\text{Mach Index, } MI = \frac{V_T}{V_S} \text{ (any value)}$$

where V_T - cutting velocity for 60 minute tool life on test work piece

V_S - cutting velocity for 60 min. tool life on a standard work piece.

— Standard work piece: Free machining steel or free cutting steel has the highest machinability. So it is taken as the standard work piece.

Steel with	0.05% sulphur	} free cutting steel
	0.25% Phosphorous	
	2 to 4% lead	

NOTE:

The addition of sulphur, phosphorus and lead increases the machinability of the tool.

— Adding S beyond 0.05%

+ increases machinability

+ increases brittleness.

— Sulphur present on the surface forms SO_2 (poisoners)

— Adding P beyond 0.05%

+ increases machinability

+ increases brittleness

— Adding Pb more than 4%

+ increase machinability

— reduces the melting point of the workmaterial drastically

— The machinability index can have any value. Because, after defining M.I., many materials having machinability greater than the free cutting steel have been invented.

— Without comparing, the machinability can be defined using a parameter called universal machinability index

$$U.M.I = \frac{\cos(\beta - \alpha)}{\cos(\phi + \beta - \alpha)}$$

From Merchant's circle, $\frac{F_c}{\cos(\beta - \alpha)} = \frac{F_s}{\cos(\phi + \beta - \alpha)}$

$$U.M.I = \frac{F_c}{F_s}$$

ECONOMICS OF MACHINING

- The optimum process parameters used for a given economic condition of machining is called economics of machining.
- Out of the three process parameters, cutting velocity is the one which has the highest influence on the economics of machining. Therefore it is required to determine the optimum cutting velocity for given economic condition of mach

Criteria for economic machining : 3 criteria.

- Minimum cost criteria
- Maximum production criteria
- Maximum profit criteria

1. Minimum cost criteria

$$\text{Total cost} = \text{cost of raw materials} + \text{cost of loading and setting of work piece} + \text{cost of unloading and inspection} + \text{cost of machining } (C_m) + \text{cost of tool replacement } (C_t)$$

$$\text{Total cost} = k + C_m + C_t$$

- Only machining and tooling costs are influenced by the cutting velocity. Therefore other costs are taken as a constant.

$$\text{cost of machining} = C_m = T_m \times \text{machining time in min}$$

$\downarrow$ $\rightarrow$
 in direct proportion to machining charge in
 labour cost per hour

Cutting velocity, $V = \frac{1000}{1000}$

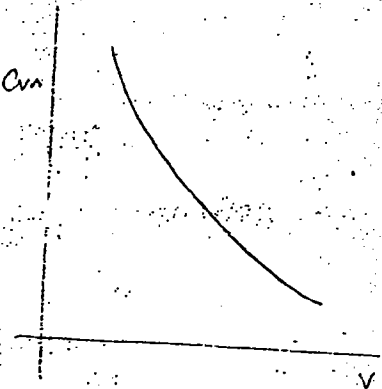
$N = \frac{1000 V}{1000}$

$\therefore C_m = T_m \times L_m = \frac{L}{f \cdot N} \times L_m$

$= \frac{L}{f \cdot \left(\frac{1000 V}{1000} \right)} \times L_m$

$C_m = \frac{100 L}{1000 f V} \times L_m$

$\Rightarrow C_m \propto \frac{1}{V}$



Tooling cost, $C_t = \text{no. of tools} \times \text{cost of regrounding one tool in time}$ OR

cost of one cutting edge if it is a throw away type of tip of the tool.

$C_t = \text{no. of tools} \times C_g$  ≈ 100 $C_g = \frac{100}{4} = 25$

Throwaway type tip of tool $\rightarrow$ tool is square shaped. ^{no. of edges}
(It has 4 edges).

No. of tools $= \frac{T_m}{T}$ T_m - machining time
 T - tool life

Suppose $T_m = 20 \text{ min}$ and $T = 4 \text{ min}$

$\therefore$ The no. of tools $= 5$

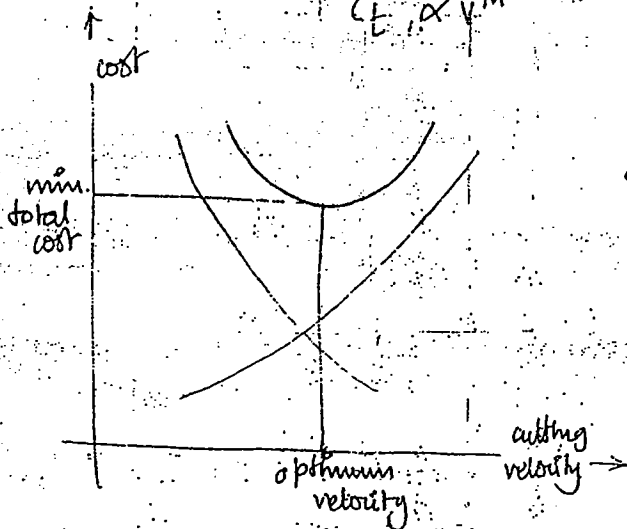
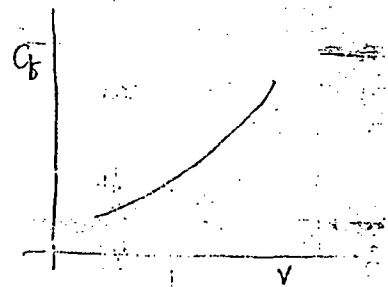
$V T^n = C$

$T = \left(\frac{C}{V} \right)^{1/n}$

$$\text{No. of tools} = \frac{T_m}{T} = \frac{\left(\frac{\pi D L}{1000 f_v}\right)}{(C_g)^{1/n}}$$

$$C_t = \frac{\pi D L V^{1/n-1}}{1000 f_v^{1/n}} \cdot C_g$$

$$C_t \propto V^{1/n-1}$$



$$\text{Total cost} = K + \frac{\pi D L}{1000 f_v} L_m +$$

$$\frac{\pi D L V^{1/n-1}}{1000 f_v^{1/n}} C_g$$

$$\text{For minimum total cost, } \frac{d(TC)}{dV} = 0.$$

$$\Rightarrow V = V_{opt} = C \left[\frac{n}{1-n} \cdot \frac{L_m}{C_g} \right]^n$$

where C - Taylor's constant

n - Taylor's exponent

L_m - machining charge in ₹/minute.

C_g - cost of regrinding tool once or
cost of one cutting edge.

= cost of regrinding the tool one if it is a
regrindable tool.

= cost of one cutting edge if it is a throwaway
type tip of tool.

$$T_{opt} = \left(\frac{C}{V_{opt}} \right)^{1/n} = \left[\frac{1-n}{n} \cdot \frac{C_g}{L_m} \right]$$

Q. Maximum production rate criteria
(or minimum total time criterion)

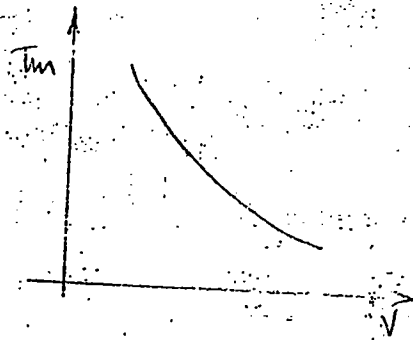
Total time required, T.T. = $T_{\text{required for loading \& setting}}$ + $T_{\text{machining}}$

+ $T_{\text{required for tool change (} T_{tc} \text{)}}$ + $T_{\text{kept for inloading and inspection (} T_{LI} \text{)}}$

$$T.T. = K_1 + T_m + T_{tc}$$

$$T_m = \frac{L}{FN} = \frac{100L}{1000 f_v} =$$

$$\Rightarrow T_m \propto \frac{1}{V}$$

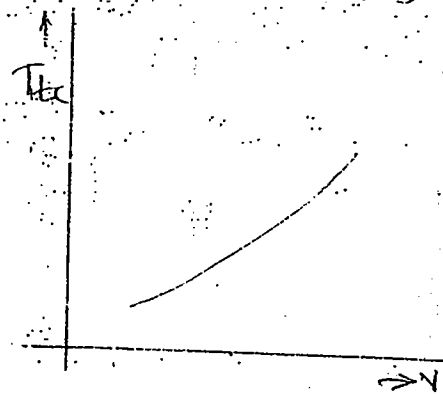


$T_{tc} = \text{no. of tool changes required} \times T_c$
(time needed for changing the tool once)

$$T_{tc} = \frac{T_m}{L} \times T_c$$

$$= \frac{100L V^{1/n-1}}{1000 f_c^{1/n}} T_c$$

$$T_{tc} \propto V^{1/n-1}$$



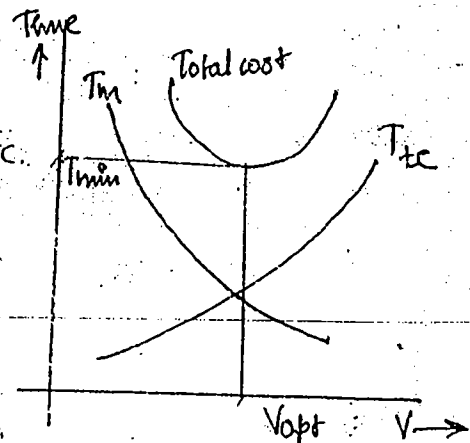
$$\text{Total time} = K_1 + T_m + T_{tc}$$

$$= K_1 + \frac{100L}{1000 f_v} + \frac{100L}{1000 f_c^{1/n}} T_c$$

For minimum total time,

$$V \propto V_{opt} = C \left[\frac{n}{1-n} \cdot \frac{1}{T_c} \right]^n$$

optimum tool life, $T_{opt} = \left[\frac{1-n}{n} T_c \right]$



3. Maximum profit criterion

Profit = selling price - total cost of production.

To maximize the profit,

- increase the selling price.
- decrease the cost of production.

- By varying the cutting velocity, the selling price of a component cannot be varied. Therefore it is assumed as a constant. Hence the profit can be maximized by minimizing the total cost of producing the component.
- The maximum profit criterion thus remains same as that of minimum cost criteria.

$$V_{opt} = c \left[\frac{n}{1-n} \cdot \frac{L_m}{C_g} \right]^{\frac{1}{1-n}}$$

$$T_{opt} = \left[\frac{1-n}{n} \cdot \frac{C_g}{L_m} \right]^{\frac{1}{1-n}}$$

Qualitatively,

Cutting velocity $\uparrow \Rightarrow$ surface finish $\uparrow \Rightarrow$ quality $\uparrow \Rightarrow$ selling price $\uparrow$

V_{opt} = contains 12 to 15 constants

$$(V_{opt})_{\substack{\text{max.} \\ \text{Profit}}} > (V_{opt})_{\substack{\text{min.} \\ \text{cost}}}$$

$$(V_{opt})_{\substack{\text{max} \\ \text{production rate}}} > (V_{opt})_{\substack{\text{max} \\ \text{profit}}} > (V_{opt})_{\substack{\text{min} \\ \text{cost}}}$$

$$(V_{opt})_{\substack{\text{max.} \\ \text{prod}}} < (V_{opt})_{\substack{\text{max} \\ \text{profit}}} < (V_{opt})_{\substack{\text{min} \\ \text{cost}}}$$

S.10

Effective rake and relief angles

1. In external turning operations:

Tool tip is always set with respect to the centre of workpiece.
(or the dead centre of the tail stock)

— During actual machining process,

the tool is always set w.r.t to

the dead centre of the tail stock using

visual judgement. But the tool may actually be slightly above or below the centre line. This is called offset

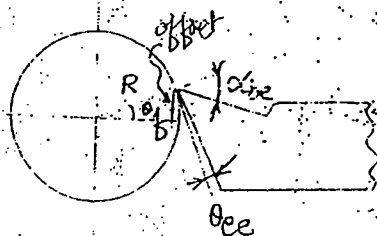
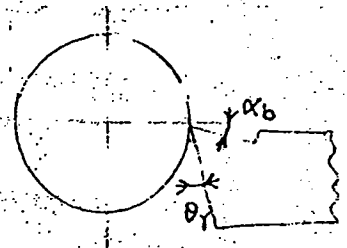


Fig. 1. Tool set above
the centre line.

α_{be} — effective rake angle

θ_{re} — effective relief angle

$$\sin \theta_r = \frac{OF}{R}$$

$$\theta_r = \sin^{-1} \left(\frac{OF}{R} \right)$$

$$\alpha_{be} = \alpha_b + \theta_r$$

$$\theta_{re} = \theta_r - \theta_r$$

Since the setting of the tool above the centre line, effective rake angle is increasing and effective relief angle reduces.

Due to the increase of α_{be} , the force and power consumption reduces and tool life increases. The strength remains the same.

Due to the reduction in effective back relief angle the rubbing action between the tool and the workpiece increases. In case of

$\Rightarrow$ 3 components of force can be measured: $F_c > F_a > F_f$ ^{largest}
 $\Rightarrow F_T = \frac{F_a}{\cos \lambda} = \frac{F_f}{\sin \lambda}$ ^{$F_{T \text{ loss}}$ $F_{T \text{ shd}}$}

CUTTING TOOL MATERIALS

Properties to be possessed by a material for using it as a cutting tool material are

1. Hardness of the material must be 30 to 50% higher than the hardness of work material.
2. It should have high hot hardness temperature.
3. High strength.
4. High toughness - to withstand impact load.
5. High thermal conductivity (to eliminate heat concentration at tip).
6. High wear resistance.
7. Lower coeff. of friction.
8. Lower coeff. of thermal expansion.
9. Easiness in fabrication.
10. Cheaper.

High carbon steel:

- harden RC 65
- hot harden temp 250°C
- since forged components are regreainable, the total body of the tool can be made using same material.
- max. cutting velocity 5m/min
- manufactured by forging (grain orientation is possible)

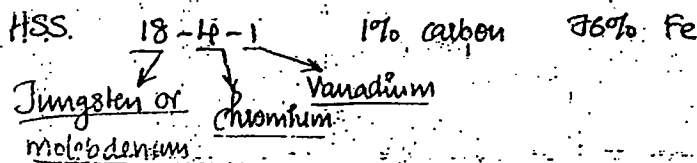
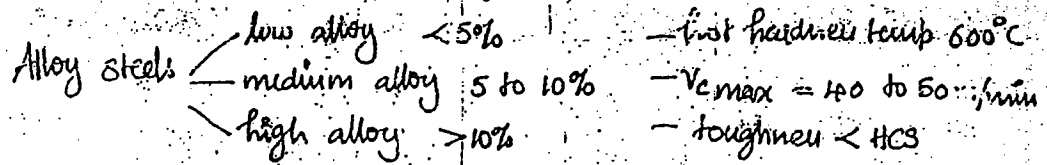
$\uparrow$ cutting velocity $\uparrow$ power required $\uparrow$ High temp
 (max. temp. hot hardness temp.)

- Used in a cutting tool material for low speed cutting.

② High speed steel

- Even today, chisels are made of HCS. because it has a high toughness. The chisel continuously experiences impact loads. To resist it, high toughness is required.

2. High speed steel or high alloy steel. (HSS)



- Tungsten or Molybdenum is added to increase the hot hardness temp. of tool material. Chromium increases strength. Vanadium increases the wear resistance or maintaining sharpness of cut edge.

$\text{Ti} + \text{Vn} + \text{Cr} \rightarrow \text{Tungsten based H.S.S.}$

$\text{Mo} + \text{Cr} + \text{Va} \rightarrow \text{Molybdenum based H.S.S.}$

- Mo is cheaper than Ti but Tungsten based H.S.S. is widely used due to its higher wear resistance.
- H.S.S. is regroundable. Thus the total body of the tool can be made by using the same material.
- Used for manufacturing of general purpose cutting tools like single point cutting tools, milling cutters, broaching tools, drill bits etc.
- Since 76% Fe is present, during machining of high carbon w.p., the carbon atoms diffuse from the w.p. and deposit on the tool forming a B.U.F. which increases the force and power consumption. Therefore HSS should not be used for H.C. w.p.

passing off operation with setting of the tool above centre line, as the tool is proceeding towards the centre, the offset remains the same.

- Due to the reduction of θ_{ce} , the rubbing action between the tool and workpiece increases. Increase of passing off operation with setting of the tool above centre line, as the tool is proceeding towards the centre, the offset remains same.

Due to the reduction in the dia. of the component, offset angle is increasing and effective relief angle is reducing.

At the same point, the effective relief angle may become equal to zero, so that the tool is simply rubbing the workpiece without doing any machining.

$$\theta_{ce} = 0$$

$$\Rightarrow \theta_{ce} = \theta_f$$

$$\sin \theta_f = \sin \theta_{ce} = \frac{O_f}{R}$$

$$R = \frac{O_f}{\sin \theta_f}$$



$$\alpha_b = 10^\circ, \theta_{ce} = 6^\circ, O_f = 1.5 \text{ mm}$$

$$D = 50 \text{ mm}$$

$$O_f = \sin^{-1} \frac{O_f}{R} = \sin^{-1} \frac{1.5}{25}$$

$$\alpha_{be} = \alpha_b + \theta_f = 13.41^\circ$$

$$\theta_{ce} = \theta_{ce} - \theta_f = 2.26^\circ$$

When rubbing,

$$\theta_e = \theta_f = 6^\circ$$

$$\theta_e = \frac{\theta_f}{R'} \quad R' = \frac{1.5}{\sin 6} = 14.325$$

$$\theta_e = 14.325 \times 6 = 85.95^\circ$$

D' - dia at which the tool is rubbing the workpiece.

$$\sin \theta_f = \frac{\theta_f}{R}$$

$$\theta_f = \sin^{-1} \frac{\theta_f}{R}$$

$$\alpha_{be} = \alpha_b - \theta_f$$

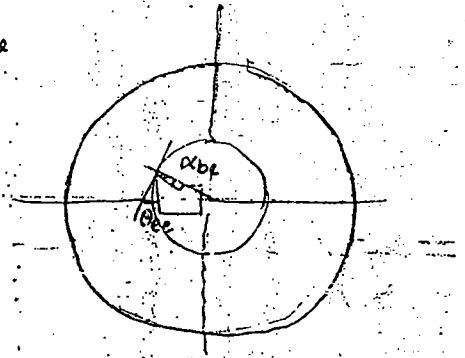
$$\theta_{ee} = \theta_e + \theta_f$$

Because of the setting of the tool below the centre line, the effective rake angle is reducing and eff. relief angle is increasing. Due to the redⁿ in the rake angle, the force and power consumption during machining increases, tool life reduces and hence the tool becomes blunt very fast.

Because of the increase in effective relief angle, the rubbing action between the tool and workpiece is eliminated completely.

2. Internal turning operation:

— The effects of setting the tool above the centre line in case of internal turning remains the same as the effect of setting the tool below the centre line in case of external turning.



— For analysing the given problem as an orthogonal machining problem, the following 5 basic parameters are required.

1. uncut chip thickness, t_1
 2. width of cut, b
 3. rake angle, α (taken from tool geometry)
 4. Cutting force, F_c
 5. Thrust force, F_T
- } measured forces

— In orthogonal cutting, we take

1. $t_1 = f$
 $b = d$ } If f, d are given: f - feed, d - depth of cut, w - width of cut.
2. $t_1 = d$
 $b = w$ } If d, w are given
3. $t_1 = f$
 $b = w$ } If f, w are given.

— As no direct methods are available for the analysis of oblique machining, the oblique machining problem is converted into orthogonal. For this, it is required to determine the above 5 parameters.

Oblique machining problems:

1. Shaping and planing: It is a single point cutting tool oblique machining problem which has to be converted into orthogonal one.

$$-\alpha = \alpha_b \text{ (ASA)} = \alpha \text{ (ORS)}$$

$$-t_1 = f \cos \lambda = f \sin C_s$$

$$-b = \frac{d}{\cos \lambda} = \frac{d}{\sin C_s}$$

λ - approach angle

C_s - side cutting edge angle

In oblique machining, three component of forces are measured.

F_c - largest

$$F_a - \text{next largest} = F_T \cos \lambda$$

$$F_f - \text{smallest} = F_T \sin \lambda$$

$$F_T = \frac{F_a}{\cos \lambda} = \frac{F_f}{\sin \lambda}$$

$$\text{Material removal rate} = t_1 b v_c = f d v_c$$

2. Turning and boring operation (internal) single point

$$-\alpha = \alpha_b \text{ (ASA)} = \alpha \text{ (ORS)}$$

$$-t_1 = f \cos C_s = f \sin \lambda$$

$$-b = \frac{d}{\cos C_s} = \frac{d}{\sin \lambda}$$

$$-MRR = t_1 b v_c = f d v_c$$

$$-F_c - \text{largest}$$

$$-F_a - \text{next largest} = F_T \cos C_s$$

$$-F_f - \text{smallest} = F_T \sin C_s$$

$$-F_T = \frac{F_a}{\cos C_s} = \frac{F_f}{\sin C_s}$$

3. Drilling operation: multipoint cutting tool



DRILL BIT

No. of webs = no. of flutes

= even, for balancing of forces

2ϕ - point angle (angle b/w inclined faces)

$2\phi = 118^\circ$ (standard point angle)

$> 118^\circ$ for machining hard w/p.

$< 118^\circ$ for machining soft w/p.

≈ 45 to 55° for very soft w/p

The conical length of the drill bit increases with decrease of point angle

$$\text{conical length} \propto \frac{1}{\tan \phi}$$

- During machining of hard work pieces the forces induced are higher if small point angle is used, because of longer conical length of the drill bit, the buckling failure of drill bit occurs. To avoid this, large point angle can be used.

- Helix angle α_n : angle made by the web with horizontal.

α_n is minimum at the centre & max. at the periphery.

It varies only in conical position.

Effective back rake angle, $\alpha = \alpha_b = \alpha_n = \tan^{-1} \left(\frac{V_a \tan \alpha_b}{\sin \phi} \right)$

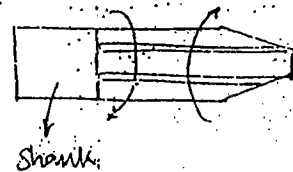
$\Rightarrow \alpha_{\text{effective}}$ also varies from min. at centre to max. at periphery.

So that due to small rake angle at the centre, the tip of the tool is becoming stronger at the centre. As rake angle increases towards periphery, chip disposal becomes easier.

- During machining of soft w.p. continuous chips are produced. To dispose them easily, it needs to vary the helix and back rake angles by large amount. A large variation can be achieved by long conical length of drill bit, for which small point angles need.

- The final process used in the manufacturing of a drill bit is twisting.

The twisted portion of the drill bit can be attached to the straight cylindrical portion (shank) using friction welding.



$$t_1 = \frac{b}{2} \sin \phi$$

b = dia of drill bit.

$$b = \frac{D}{2 \sin \phi}$$

In drilling, the measurable quantities are

1. Total thrust

2. Total torque required for drilling

$$C_{te} = 0.5 \times 10^{-3}$$

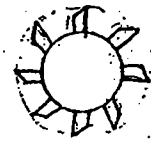
$$F_c = \frac{\text{total axial}}{S \sin \theta}$$

$$\text{Total torque} = 0.6 F_c D$$

$$F_c = \frac{\text{total torque}}{0.6 D}$$

14. Milling (multipoint)

Milling cutter is produced by mounting many number of single point cutting tools along the circumference of a circular disc.

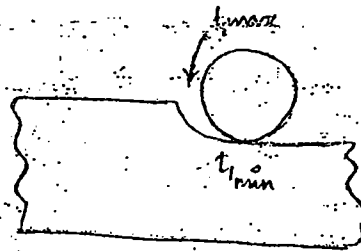


milling cutter.

Here back rake $\alpha = \alpha_b$

In milling, instant chip thickness is not uniform. It varies from

$$t_{\min} = 0 \text{ to } t_{\max} = \frac{2 f_m}{N Z} \sqrt{\frac{d}{D}}$$



where d - depth of cut; D - dia. of milling cutter

N - rpm of milling cutter; Z - no. of teeth of milling cutter

f_m - table feed in mm per min

$$f_m = f_t N \quad \text{table feed in mm/rev}$$

$$= f_t Z N \quad \text{table feed in mm/tooth}$$

$\Rightarrow$ 3 feeds are defined i.e., f_m , f_t , f_t
 (table feed in mm/min.)

$$t_{\max} = \frac{2 f_t}{N Z} \sqrt{\frac{d}{D}} \quad \therefore \frac{f_m}{N Z} = f_t$$

$$t_i = t_{\text{avg}} = \frac{t_{\min} + t_{\max}}{2} = f_t \sqrt{\frac{d}{D}}$$

Width of cut, b - minimum (width of w/p, width of tool)

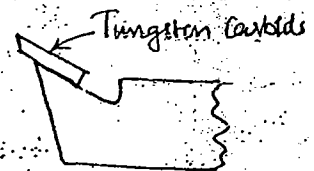
3. Non ferrous cast alloys (stellite)

- Co 40 to 50% — manufacturing method: casting
- Cr 27 to 35% — regrindable. Therefore tool can be made of the same material wholly.
- Ti 19 to 22%
- C 2 to 4% — hot hardness temp 800°C

— All other properties are similar to that of H.S.S, but it ~~has~~ been developed as a suitable cutting tool material for machining of H.C. w/p in place of H.S.S.

4. Tungsten carbide / sintered / cemented carbide

- major constituent - Tungsten $\Rightarrow$ very high hardness
- manufactured by powder metallurgy
- not regrindable.
- tip of tool is snow away type (all tools manufactured by powder metallurgy are snow away type.) Or can be mounted at the top of the tool
- They can be reground by using Electro Chemical Grinding (ECG). But the cost of ECG is higher than new tool.
- hot hardness temp 1000°C
- $V_{\text{max}} = 800$ to 350 m/min
- low toughness
- weak in tension. So negative back rake angles are provided
- Based on the variation in the composition of Tungsten, the carbide tools are divided into
 1. P type - for ferrous w/p $P_{10}, P_{20}, P_{30}, P_{40}, P_{50}$
 2. M type - for non-ferrous cast base & non-ferrous



— however the subscripts

~~Ex~~ Higher numbered tools can be used for rough machining and lower for finish machining.

5. Ceramics:

- Major constituent Al_2O_3
- manufacturing method: powder metallurgy
- Hot hardness temp: $1200^\circ C$
- $V_{max} = 400$ to 500 m/min
- Very high brittleness and low toughness. So can be used only for continuous machining applications.

Intermittent machining $\rightarrow$ impact load $\rightarrow$ easy failure

- Good surface finish is possible, friction is minimum.
- low thermal conductivity.

6. Cermets: $\begin{matrix} \text{Ceramics} \\ 90\% \end{matrix} + \begin{matrix} \text{metal} \\ 10\% \end{matrix}$

- To reduce the brittleness and increase the toughness of ceramics, small quantity of metals are added.

Toughness $> T_{\text{ceramics}}$ ~~or~~ They are used for intermittent machining operations.
i.e., ~~ceramics~~ cermets

- Hot hardness temp $1200^\circ C$
- manufactured by powder metallurgy, $V_{max} = 400$ to 500 m/min
- other properties are same as ceramics.

7. Diamond:

- Manufactured by powder metallurgy or graphitisation
- Hot hardness temp $2000^\circ C$ $V_{max} = 1500$ to 2000 m/min
- high toughness, thermal conductivity
- lower thermal expansion

Limitation: High cost, cannot be used for machining of ferrous w/p.
because of high diffusion wear.

8. CBN (Cubic Boron Nitride or Borazone)

- Major constituent: Boron
- manufacturing method: powder metallurgy
- other properties: same as diamond.
- It has been developed for machining of ferrous materials

9. UCON:

Major con: Columbiun 50%, Titanium 30%, Tungsten 20%

Properties: better than CBN & diamond.

cost: higher than CBN & diamond. So not commercial viable.

- This is rolled into sheets and cut in the form of snow away type of tip of the tool using wire cut EDM (electric discharge machine)

10. Stalon: ($Si + Al + O_2 + N_2$)

Manufactured by powder metallurgy.

Properties: better than UCON. but costs higher than UCON.

The list specified from 1 to 10 is in the increasing order of w.r.t cost, cutting velocity, hardness, hot hardness, wear resistance etc except toughness

w.r.t toughness in decreasing order is

H.C.S
HSS
Stellite
Diamond
CBN
UCON
Stalon
Carbide
Cermets
Cermets

Points to be remembered in solving m/c problem.

1. Check whether orthogonal machining is indicated in the problem. If so, use orthogonal m/c directly.

2. If it is not mentioned as orthogonal, check whether the problem belongs to broaching, sawing or parting off operation, jack plane operation etc. If so, analyse the problem as orthogonal directly.

3. If not mentioned as orthogonal, check whether the problem belongs to tool life, economics of machining, effective rake and relief angles etc. Need not worry about orthogonal or oblique.

4. If the problem does not belong to above three cases, assume the given problem as oblique and convert into orthogonal and analyse it as orthogonal.

8/10 List of components Lathe $\leftarrow$ function, manufacturing method, material, shape

U.V. Machining and M/c Tool construction

Hagira Chaudhary,

R.K. John, Sen Battacharyya

Lathe
drilling m/c
broaching
milling
shaping

Whatever the power or energy required for machining operation, is obtained from the prime mover only. The initial machines were equipped with I.C. engine as prime mover. But with I.C. engines, noise pollution is very high, the reciprocating parts in it can only be balanced partially so that the unbalanced force cause vibrations results in poor surface finish on the component. Hence after the invention of electrical motors, I.C. engines became obsolete.

Electrical motors - 3 types are used as prime movers

1. Induction motors
2. Stepped motors
3. Servo motors

- On conventional m/c tools, the induction motors are used as prime movers because it is the cheapest one.
- Whenever the power supply is given to the induction motor, it will always rotate only at a particular rpm, i.e., designed rpm.

$$V_{opt} = \frac{2DN}{1000}$$
$$N = \frac{1000 \times V_{opt}}{2D}$$

- To get the variable rpm of the spindle of job, even though the prime mover is rotating at only one particular rpm, the speed of the spindle is varied by the use of a gearbox.

- The most commonly used mechanical transmission system is belt drive with stepped pulleys because any sudden increase in the force in machining, cause the belt to slip. And hence failure of the prime mover can be eliminated.

The no. of spindle speeds used generally = 14 to 12.

The lowest and highest speeds are denoted as N_{min} and N_{max} .

$$N_{min} = \frac{1000 V_{min}}{\pi D_{max}}$$

$$N_{max} = \frac{1000 V_{max}}{\pi D_{min}}$$

N_{min} to N_{max} is called speed range.

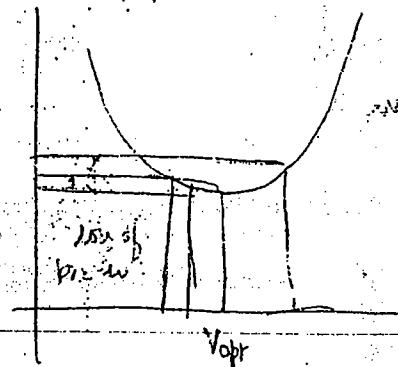
$$\frac{N_{max}}{N_{min}} = \text{Speed range ratio} = \frac{V_{max} \cdot D_{max}}{V_{min} \cdot D_{min}}$$

Q. $D = 5 \text{ to } 25 \text{ mm}$
 $V = 120 \text{ to } 180 \text{ m/min}$

$$\frac{N_{max}}{N_{min}} = ?$$

$$\frac{N_{max}}{N_{min}} = \frac{180 \times 25}{120 \times 5} = 3 \times 5 = 15 //$$

- The spindle speeds in a machine tool are selected based on geometric progression because, during machining whenever an required optimum spindle speed is not available, we select a nearby spindle speed. Due to this, a productivity loss takes place which will be minimum if the spindle speeds are selected in geometric progression.



eg. $\frac{N_6}{N_1} = \frac{N_6}{N_5} \times \frac{N_5}{N_4} \times \frac{N_4}{N_3} \times \frac{N_3}{N_2} \times \frac{N_2}{N_1} = r^5$

$r = \sqrt[5]{\frac{N_6}{N_1}} \Rightarrow N_2 = N_1 r, N_3 = N_2 r^2, N_4 = N_1 r^3 \dots$

In general $r = \sqrt[n]{\frac{N_{max}}{N_{min}}}$

Parameters: V_{opt} , feed, depth of cut

- During machining operation, the rpm of the job or the tool is always calculated based on the maximum diameter to which the tool is exposed for machining.
- The linear distance travelled by the tool along the workpiece for 1 revolution of the workpiece is called feed (mm/rev)

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

$= \text{mm/min} = \text{feed velocity}$

- The depth by which the tip of the tool is penetrating into the w/p from the surface is called depth of cut (mm)

[illegible]

LATHE

Operations performed in a lathe:

1. Plain turning: The method of reducing the dia. of w/p is called

plain turning

$$\text{Time of cut} = \frac{\text{Length of tool travel}}{\text{Feed velocity}}$$

$$= \frac{L}{fN}$$

$$L = l + AP + OR$$

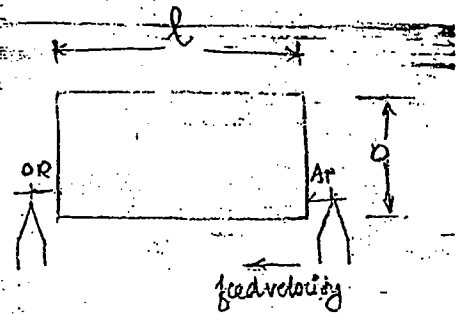
AP = approach

OR = over run

f = feed mm/rev. { Large feed for rough machining
small feed for finish machining

$$N = \frac{1000 V_{opt}}{\pi D}$$

D = max. dia. to which tool is exposed



Q. $D_i = 100 \text{ mm}$; $D_f = 80 \text{ mm}$; $d_{max} = 3 \text{ mm}$; no. of cuts?

$$\text{no. of cuts} = \frac{\text{total dia reduced}}{\text{dia reduced/cut}}$$

$$= \frac{100 - 80}{2 \times 3}$$

$$= \frac{20}{6} \approx 3.3 \approx 4 \text{ cuts}$$

$$\text{No. of cuts} = \frac{D_i - D_f}{2d_{max}}$$

The machining time does not depend on the depth of cut.

It depends on feed

$$\text{Total time } T_T = T_1 + T_2 + T_3 + T_4$$

$$= \frac{L}{fN_1} + \frac{L}{fN_2} + \frac{L}{fN_3} + \frac{L}{fN_4}$$

$$N_1 = \frac{1000 V_{opt}}{\pi D_i}$$

$$N_2 = \frac{1000 \text{ Vopt}}{\pi D_1}$$

$$\therefore D_1 = 100 - 3 \times 2 = 94$$

$$N_3 = \frac{1000 \text{ Vopt}}{\pi D_2}$$

$$\therefore D_2 = 94 - 3 \times 2 = 88$$

If $n > 5$, $T.T. = n \times T_{avg/ut}$

$$T_{avg/ut} = \frac{L}{f N_{avg}} \quad \checkmark$$

$$N_{avg} = \frac{N_1 + N_2}{2}$$

$$N_1 = \frac{1000 \text{ Vopt}}{\pi D_1}$$

$$N_2 = \frac{1000 \text{ Vopt}}{\pi D_2}$$

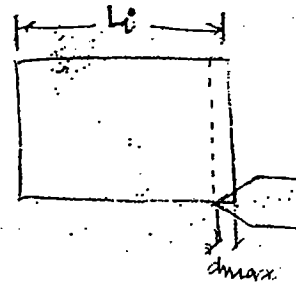
2. ^{Face} ~~Phase~~ turning

- The turning operation used for reducing the length of work.

$$\text{Time of cut} = \frac{L}{f N}$$

$$L = \frac{D_o - D_i}{2} + AP + OR \quad \text{for solid}$$

$$L = \frac{D_o - D_i}{2} + AP + OR \quad \text{for hollow}$$



$$f = \text{feed mm/rev}$$

$$N = \frac{1000 \text{ Vopt}}{\pi D} \quad \text{for solid}$$

$$N = \frac{1000 \text{ Vopt}}{\pi D_i} \quad \text{for hollow}$$

$$\text{No. of cuts} = \frac{L_i - L_f}{d_{max}}$$

$$T.T. = \text{no. of cuts} \times \text{time for cut}$$

$$T.T. = \frac{nL}{fN}$$

Taper turning

is the turning operation used for producing tapered components.

$$\text{Time of cut} = \frac{L_i}{fN}$$

L_i - inclined length of tool travel

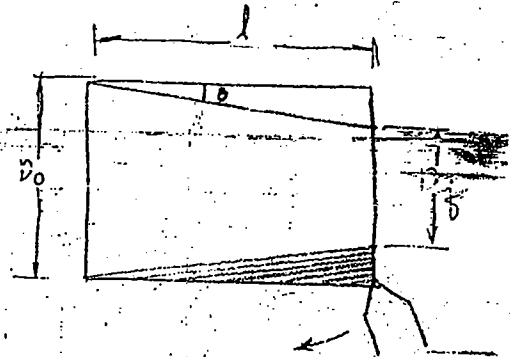
$$L_i = l_i + AP + OR$$

f - feed

$$N = \frac{1000 V}{\pi D_0}$$

l_i - inclined tool travel each having

an inclination of θ with the horizontal/length l



$$\tan \theta = \frac{D_0 - D_f}{2l}$$

$$\sin \theta = \frac{d_{\max}}{l_i}$$

$$\Rightarrow l_1 = d_{\max} \csc \theta$$

$$l_2 = 2d_{\max} \csc \theta$$

$$l_3 = 3d_{\max} \csc \theta$$

$$\text{No. of cuts} = \frac{D_0 - D_f}{2d_{\max}}$$

$$T.T. = T_1 + T_2 + T_3 + \dots + T_n$$

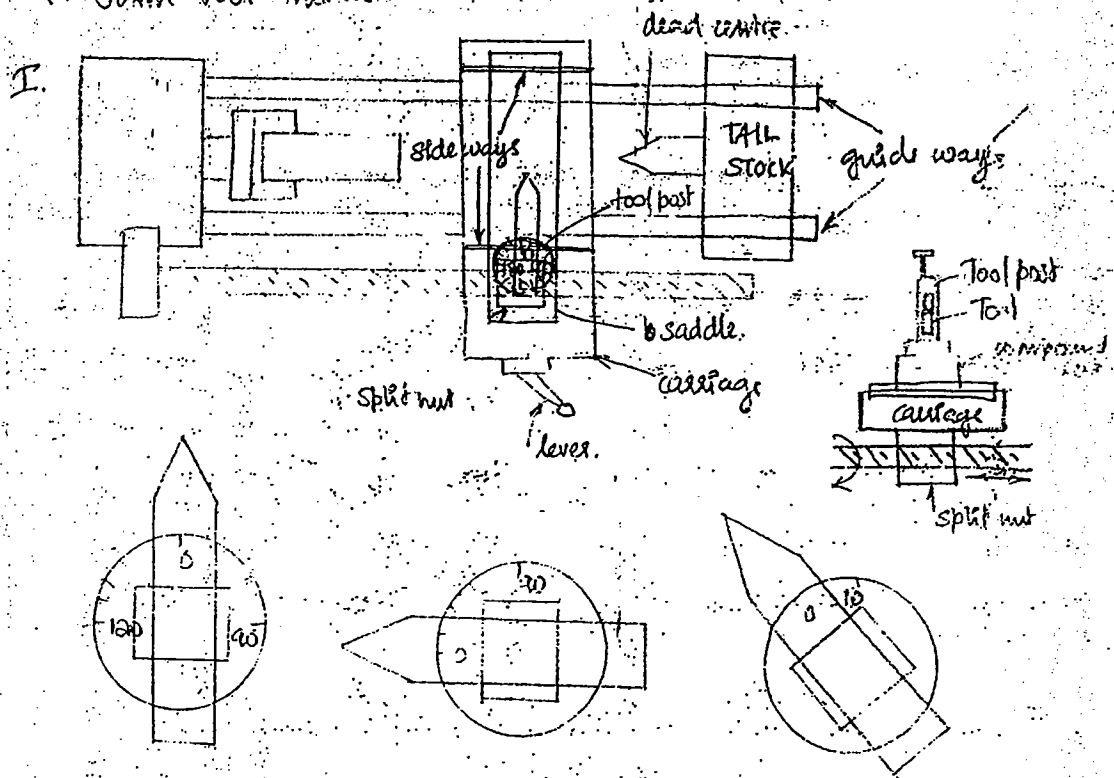
$$= \frac{1}{fN} (l_1 + l_2 + l_3 + \dots + l_n)$$

$$= \frac{d_{\max} \csc \theta}{fN} (1 + 2 + 3 + \dots + n)$$

$$= \frac{d_{\max} \csc \theta}{fN} \times \frac{n(n+1)}{2}$$

Methods of taper turning

1. Compound rest method.
2. Tailstock offset method.
3. Taper attachment method.
4. Form tool method.



— For plain turning, zero of compound rest coincides with the fixed marking. Similarly for taper turning, the compound rest can be rotated by an angle equal to the taper angle of the component. $\left(\alpha = \tan^{-1} \frac{D_0 - D_1}{2L} \right)$

— Advantages of compound rest method:

1. Can be used for both internal and external taper turning.
2. The angle of taper that can be produced is $\pm 45^\circ$

Limitation:

- The range of angle that can be produced is upto 0.5° only.
i.e., angle b/w 2 consecutive points is 0.5° .

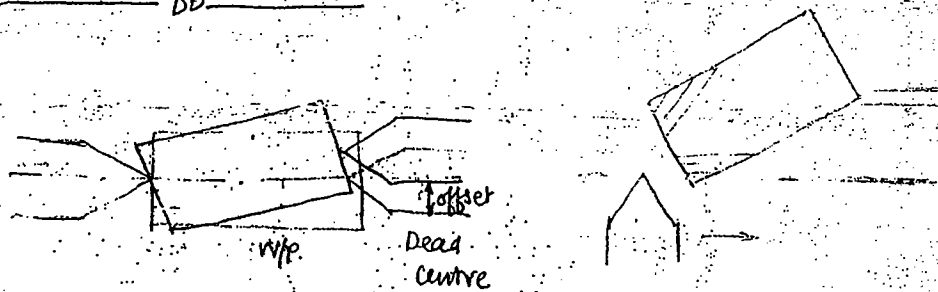
$$P = 8 \times 100 = 814$$

$$\text{Division} = \frac{814}{160} \approx 5$$

eg. $6^\circ, 6.5^\circ, 7^\circ$ are possible.

6.15° is not possible.

II. Tailstock offset method:



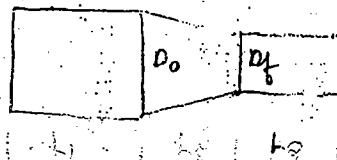
- In tailstock offset method, the dead centre can be offset according to the size of the component and the angle of taper to be produced so that even though the tool is moving like in a plain turning, the taper turning will be taking place automatically.

$$\text{Offset to be given} = \frac{D_o - D_f}{2}$$


Q. Calculate the offset for the component.

$$\text{Taper per unit length} = \frac{D_o - D_f}{2L_f}$$

$$\text{Offset} = \text{total taper} = \frac{\text{taper}}{\text{unit length}} \times L$$

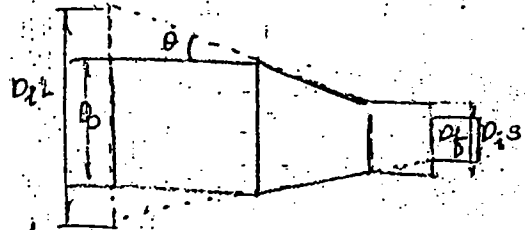


$$\text{Offset} = \frac{D_1 L - D_2 S}{2}$$

$$\theta = \tan^{-1} \left(\frac{D_1 - D_2}{2S} \right)$$

$$\Rightarrow \text{offset} = L \tan \theta$$

$$\theta = \text{taper angle} = \frac{\text{included angle}}{2}$$



Q. A 1000mm long component in which the central 200mm is tapered to included angle of 3° . What is the tailstock offset required for performing this job?

$$\text{offset} = L \tan \theta$$

$$= 1000 \tan 1.5 = 10.4 \text{ mm}$$

Advantages

1. Any accuracy upto 0.1° is possible

Limitations

1. only for external taper turning

2. max. offset possible is 10mm, unbalanced forces become large.

III Taper attachment method

- In normal turning operation, taper turning with compound set method and tailstock method, the slide ways are kept parallel to the guideways.

- In case of taper attachment method, the slide ways are tilted by an angle equal to taper angle of the component

so that the saddle, compound rest, tool post and tool are tilted by the same angle.

- Now by keeping the carriage stationary, the saddle can be travelled for taper turning operation.

Advantages:

1. upto 0.1° accuracy
2. can be used for both internal and external taper turning.

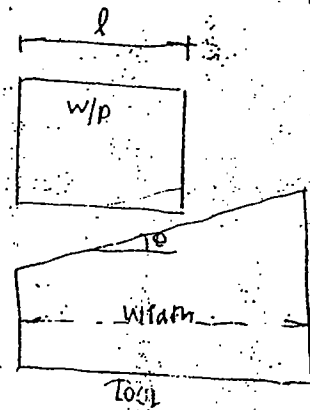
Limitations:

1. The slideways can be tilted only upto 8° or (16° inclined angle)
2. It is one setting maximum length of the component which can be taper turned is 225 mm only.

IV. Form tool method

- Whenever the shape of tool used remains same as that of the shape of the component to be produced is called form tool method of manufacturing.

- The accuracy of the taper depends on the accuracy of taper on the tool.
- For every angle, separate tool must be used.



- The force and power consumption goes on increasing due to increasing contact area.
- The width of the tool must be greater than or equal to the length of the workpiece to be taper turned.
- The maximum width of the tool that can be tapered is 225 mm.
- Hence the maximum length of w/p which can be tapered is less than or equal to 225.

that under dry conditions

4. Thread cutting: producing threads on cylindrical components by turning.

$$\text{Time for cut} = \frac{L}{fN}$$

$L = l + AP + OR$ (length of tool travel)

f = feed mm/rev.

= Pitch for single start thread

= lead for multistart thread.

Lead = pitch $\times$ no. of starts.

Multistart thread can be used for producing joints.

eg. mineral water bottle.

— Multistart threads can be used

1) whenever the leak proof joint need to be produced.

eg

2) whenever

eg

30 N -

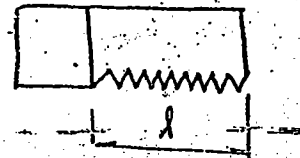
Mechani

$$T_u = \frac{L}{fN} \quad \begin{matrix} N \\ N \end{matrix}$$

→ Very low rpm is used in thread cutting

— for easy engagement and disengagement of the tool

— to minimize



○ single start

○ double start

○ triple start

∴ Total time = time per cut x no. of cuts.

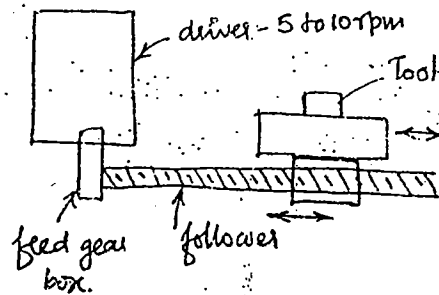
- The thread is cut in more than one cut even though the ^{or total depth of threads} required depth of cut is less than the max. possible depth of cut on a given machine. * because, if thread cutting is produced using large depth, a large amount of sideward thrust force is acting which may weaken the thread.

$$\text{No. of cuts} = \frac{QS}{\text{TPC}} \text{ for external}$$

$$= \frac{80}{\text{TPC}} \text{ for internal where TPC - threads per cm}$$

- In case of plain, face and taper turning operation, the feed given to the tool may be either manual or automatic. But in case of thread cutting, the feed given to the tool must be only automatic.

- The automatic feed is possible by means of the lead screw, split nut and the feed gear box.



The feed gear box consists of

20 to 120 toothed gears in

steps of 5 + 127 toothed gear are available.

20, 25, 30, 35, ... 120, 127

- * To produce different pitch of the threads on the job, the feed given to the tool is changed.
- This is called as *change of feed*.

- The special gear having 127 teeth is used for producing English threads on metric lathes as metric threads on English lathes.

(If pitch of the threads is represented in inches - English threads and if it is in mm, metric threads.

If p.t.h of lead screw is represented in inches - English lathes and if it is specified in mm, metric lathes)

- For calculation of change gears, in feed gear box, gear ratio is used

$$\text{Gear ratio} = \frac{N_{\text{follower}}}{N_{\text{driver}}} = \frac{N_{\text{lead screw}}}{N_{\text{job}}}$$

$$= \frac{\text{no. of teeth of follower}}{\text{" " " driver}} = \frac{\text{Pitch job}}{\text{Pitch L.S.}}$$

Q. Calculate the suitable gear train for cutting

10mm pitch 3 start threads on a lathe with lead screw

having 6.25mm pitch

$$G.R. = \frac{10 \times 3}{6.25 \times 1} = \frac{30}{6.25} \left(\frac{4}{4} \right)$$

$$= \frac{120}{25} \quad \text{simple gear train.}$$

$$\text{OR } G.R. = \frac{120}{6.25} \times \frac{4}{4} \times \frac{8}{1} \times \frac{250}{250}$$

$$= \frac{40}{25} \times \frac{60}{20} \quad \text{compound gear train.}$$

Same numbered teeth cannot be used more than once in a single setting.

- For every pitch of the threads to be produced, it is possible to design compound gear train. But simple gear train is possible only for some pitches and not for all.

- The feed gear box and its specification is according to an Indian standard gear box.

Q. Find the change wheel for cutting 1.75 mm pitch threads on a lathe machine having 6TPI (threads per inch).

$$G.R. = \frac{1.75 \text{ mm}}{1/6 \text{ inch}}$$

$$1 \text{ inch} = 25.4 \text{ mm} \\ \approx \frac{127}{5}$$

$$= \frac{1.75}{1/6 \times \frac{127}{5}} = \frac{1.75 \times 30}{1 \times 127} \\ = \frac{52.5}{127} \approx \frac{2}{2}$$

$$= \frac{105}{254} \rightarrow \text{not available. So we have}$$

to look for compound gear train.

$$\therefore G.R. = \frac{105}{127 \times 2} = \frac{105}{127 \times 2} \times \frac{20}{20} \\ = \frac{105}{127} \times \frac{20}{40}$$

OR

$$G.R. = \frac{20}{127} \times \frac{1.75}{1} \times \frac{40}{100} \\ = \frac{20}{127} \times \frac{70}{40}$$

Q. Calculate the gear train needed to cut 3mm pitch threads on an english lathe having lathe constant 8, gear progression is 4, gear available are 24, 28, 32, ..., 100, 127.

$$\text{Lathe constant} = \frac{25.4}{\text{Pitch}} \times \frac{1}{\text{Gear progression}}$$

$$\text{Lathe constant} = \frac{25.4}{3} \times \frac{1}{4} = \frac{25.4}{12}$$

$$\text{Gear ratio} = \frac{3\text{mm}}{\frac{1}{8} \times 127} = \frac{3 \times 100}{127} = \frac{120}{127} \text{ not available}$$

$$\text{G.R.} = \frac{120}{127} \times \frac{3 \times 24}{1 \times 24} = \frac{120}{127} \times \frac{72}{24}$$

→ Left hand and right hand threads

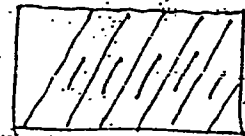
— For producing both LH and RH threads the direction of the rotation of the job must be counter clockwise.

— Most commonly used threads is RH: only because of easy tightening

— LH are used in jewellery, acetylene cylinders in oxyacetylene gas welding.

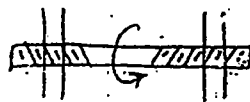


RH



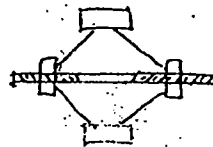
LH

eg. In tractors, for holding agricultural equipments on the back,



tightens or loosens in different direction

eg. Screw jacks to lift car.



— To produce RHT,

tool movement → right to left.

The direction of rotation of the lead screw must be same.

is determined by RH screw thread principle.

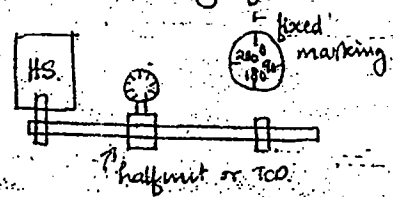
i.e., for producing RH threads, the direction of movement of tool must be from right to left direction, for this, the direction of rotation of lead screw is counter clockwise. Hence for producing RH threads, the direction of rotation of lead screw must be same.

To obtain this

- 1. If the designed gear train is a simple type, use odd no. of idle gears
a (cw) / b (ccw).
- 2. If it is compound type, use even no. of idle gears.

10.10
The tool has to follow the same path in all the cuts. In thread cutting operation, the path followed by the tool during second and subsequent must be same as the path followed by the tool during first cut itself.

- This is done by thread checking dial or half nut mechanism.



Rotation of TCO is at less than 1 rpm.

- When the selected position of TCO coincides with the fixed marking engage the lever.

- To satisfy the above condition, for every cut, the split nut can be engaged when the selected position TCO which coinciding with fixed marking i.e., first bring the tool away from the w.p.

Set the depth of cut, engage the lever of split nut. Then select the position of TCO coinciding the fixed mark. Continue thread cutting, • disengage the lever of split nut mechanism at the end,

take the tool backward and away from the w.p. set the tool for depth of second cut and engage the lever of split nut again

select the position of TCO coinciding with the fixed mark

and so on.

Multihead:

eg. 2 threaded produce

1st cut 1st start 0° or 90°
1st cut 2nd start 180° or 270°

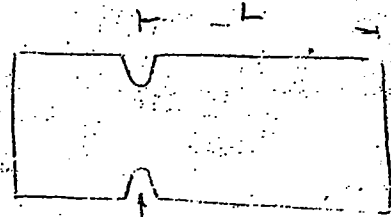
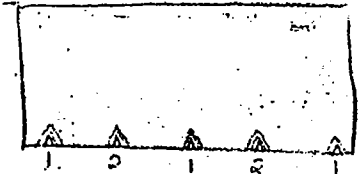
2nd cut 1st start 0° or 90°

2nd cut 2nd start 180° or 270°

3rd cut 1st start 0°

3rd cut 2nd start 180°

Gap = $\frac{360^\circ}{\text{no. of starts}} = \text{angle b/w 2 consecutive turning angles}$



— Just before thread cutting, a groove has to be produced at the end of length of thread on the component called grooving or necking or undercutting so that during thread cutting, whenever the tool is coming to the groove, the operator can get some time to disengagement of the tool.

— In general the thread cutting will be the last operation, after which no other operations are allowed to perform except chamfering.

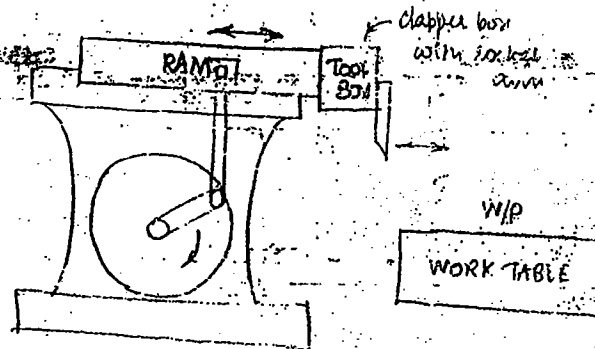
Q. Write the correct sequence.

1. Undercutting
2. Plain turning
3. Thread cutting
4. Taper turning

Ans. 2-4-1-3

SHAPING & PLANING remove

- Shaping is the operation used for removing material from the flat surface using reciprocating single point cutting tool.



1 rev of crank
 = 1 forward stroke + 1 return stroke
 = 1 cutting stroke + 1 idle stroke

- During machining, the tool has to travel at optimum cutting velocity during cutting stroke. But during return stroke the tool should travel at maximum possible velocity so that machining time can be minimized.
- To get the variable speed of ram during forward and return strokes during machining, even though the crank is rotating at uniform velocity, a mechanism is used called Whitworth quick return mechanism.

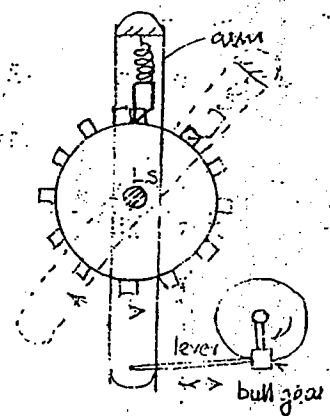
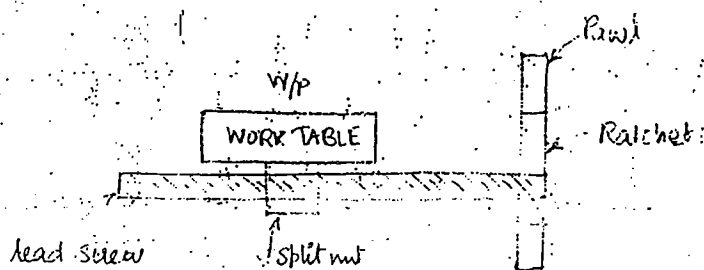
$$\frac{V_{\text{cutting}}}{V_{\text{idle}}} = M = \left(\frac{1}{2}\right) \text{ to } \frac{2}{3} \quad \text{most common} \quad M < 1$$

- The maximum velocity occurs at the middle of the return stroke, next maximum at the end of R.S. and minimum at the beginning of the forward stroke.

— In front of the ram, the clapper box with rocker arm is used. It lifts the tool during the beginning of the return stroke avoiding the wear and tear and again returning the tool's original position at the beginning of the cutting tool.

— In case of turning, the feed is always given to the tool as a continuous feed, only using feed gear box, lead screw and split nut. In shaping, feed is always given to the work table because the tool is always moving on a fixed guide ways. The feed given to the work table is always intermittent and during the return stroke of the ram. This intermittent feed required for the work table is given by using Ratchet and Paul mechanism:

$$1 \text{ rev. of Ratchet} = 1 \text{ rev. of L.S.}$$



— During first half revolutions of the crank, the lever is moving right to left direction, rotating the arm in clockwise direction w.r.t the Paul.

During this process, the Paul is simply lifting upwards against the

and whenever Paul finds the gap b/w 2 teeth it will fall down due to spring force.

During second half revolution of the crank, lever moves from right to left direction, the arm is rotating in counterclockwise direction w.r.t pivot. Since there is no inclination present of the other side of the Pawl, it rotates the Ratchet so that lead screw is rotating and work table is moving to obtain the feed.

eg. $p = 5 \text{ mm}$

Ratchet = 20 teeth

Pawl is indexing ^{the ratchet by} 1 tooth

1 rev. of ratchet = 20 teeth has to be indexed

= 20 return strokes = 20 double strokes

= 1 rev. of lead screw

= 1 pitch or 1 lead = 5 mm

1 double stroke = $\frac{5}{20} = 0.25 \text{ mm} = \frac{1}{4}$

$$\frac{1}{4} = \frac{P}{\text{no. of teeth}} \times \text{no. of teeth indexed / return stroke}$$

Let v = velocity of ram during cutting/forward stroke.

L = stroke length = $l + AP + OR$

T_c = time taken for one cutting stroke = $\frac{L}{v}$

$$M = \frac{v_c}{v_r} = \frac{T_r}{T_c} \Rightarrow T_r = M T_c = M \cdot \frac{L}{v}$$

Time/double stroke = $T_c + T_r$

$$= \frac{L}{v} (1 + M)$$

$$\text{D.S./time} = \text{RPM of crank} = \frac{v}{L(1+M)} \quad \text{generally } 10 \text{ to } 100 \text{ rpm for crank}$$

$$\text{Time/rev} = \frac{\text{time}}{\text{D.S.}} \times \frac{\text{D.S.}}{\text{rev}}$$

$$= \frac{L}{v} (1+M) \times \frac{60}{f}$$

Total time = time/cut $\times$ no. of cut

$$\text{No. of cuts} = \frac{\text{total depth of material to be removed}}{\text{depth of cut.}}$$

- To reduce machining time of large components using shaping machine, it is required to use more than one cutting tool simultaneously.

But on one ram, only one tool can be mounted. Therefore for mounting more than one tool, more than one ram is required.

i.e., it is nothing but more than one shaping machine kept parallel which is not possible and economical. So more than one single point cutting tool is fixed on the beam,

The beam is kept stationary and w/p is moved called planing.

- In shaping operation, the w/p is ^{kept horizontal and the tool is} reciprocating horizontally.

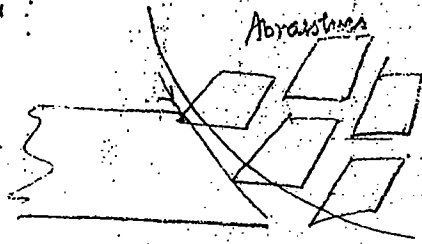
If it is rotated by 90° so that the w/p is vertical

and tool is reciprocating vertically, then it is called slotting machine.

GRINDING

- It is used for finishing machining operation.
- In grinding, each and every abrasive particle present in grinding wheel acting like a single point cutting tool for work.
- The approximate shape of particle is cubical or rectangular in c/s.

- Approximate shape of the chip produced is triangular.



- As the machining is progressing, the abrasive particles wear out slowly. The worn out particles start rubbing the w/p producing rubbing forces which are more than sufficient to pull out blunt particles so that the fresh and abrasive particles is coming into contact with w/p for removing the metal. This is called self sharpening.

- Sometimes the rubbing forces produced is too sufficient to pull out the blunt abrasive particles, during which resharpening of the grinding wheel can be done by dressing operation.

Dressing is a turning operation performed in diamond cutting tool for removing thin layer of material from the surface of the grinding wheel.

- Out of all the conventional machining operation, grinding is the one that produces the finest surface finish.

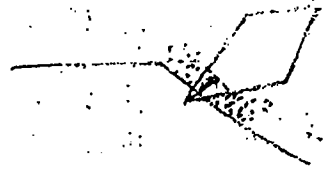
The 1000 is a random orientation of abrasive particles.

Random orientation of abrasive particles:

- During manufacturing using power metallurgy, the abrasive particles are getting randomly oriented so that only $\frac{1}{3}$ of the abrasive particles will act as single point cutting tool and others simply rubbing with the w.p. So a large cutting energy will be wasted.

2. Lower ploughing action
(penetrating)

Sometimes because of the presence of bonding material, besides the abrasive particles, it will not allow the abrasive particles to penetrate largely into the w.p. Therefore the chip thickness will be reducing and so is the material removal rate.



$$\text{Machining ratio} = \frac{\text{M.R. on w.p.}}{\text{tool wear}}$$

$$\text{Machining ratio (grinding ratio)} = \frac{\text{M.R. on w.p.}}{\text{G.W. wear}}$$

$$= 0.1 \text{ to } 100$$



$$\text{Grind ratio} = \frac{L \cdot W \cdot R \cdot d}{\pi \cdot (r_1^2 - r_2^2) \cdot b}$$

Very small as compared to other Maching)

Machining time for grinding

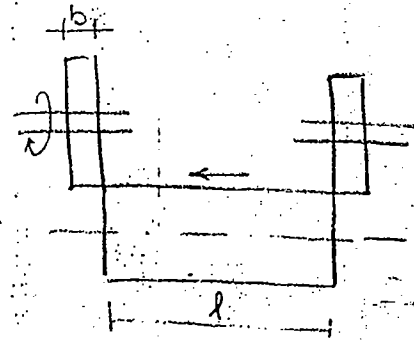
$$L = l + b \cdot A_p + O.R.$$

$$\text{Time of cut} = \frac{L}{fN}$$

f - feed mm/rev

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

$$V = 18000 \text{ to } 30000 \text{ m/min}$$



- For easy identification of different elements present in a grinding wheel, a standard designation must be used, called grinding wheel designation and specification.

- The grinding wheel can be designated using 5 code with suffix and prefix where suffix and prefix are used by the manufacturer and need not be standard.

Prefix	Alphabet 1	Number 2	Alphabet 3	Number 4	Alphabet 5	Suffix

1. Type of Abrasive

- A - Al₂O₃
- B - B₄C
- C - SiC
- D - Diamond

2. Grain size

or
grit size

- 16-24 - coarse
- 30-60 - med
- 80-180 - fine
- 220-600 - very fine

3. Grade of G.W.

- A to H - soft
- I to P - medium
- Q to Z - hard

4. Structure

- 0-7 - dense structure
- 8-12 - open structure

5. Bond.

V - vitrified.

B - Bakelite

S - Silicate

E - Shellac

R - Resin

— The type of abrasive indicates the material used for the manufacturing of abrasive particles.

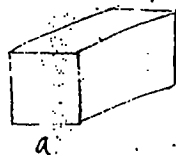
Because of very high cost, diamond is not commonly used.

Because of poor performance, SiC is also not commonly used.

Al_2O_3 is soft and tougher than SiC.

The selection of type of abrasive particle is based on the mechanical properties of work material i.e., for grinding of soft w/p, Al_2O_3 is selected and SiC for hard w/p.

Grain size or grit size



$$a = \left(\frac{1}{GSN} \right)^{\frac{1}{4}} \rightarrow \text{grain size no.}$$

$$a = \left(\frac{25.4}{GSN} \right) \text{ mm.}$$

— a is the side of cubical abrasive particle or square cross section abrasive particle.

— As the size of the abrasive particle or grain size is increasing, the MRR from the w/p increases first and then reduces.

— Grain size can be selected based on the surface finish required on the work. i.e. for rough grinding (discontinuous surface) or medium

grain size can be selected and for finishing, fine or very fine can be selected.

— Grade of grinding wheel: indicates the hardness of grinding wheel. Even though everything is same, it is possible to vary the grade of a grinding wheel by varying compacting pressure used in the powder metallurgical process used in the manufacture of grinding wheel. i.e., during high compacting pressure is obtained, higher grain compactness can be obtained which gives higher hardness of grinding wheel.

— The grade of a G.W. is selected based on the mechanical properties of work material.

— During max grinding of hard w.p., the force involved is very high, tool wear is higher, the abrasive particles become blunt very fast (1 to 2 minutes). This blunt abrasive particle starts rubbing onto the w.p. but rubbing force produced is not sufficient to pull out blunt abrasive particles if the G.W. is a hard wheel. Hence the G.W. simply rubbing on w.p. without doing any machining called glazing or blunt grinding wheel. To remove this glazing, the G.W. has to be dressing (10 to 20 minutes). i.e., If hard wheels are used for hard w.p. for even 1 to 2 minutes of dressing, the tool is wasted which is not economical.

— If soft wheels are used for m/c-ing of hard w/p as soon as the abrasive particles are becoming blunt, it starts rubbing onto the w/p, the rubbing force is more than sufficient to pull out the blunt abrasive particles.

— During m/c-ing of soft w/p, the forces induced are low, tool wear is low, tool life is high. i.e. one abrasive particle can be used for machining about 2 to 3 hours. If soft wheels are used, as soon as a small amount of wear is taking place in the abrasive particles, the rubbing force produced will pull out the abrasive particle. i.e. effective utilization is not possible. If hard wheels are used, the abrasive particles can be effectively utilised. Hence after 2 to 3 hrs of m/c-ing spending 30 mins for dressing is very small and negligible.

— Structure ^{is} selected based on mechanical properties of w/p and surface finish requirement.

$$\left(\frac{\text{Structure no.}}{1000} \right)^4 = \text{average gap b/w 2 consecutive or successive abrasive particles on a grinding wheel.}$$

soft w/p	- open
hard w/p	- dense
rough grinding	- open
finish grinding	- dense

— During m/c-ing of soft w/p and rough grinding operation, the size of the chip produced is larger. If dense structure is used,

because of small gaps b/w abra. particles, the chips may get lodged in b/w the ab. part, not allowing the next ab. part to participate in grinding, called loading of G.W. If open structure is used, because of large gap b/w ab. part, the chances of clogging the chip will be eliminated.

For rough grinding of soft w/p $\rightarrow 12$ to 16

" " " " " hard w/p $\rightarrow 7, 8, 9$

finish grinding soft w/p $\rightarrow 6, 7, 8$

" " " " " hard w/p $\rightarrow$ below 5

— The material used for producing the bond between the ab. particles is called bond.

— ~~veratified~~ Veratified is the most commonly used bonding material because, it provides high temp. withstand and high coeff. of thermal expansion.

— Shellack and rubber bonding materials are used for producing flexible grinding wheel called buffing wheel.

Q. Select a grinding wheel for finish grinding of HSS cutting tool

A-350-K-8-V

HSS medium hard Al_2O_3 & sufficient

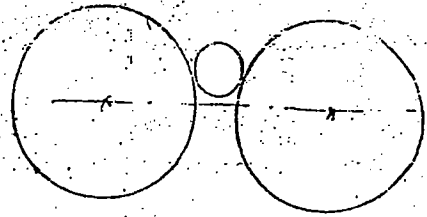
finish grinding - fine or very fine - 350

Q. Select a G.W for rough grinding of brass bracket.

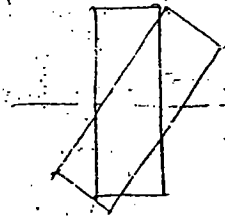
Q. finish grinding of GI w/p.

Centreless grinding: The cylindrical component can be ground without losing its roundness and straightness for which the best preferable method is centre less grinding.

The centre of w/p is lying above the line joining the centres of the grinding and regulating wheel.



The axis of grinding and regulating wheel are tilted by an angle α .



$\alpha \rightarrow 1$ to 6°

V - surface velocity of regulating wheel

$V \sin \alpha$ - used for providing necessary feed to the workpiece.

$V \cos \alpha$ - used for providing necessary rotation to w/p.

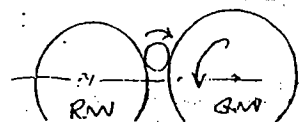
— For finish grinding, high speed of regulating wheel combined with lower value of α can be used.

— For rough grinding, $\rightarrow$ low speed of R.W. + higher value of α

— Power is given only to the grinding wheel. The w/p & R.W. are regulating due to friction.

— The direction of rotation of the grinding wheel is always such that it pushes the workpiece downwards.

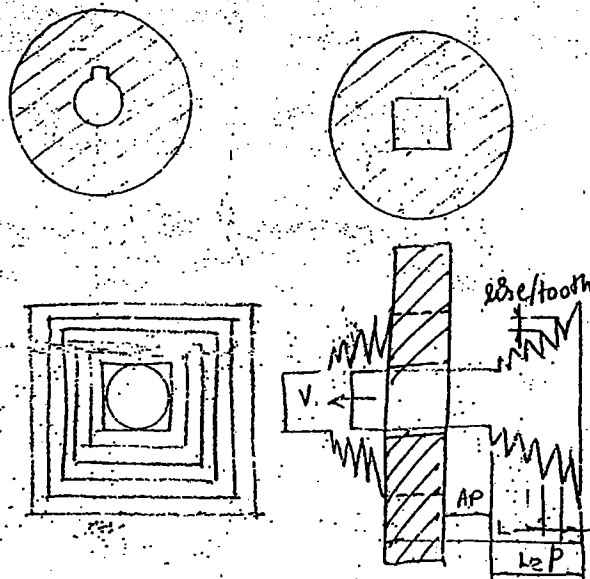
— To avoid the falling of w/p's, a wedge



BROACHING

- Broaching is always done as a secondary machining process, since it needs a hole to be produced before broaching.

- Broaching is used for producing large size non circular holes, internal gear, internal keyways etc.



- Small sized non circular holes can be produced by using non conventional machining methods, large size non circular holes are produced by using broaching. Though the large sized non circular holes can be produced by using non conventional methods, but the energy and power consumption is very high and is thus uneconomical.

$$P_{\text{BEM}} \approx 150 \times (P)_{\text{TM}} \text{ traditional machining}$$

$$\text{Time of cut} = \frac{L}{V}$$

or throat vel

$$= 0.1 \text{ to } 0.5 \text{ m/min}$$

effective cutting length of

$$h_e = \underbrace{h_{or}}_{\substack{\text{length of} \\ \text{broach for} \\ \text{rough tooth} \\ (n_r \times p_r)}} + \underbrace{h_s}_{\substack{\text{" for} \\ \text{semi finish} \\ \text{tooth} \\ (n_s \times p_s)}} + \underbrace{h_f}_{\substack{\text{" for} \\ \text{finish} \\ \text{tooth} \\ (n_f \times p_f)}}$$

- In a standard broaching tool, 3 types of teeth are available.

1. Rough tools: are used for removing the maximum amount of material for producing an approximate rough shape of the component. The no. of rough tools may be as many as required.

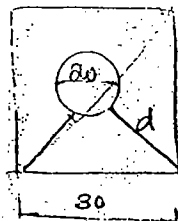
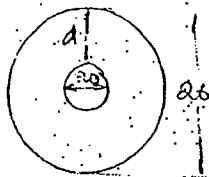
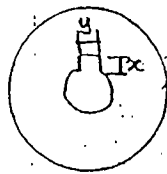
2. Semi finish tools: are used for removing small amount of material to produce the size of the component nearly as required. The no. of semi finished tools is 4 to 10.

3. Finish tools to produce exact size of the component with good surface finish. Hence they remove very small or negligible amount of material. The no. of finish tools used is 2 to 6.

* d = total depth of material to be removed

$$d = d_r + d_s + d_f$$

$$n_r = \frac{d_r}{h_{or}} ; n_s = \frac{d_s}{h_s} ; n_f = \frac{d_f}{h_f}$$



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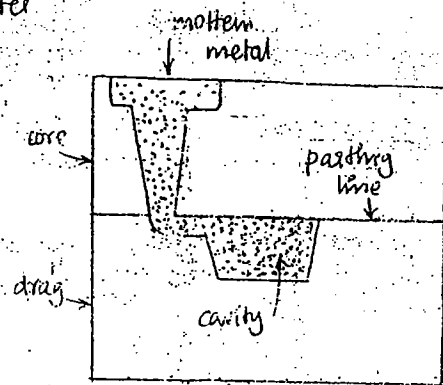
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CASTING PROCESS

Casting is the process in which the liquid molten metal is poured into the casting cavity whose shape is same as that of the casting to be produced, allowed to solidify, after which the casting can be taken out by breaking the mould or taking the mould apart.

The shape of the casting to be produced is same as the cavity. The solidified object is called casting.



Advantages of casting

1. Molten material flows into any small section in the mould cavity and as such many intricate shapes - internal or external - can be made.
2. It is possible to cast any material - ferrous or non ferrous.
3. The necessary tools required for casting moulds are very simple and inexpensive.
4. Weight reduction in design can be achieved as it is possible to place the amount of material where exactly required.
5. Castings are cooled uniformly from all sides and therefore they are expected to have no directional properties.
6. Castings of any size and shape can be made.

Steps in casting

1. Pattern making: Pattern is the replica of the casting to be produced but with some modification. Replica means, the shape of the pattern is same as that of the casting. But the size of the pattern is different from the casting shape.

$$\text{Pattern size} = \text{C.S.} \pm \text{Allowances.}$$

5 types of allowances.

1. Shrinkage allowance:

$$\text{Pouring temp.} = \text{melting point} + \underbrace{150 \text{ to } 200^\circ\text{C}}_{\text{degree of superheat}}$$

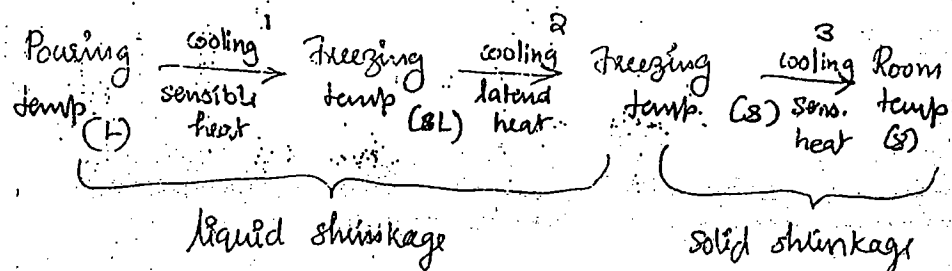
P.T.

$$\text{eg Fe, P.T.} = 1539 + 150 \text{ to } 200^\circ\text{C} \\ = 1700^\circ\text{C}$$

$$\text{Al, P.T.} = 660 + 150 \text{ to } 200 = 800^\circ\text{C}$$

$$\text{Cu, P.T.} = 1084 + 150 \text{ to } 200 = 1250^\circ\text{C}$$

— To avoid the solidification of molten metal in the passages.



— During casting process, the shrinkage is taking place in all the 3 stages. The shrinkage occurring in 1st and 2nd stage is called liquid shrinkage and that occurring in 3rd stage is called solid shrinkage.

- Liquid shrinkage is always specified by %/volume.
- Out of the commonly used metals, Aluminium is the one which is having the highest shrinkage ($\sim 6\%$)
- The liquid shrinkage in casting process can be compensated by providing riser in the casting process.

$$\text{Solid shrinkage} = L \alpha (T_f - T_r) \quad (\% \text{ over dimension})$$

where L - dimension of the component

α - coeff. of linear thermal expansion.

T_f - freezing temp.

T_r - room temp.

- Solid shrinkage is directly proportional to the coeff. of linear expansion

$$\alpha_{\text{brass}} = 83 \mu\text{m}/^\circ\text{C}$$

$$\alpha_{\text{admiralty metal}} = 83.5 \mu\text{m}/^\circ\text{C}$$

↑ slightly modified brass
(not commonly used)

$$\alpha_{\text{invar}} = 0.0000096 \mu\text{m}/^\circ\text{C} \sim 0$$

$$\alpha_{\text{Platinum-Iridium alloy}} \approx 0$$

$$\alpha_{\text{grey C.I.}} = -1.3 \mu\text{m}/^\circ\text{C}$$

- Solid shrinkage occurring during casting is compensated by shrinkage allowance

— From the above, the shrinkage allowance on the pattern is the allowance provided to compensate the solid shrinkage occurring during cooling from freezing temp. to room temp.

— The total shrinkage ~~for cast~~ is highest for steel

Q. During which of the following needs the ^{highest} riser size, the

Casting size = $200 \times 100 \times 150$ mm.

a) Steel ✓ b) Al c) Brn d) G.C.I.

Q. Maximum $\frac{\text{vol of pattern}}{\text{vol of casting}}$ = for brass

Q. If G.C.I. to C.S. = $200 \times 100 \times 150$ mm. shrinkage allowance 1%.

$\frac{\text{vol. of pattern}}{\text{vol of casting}} = ?$

✓ a) 0.97 b) 0.99
c) 1.01 d) 1.03

$$\frac{\text{Vol. of pattern}}{\text{vol. of casting}} = \frac{(0.99 \times 200)(0.99 \times 100)(0.99 \times 150)}{200 \times 100 \times 150}$$

$$= (0.99)^3 = 0.97$$

3 Machining allowance

— The extra material provided on the casting so that it can be removed by machining after casting

— Machining allowance is provided due to—

i.) As it is the casted component will have poor surface finish

Therefore to get the good surface finish, the extra material is provided so that at last it can be removed

ii.) To minimize the variation in shrinkage during a whole piece.

solidification due to variation in the room temp.

Machining allowance = $X \text{ mm/side}$. ^{← depends on the complexity.} of the component

— Shrinkage and machining allowances are the major allowances which affect the dimensions of the pattern.

Q. Cylinder casting $D = 100 \text{ mm}$ $L = 150 \text{ mm}$ $SA = 1 \text{ in } 50$ $MA = 2 \text{ mm/side}$

Determine the dimensions of the pattern.

Pattern size with MA

$$D = 100 + 2 + 2 = 104$$

$$L = 150 + 2 + 2 = 154$$

P.S. with SA + MA

$$SA = 2\%$$

$$D = 104 + \frac{2}{100} \times 104 = 108.08$$

$$L = 154 + \frac{2}{100} \times 154 = 160.08$$

Pattern size with S.A shrinkage allowance

$$D = 104 + 2 + 2 = 108 + \frac{2}{100} \times 4 = 108.08$$

$$L = 156 + 2 + 2 = 160 + \frac{2}{100} \times 4 = 160.08$$

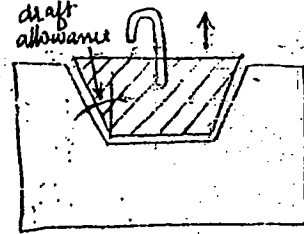
P.S. with SA + MA

— Shrinkage allowances have to be provided for machining allowances also

3. Draft allowance:

- Making the vertical surface of the pattern into inclined surface. This is provided for easy removal of pattern from the mould.

- Generally the pattern is removed by hand. Draft is given to avoid the damage which can occur at the mould walls.



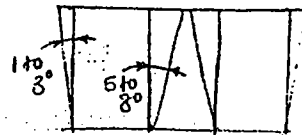
- Without providing the draft allowance, during the removal of the pattern from the mould, until end, a contact is present b/w the pattern and the mould. Hence any vibration occurring during removal or withdrawal results in damage to mould.

- With the provision of draft allowance, as soon as the pattern is lifted by small amount, the clearance is adjusting with the pattern and the mould. So that the removal of the pattern afterwards is easier and vibration will not damage the mould.

Draft allowance on the

external surface -- 1 to 3°

Internal surface -- 5 to 8°



NOTE:

If the pattern is made by using materials like wax, Hg, polished pyrex, Polystyrene as pattern material, there is no draft allowance to be provided on the pattern.

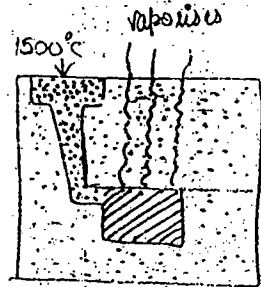
Polystyrene - TPP

Polystyrene - TSP

Mould is heated to 80 to 100°C before the pattern removal. (for wax)
Hg - freezing point - 39°C. Hg cooled to -70 to -80°C (solid).
Molten metal is poured. After solidification Hg is removed.

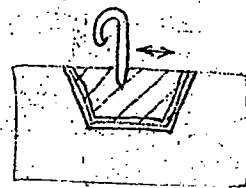
Polystyrene: M.P. 105°C B.P. 380 to 390°C.

The pattern is removed in the form of
vapour or gas. Polystyrene instantaneously
melts, vaporises and escapes through mould
- sand



14. Shake allowance.

— During moulding process, when the
pattern is removed from the mould,
because of the adhesiveness property



of moulding sand, the adhered
moulding sand to the pattern is coming along with the pattern
which damages the mould walls. To avoid this, before removal
of the pattern from the mould, the pattern will be shaken by
a small amount so that the adhered moulding sand is separated
from the pattern and increases the size of the cavity and casting.

To maintain the size of the casting, the pattern size has to
be reduced by an amount equal to the shake allowance.

— Since it is the reducing of dimensions of the pattern, the
shake allowance is taken as a negative allowance.

— Shake allowance depends on the mould making person.

5. Distortion allowance: (Bending allowance).

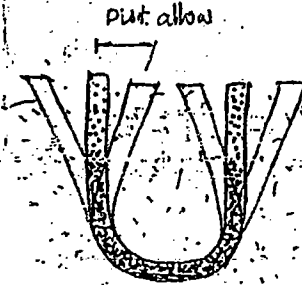
- not provided on a V and U types of castings only

- The amount of ~~dist~~ δ by which the leg of the U shaped comp.

leans towards is called distortion allow

- It depends on $\frac{l}{t}$ ratio.

$$\frac{l}{t} \uparrow \quad P.A. \uparrow$$



Pattern material properties

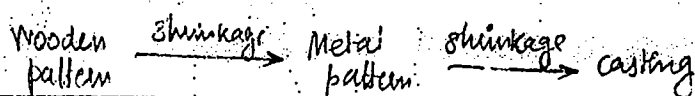
1. No moisture absorption
2. Low density: as minimum as possible for easy handling
3. Good surface finish
4. Easiness in fabrication
5. Cheap

Eg. 1. wood $P = 0.4$ to 0.8 g/cc. High moisture absorption. All

the other properties are possessed by the wood. Therefore

the wood which has low moisture absorption capacity can be used. (Teakwood, Mahogany)

2. Metals Whenever the metal patterns are produced using wooden patterns, on which the double shrinkage allowance can be provided.



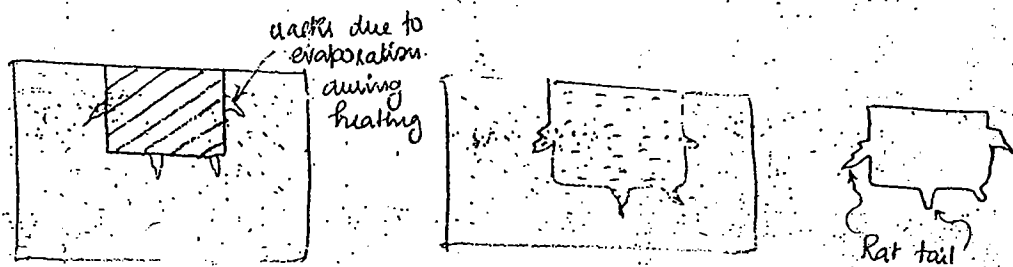
(Al, White metal, Ti) costly

$P_{0.2}$ $P_{0.2}$ $P_{0.2}$

3. Plaster: Since it possesses all the desirable properties, it plaster is the most commonly used pattern making material.

(PVC, epoxy resin, cellulose, Nylon, polystyrene)

4. Wax: It is used only because it can be produced to any complex shape easily due to very high strength. And also its removal is easy in the form of a liquid. It produces very good or excellent surface finish. Therefore no post casting process is required. For wax, close dimensional accuracies are possible to obtain. They are used for producing complex shapes of the casting. Since it is very soft, only small amount of ramming force can be applied hence loose sand moulds can be produced.



As a single piece pattern, the maximum size of the pattern used is upto 5 kg only due to the distortion - possibility of cracking during handling.

wax pattern can be used in the form of expansion patterns.

eg. ~~many~~ ~~of~~ sparse applications

- Basic constituents of molding sand are

- [illegible]

—when increase in % of clay, the porosity property of the clay decreases.

Additive to improve the properties of molding sand.

1. Wood powder / saw dust

used to increase the porosity or collapsibility property of molding sand.

3. Coal powder: to increase the reflectiveness of molding sand.

3. Starch/dextrine: to improve the strength or resistance to deformation.

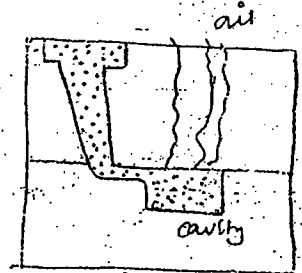
These additives can be added to a max 2% each.

Properties of molding sand.

1. Porosity: ability of the sand to allow air or gases to escape through

When molten metal is poured, the air present in the cavity gets compressed which escapes through the pores.

Defects like blowholes result if the air or gases don't escape from the cavity.

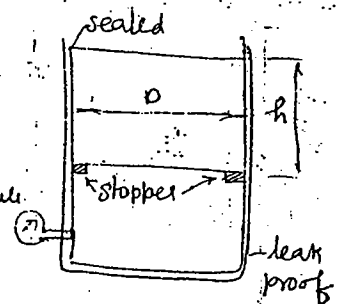


Deformation of porosity of moulding sand is done by means of permeability test.

As per the AFS/ASTM standard, a circular disc shaped sand specimen having dia a and height h is produced, where

$$h = D = 5.08 \text{ cm.}$$

The sand specimen is placed on a leak proof container. Volume below sand is 2000 cc. A pressure gauge is connected to measure the pressure.



The air inside the volume at pressure $P > P_{atm}$.

So air starts escaping through the sand. At some time T , the pressure outside and inside becomes equal.

Permeability number, $PN = \frac{Vt}{PA\sqrt{P}}$

$$PN = \frac{2000 \times 5.08}{A \sqrt{P_{atm} - P} \times T}$$

$$P = 100 \text{ mm Hg} \quad T = 10 \text{ sec}$$

Higher P.N. indicates higher porosity property of the mould sand.

The methods of improving porosity property are

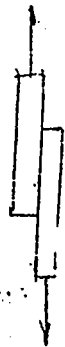
- Increasing the sand particle size.
- Reducing the clay content.
- Reducing ramming/compressive force.
- By adding wood powder/saw dust.
- By venting / vent holes.

2. Strength of the moulding sand.

<table border="0"><tr><td>-</td><td>tensile</td></tr><tr><td>-</td><td>compressive</td></tr><tr><td>-</td><td>shear</td></tr></table>	-	tensile	-	compressive	-	shear	} can be determined by using U.T.M.
-	tensile						
-	compressive						
-	shear						

3. Cohesiveness

- It is the ability of formation of bond b/w sand particles.
- It is measured by using or applying eccentric loads. It measures the shear strength b/w a layer of sand particles. So this method is also called inter laminae shear strength test (ILSS).



4. Adhesiveness

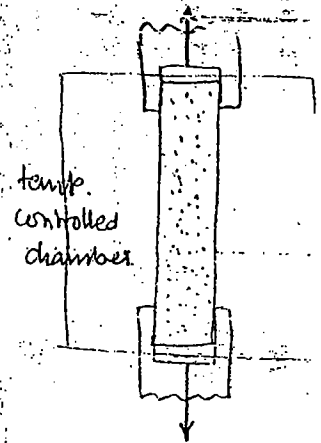
It is an ability of formation of bond b/w sand particles with other materials like pattern, mould etc.

Also measured using U.T.M.



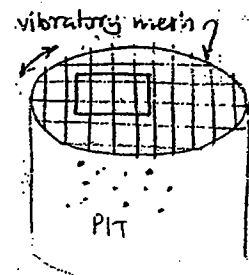
5. Refractoriness:

- It is the ability of withstanding of higher temp without losing strength and hardness.
- It is measured by using U.T.M. with temperature controlled chamb
- As the temp. of the chamber is increasing, at some temp., the sand specimen will fail.



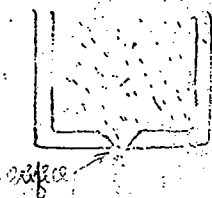
6. Collapsibility:

- It is the ability of breaking the mould with a little amount of force.
- It can be measured by using vibratory mesh. By applying vibrations to the mesh, the mould gets broken. But ^{for the} ~~with~~ collapsibility property, the vibration can be slowly increased and determine the frequency and amplitude of the vibrations on which the mould is getting broken.



7. Flowability:

- It is the ability of flowing of moulding into each and every corner of the mould.
- It is measured using orifice. By measuring the time taken for a certain quantity of sand to fall through the orifice.



orifice

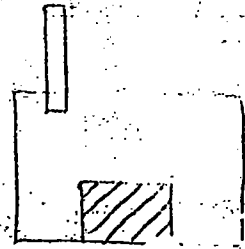
Methods of mould making

1. Hand moulding

— Whatever the force required for ramming/compressing of the mould sand, if it is obtained by human hand, is called hand moulding.

+ cheapest method as no special equipment is required.

+ The complex shapes of the patterns can be used without damages.



— The force applied by the human hand is not uniform. Therefore, the strength and hardness of the mould.

— Time taken for mould is longer as compared. So lesser production rate.

2. Machine moulding

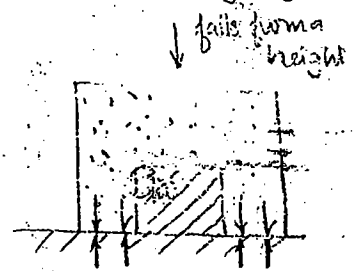
— Whatever the force required for ramming/compressing the moulding sand, if it is obtained from machine, it is called m/c moulding.

- 4 methods:
- a. Jolting
 - b. squeezing
 - c. Jolt & squeezing
 - d. Sand striking

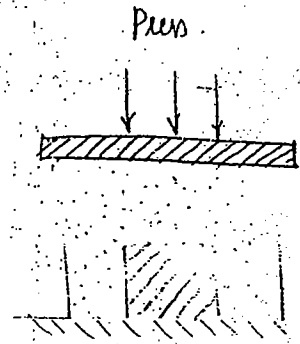
— Jolting — A sand filled mould is raised to a height and allowed to fall freely onto the ground. So that the P.E. is converted into impact load and impact energy acting on

to the ground. The equal and opposite reaction force produced by the ground is acting onto the mould for ramming of the mould to be taken place.

— With jolting operation, higher strength and hardness can be obtained at the bottom of the mould. But the top of the mould is loose sand. Hence only jolting cannot be used for mould making.



— Squeezing: The squeezing plate is placed on the top of mould and apply the force using a press onto the plate. This force is transmitted to the moulding sand for ramming of moulding sand to occur.

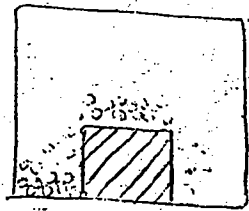


— With squeezing, high strength and hardness is obtained on the top of the mould. But at the bottom, it produce lower strength.

— By using jolt and squeezing operations combined, with jolting first and squeezing next, at both top and bottom of the mould is attaining higher strength producing uniform strength of the mould if the height of the mould is less than or equal to 200mm. For $h > 200\text{mm}$, at the middle ^{only} lower strength is obtained. So to get uniform strength throughout the height of the mould, the best solution is to use a combination of jolt and squeezing operations.

- Sand strapping: Here small quantities of moulding sand is thrown on the mould with certain force using rife.

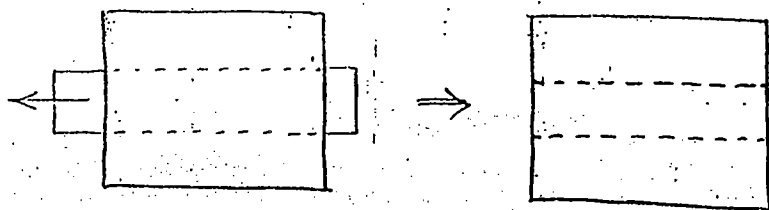
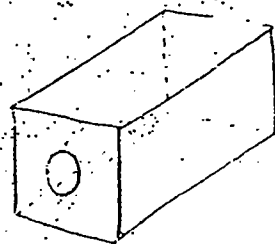
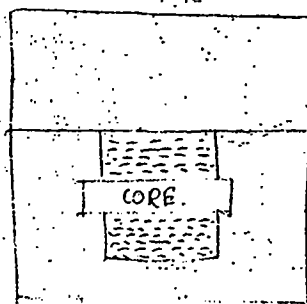
Due to this, localised ramming of moulding sand is taking place. Hence uniform strength and hardness can be obtained.



- It is a costly equipment.
- It cannot be used for making the moulds with pattern having projection and extension.

2. Core making

- Cores are used for producing hollow castings.



- Core material should be a non metal
- free from moisture
- should have high strength. (i. to withstand the self weight of the core &.
- should have high collapsibility (easily removable)

— strength and collapsibility on one the same material is hard to obtain at once. So dry sand with CO_2 molding is used.

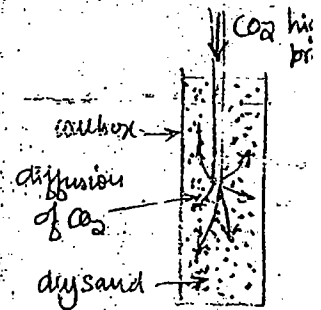
— When CO_2 at high pressure is applied on to

the dry sand, it is chemically reacting with

Sodium silicate producing silica gel. On

drying to 1-2 minutes, it gives very high

strength in core which is ^{not} easily collapsible.



— Whatever the high strength obtained due to

the formation of silica gel on drying will not last for long.

(only upto 3 hours) After 3 hours, the core starts losing its

strength, after 6 hours, core loses its strength completely and

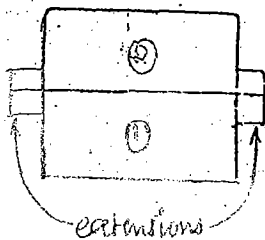
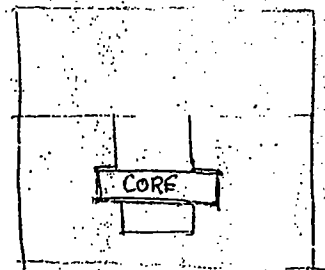
becomes loose sand which can be removed from the casting

very easily w/o any force.

CORE PRINT (Recess)

— Recess is provided on the mould for locating or positioning the core.

— It can be produced by providing extensions on the pattern.



Whenever the extensions are provided on the pattern, the removal of pattern from the mould

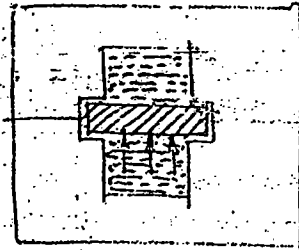
becomes difficult. Hence the pattern is

divided into 2 parts so that one part of the

pattern is kept in the core flask.

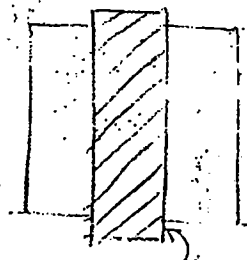
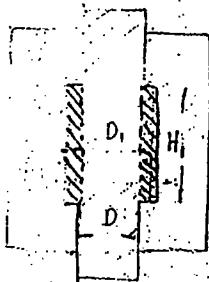
in the drag box and the mould is produced. Therefore the removal of the pattern is easier, and the placement of the core is easier.

- Since the density of core is less than that of molten metal, buoyancy force is acting onto the core in which is trying to move the core in the upward direction.



Let ρ - density of molten metal
 d - density of the core
 v - volume of core

$$\begin{aligned} \text{Net buoyancy force} &= \text{weight of liquid displaced} \\ &\quad - \text{weight of core} \\ &= v\rho g - vd g \\ &= vg(\rho - d) \end{aligned}$$



Net B.F. ≈ 0
 as there is projected area on the core for the action of buoyancy

Here Net B.F. = weight of the liquid displaced due to the projected portion of core

— total wt. of core

$$\text{ie, Net B.F.} = \left[\frac{\pi}{4} (D_1^2 - D^2) H_1 \rho g \right] - \left[\left\{ \frac{\pi}{4} (D^2 - D^2) H_1 + \frac{\pi}{4} D^2 H \right\} d g \right]$$

load which can be supported by core print $\approx 850 A$ ← surface area of the core

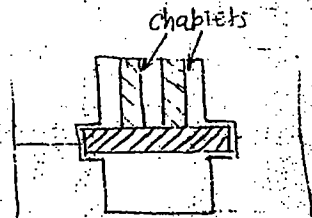
Unsupported load = net B.F - P

If net B.F - P ≤ 0 $\rightarrow$ no additional supports are required

If net B.F - P > 0 $\rightarrow$ additional supports are required

— The additional supports required for the casting process can be provided using chaplets.

Chaplets are made by using the same material as that of the casting because, it is forming an integral part of the casting.



— Before placing the chaplets into the casting cavity, it must be cleaned thoroughly to avoid the weak joint formation i.e., solidified metal on the chaplet.

For every 1N of unsupported load, 29 mm² C.S.A chaplet must be used.

— The chaplet also provides directional solidification as an additional functionality.

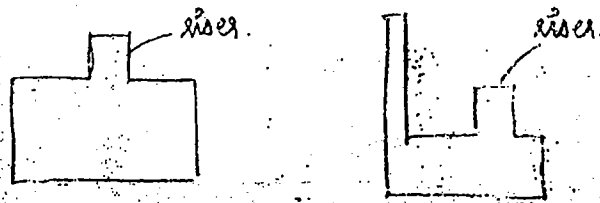
Riser

— During casting, the riser is located based on two considerations

1. During casting of uniform C.S.A. castings, the riser is provided at the topmost point of casting cavity.

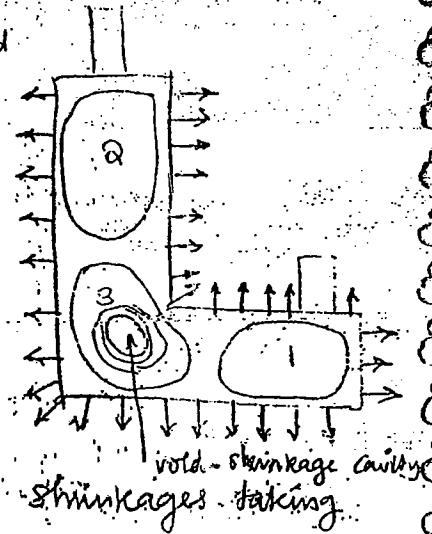
2. During casting of

provided near to the thickest portion than the thinnest portion.



eg. During casting of uniform CS. L-shaped vertical castings, the molten metal in the zone 3 or corner portion of the mould is solidifying after the other.

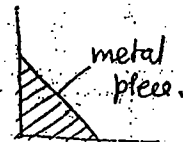
2 portions are solidified. Therefore, even though 2 risers are provided, it is not possible to compensate the liquid shrinkages taking place in the corner portions of the mould because:



- i) The volume of the molten metal in the corner portion is higher than other 2 portions. Hence heat removed is higher and so is the time taken.
- ii) At the corner portion of the mould, the heat transfer occurs in 2 directions. Therefore the temp. at the corner of the mould becomes very high and its reduced temp. and heat transfer. This further increases the time taken for solidification of corner portion of the mould.

To avoid the shrinkage cavity or void, the corner portion of the molten metal has to be solidified before other 2 portions.

This is possible by increasing the heat transfer through the corner of the L section by increasing the thermal conductivity of the corner of the mould which is possible by providing high thermal conductivity metallic piece at the corner of the cavity during moulding.



— By providing metal piece (or chills)

in the casting process, it is possible to

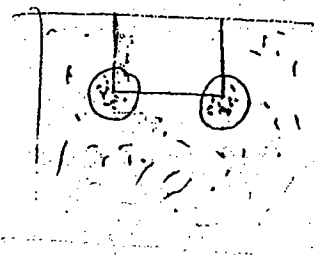
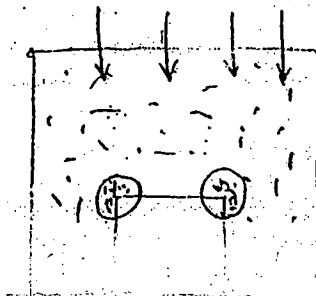
direct the heat transfer in the required methodology to get the solidification of the molten metal in the casting

cavity as per specific methodology called as directional solidification.

— The chills are made by using the metal which has high thermal conductivity and higher melting point temp. than the casting metal.

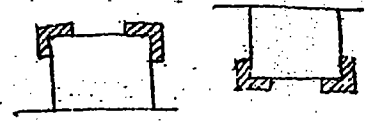
— After casting process, the chills would have adhered to the casting. If it is not affecting the performance of the casting, leave them on it, otherwise, remove it from the casting using machining.

Pads or Padding



- During casting of sharp edged castings pattern will also have sharp edges.

During moulding of sharp edged pattern when the ramming force is applied,



The sand particles present at the corner are slipping away and produce loose sand mould at the corner.

- During filling of molten ^{to} in the casting cavity, the loose sand particles present at the corner will get eroded and enters into the molten metal forming sand inclusion defects.

- To avoid this defects, the L shaped metallic piece also called pads are provided at the edges during the mould making itself. After removing the pattern from the mould, this pads will be retained in the mould so that during pouring of molten metal, this pads won't allow the molten metal to get in to contact with loose sand particles directly. Hence the sand erosion and sand inclusion defects can be eliminated.

- Pads are made by using high M.P. metallic materials. Since the metal pad has higher thermal conductivity, it transfer high heat from the edges. Thus pads also provide directional solidification functionality.

28.10

POURING

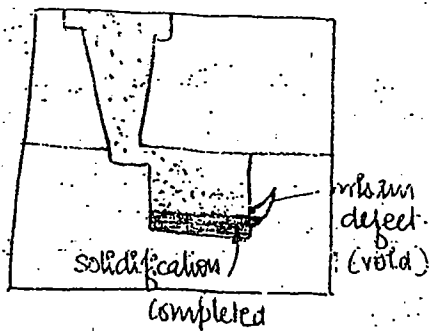
— The molten metal is always poured into the casting cavity using the gating system. It consists of 4 basic elements.

1. Pouring basin
2. Sprue
3. Runner
4. Ingate

Ideal characteristics which must be possessed by the pouring system:

1. The time taken for pouring or filling of molten metal into the casting cavity must be as min. as possible.

This is to ensure that no part of the casting cavity should start solidify before complete filling of the cavity.



$$\begin{aligned} \text{Pouring time (Pt)} &= \frac{\text{Volume of the cavity}}{\text{flow rate}} \\ &= \frac{\text{Vol}}{A \times \text{velocity}} \end{aligned}$$

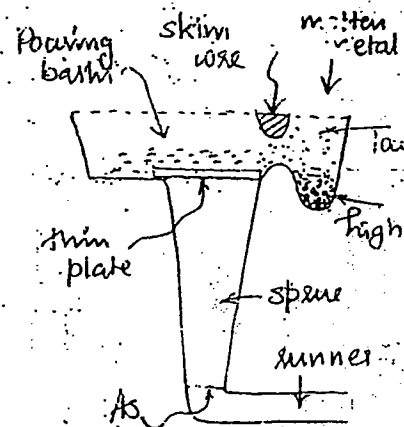
- Pt can be decreased by
1. increasing the cross sectional area
 2. increasing the velocity of flow.

But the cross sectional area has to be minimum so as to prevent the erosion of same particles

— with gating

2. The gating system is designed such that the velocity of the molten metal in the gating system is as maximum as possible within the limits of laminar flow, i.e., the turbulent flow is not allowed. Turbulence results in erosion of sand particles.
3. The flow of molten metal through the gating system is always full. The partial flow is not allowed. (forms blow holes).
4. It should separate the impurities present in the molten metal like low density and high density impurities.
5. It should avoid the sand erosion.
6. Gating system should be designed such that it avoids the aspiration effect.

— Pouring basin is acting as a reservoir for separating the molten metal into the casting cavity. Pouring basin separates the impurities present in the molten metal.



— A thin plate is provided at the bottom or neck of the pouring basin which absorbs the heat from the molten metal collected over the plate and the total plate is melting at a time so that the molten metal produced due to the melting of plate and molten metal collected over the plate flow through

the gating system simultaneously which ensures the full flow of molten metal through the gating system.

- The dimensions of the pouring basin is not affecting the flow rate or pouring time of the casting process.

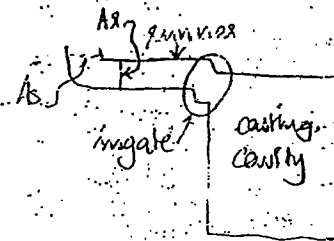
- Spire is acting as a connecting passage b/w the pouring basin and the runner which is always vertical which is tapered and circular cross section. A tapered spire is used for eliminating the aspiration in casting.

- The height of the spire is responsible for producing the velocity of the molten metal. i.e, it ensures the laminar flow and minimizes the pouring time.

A- cross section area of the spire. (always the bottom cross section is considered)

- Runner is the connecting passage b/w the bottom of the spire and the ingate. It is always horizontal.

with uniform trapezoidal cross section.



The trapezoidal c.s. is used because it is giving the highest coeff. of discharge (C_d) as $Q_{act} = C_d Q_{theo}$.

- The runner minimizes the pouring time and sand erosion.

- In case of spire, it is preferable to use circular c.s. only

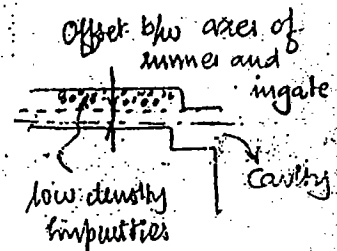
because, whenever the flow of liquid occurs, because of the presence of the datum edge, the volume of C_d remain constant irrespective of c.s. Hence whichever the c.s. is easier in manufacturing can be used for spire making.

For c.s. $\frac{1}{2}$

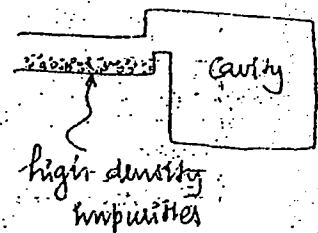
- Ingate is the last part of the gating system from where the molten metal is flowing into the casting cavity. It is also horizontal with uniform trapezoidal c.s.

There is an offset b/w the axes of the runner and the ingate.

$$\text{offset} < 5\text{mm}$$



- During casting of high density metals, it is easily separated the low density impurities when the molten metal is passing through the horizontal passages. By making the axis of the runner above that of the ingate, the ~~low~~ low density impurities are prevented.

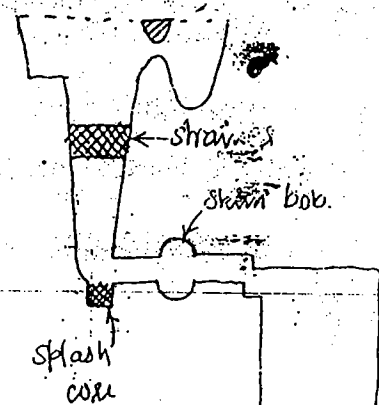


A_g C.S.A. of the ingate

$$\text{Gating ratio} = \text{Ratio } (A_s : A_x : A_g)$$

- The accessories used in the gating system for improving the efficiency of pouring of molten metal into the gating system are:

1. Strainer: filter for removing the impurities present in the molten metal. Ceramic materials with high porosity is used for making strainer.



2. Splash core: It is used to avoid the sand erosion from the bottom of the sprue. It is also made by using ceramic materials but with low porosity.

3. Skim bob: is a semi circular cut given in the runner to separate impurities present in the molten metal (both high and low densities).

Classification of gating system

I. Based on the pressure above molten metal in the pouring basin.

1. Non pressurized gating system.

2. Pressurized g.s.

II. Based on the position of ingate.

1. Top gating system.

2. Bottom gating system.

3. Parting g.s.

4. Step g.s.

— If the pressure above the molten metal in the pouring basin is equal to the P_{atm} , it is called non pressurized g.s. It is easy to maintain.

— It should not be used to casting of highly reactive metals like aluminium, magnesium etc. Because when the pouring basin is open to the atmosphere, this material produces their oxide.

For non pressurized gating system or
g.s.,

— Whenever the pressure above the molten metal is above P_{atm} in the pouring basin, it is called pressurized gating system. It is used in cases of 3 different conditions.

a) During casting of highly reactive metals: Here the top of pouring basin is ^{closed} and the space above the molten metal in pouring basin is filled by using inert gases at greater than atmospheric pressure.

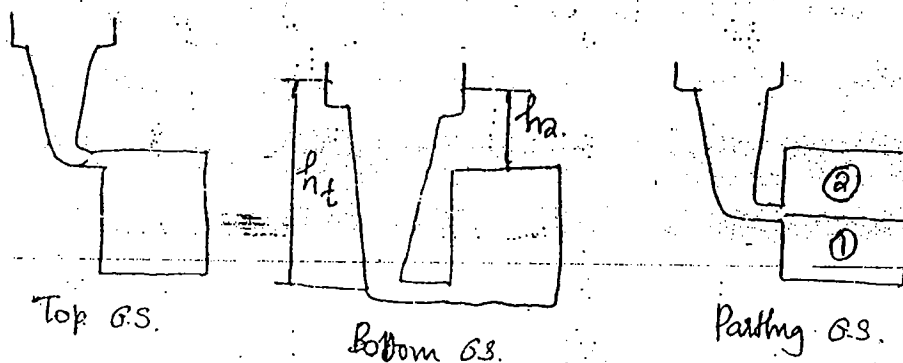
b) Back pressure G.S.: If the top of the pouring basin is ^{closed} and partial flow of molten metal is allowed to the G.S., the air which is compressed in the cavity is flowing backwards and collected over the top of molten metal in the pouring basin having the pressure greater than P_{atm} . called as back press G.S.

c) Whenever the velocity of the molten metal in G.S. to be increased without increasing the height of the sprue, increase of an external pressure above the molten metal is performed.

$$V_2 = \sqrt{2gh + \frac{P}{\rho}}$$

— For pressurized G.S.,

$$\text{Opt. G.R} \approx 1:2:1$$



TOP G.S. Pouring time, P.T. = $\frac{\text{volume}}{\text{flow rate}}$

Flow rate = Area $\times$ velocity $_{\text{max}}$

= $A_{\text{min}} \times V_{\text{max}}$

= $A_{\text{max}} \times V_{\text{min}}$

$V = \sqrt{2gh} = V_{\text{max}}$

Flow rate = $A_c V_{\text{max}}$

$A_c = \min(A_s, A_x, A_g)$

+ From the beginning ^{to end} of the filling of cavity, the molten metal is flows into the G.S. at max. possible velocity. Therefore, the time taken for filling the molten metal in casting cavity is minimum.

- Cutting of the top G.S. is easier.

- Max. height of the cavity upto which the top G.S. can be used w/o producing sand erosion is 200 mm.

- They cannot be used for filling of loose sand molds.

BOTTOM G.S.

P.T. = $\frac{\text{volume}}{A_c \times V_{\text{avg}}}$

$V_{\text{avg}} = \frac{V_i + V_f}{2}$

$V_i = \sqrt{2gh_t} = (V_{\text{max}})_{\text{top G.S.}}$

$V_f = \sqrt{2gh_b}$

- Under similar conditions, the time taken for filling of molten metal into the cavity with bottom G.S. is always higher than the top G.S.

- Cutting or making of bottom G.S. is difficult.

+ Absolutely no sand erosion is taking when whatever may be the height of the cavity and also during filling of the loose sand mold.

ARTING

22.

$$PT = T_1 + T_2$$

$$= \frac{(Vol)_1}{A_c \times V_{avg \max}} + \frac{(Vol)_2}{A_c \times V_{avg}}$$

$$V_{max} = V_i = \sqrt{2gh_1}$$

$$V_f = \sqrt{2gh_2}$$

PT for parting G.S. is greater than top G.S. but less than the bottom G.S.

STEP G.S.

$$PT = \frac{Vol}{A \times v_{el} \times n_{max}} \text{ for top step}$$

Whenever, the large casting cavities are to be filled, with top, bottom or parting gate system, the time taken is atleast half an hour. To minimize this time, the only possibility is that more than one ingate can be provided in a given horizontal plane. And this is called step gating system.

The step gating system can be taken ^{for} top, bottom or parting G.S. according, the P.T. will be varied.

For Calculation of P.T. or filling time of molten metal in the casting cavity, following assumptions are taken.

1. Loss of energy due to friction, sudden expansion/contraction etc. are assumed to be negligible.
2. The time taken for falling of molten metal into the riser is assumed negligible.

Aspiration (or) inhalation (or) breathing effect

During filling of molten metal into the casting cavity, rusting & s.s., somewhere along the G.S., if pressure falls below P_{atm} , this pressure difference b/w the inside and outside of the G.S. causes air to flow from outside to inside

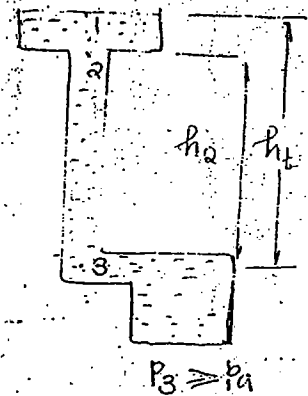
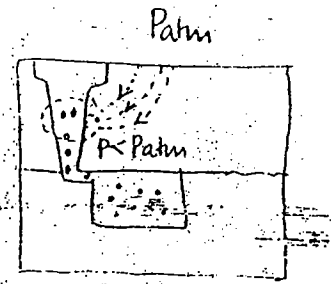
through the porosity property of the mold. This is called aspiration or inhalation or breathing effect.

Aspiration promotes blow holes in the casting.

At point (1), because of the pressure is greater than or equal to the P_{atm} ,

no aspiration is taking place.

Point (3) (very near to casting cavity). Therefore the temp at (3) is same as that of pressure in the cavity.



$$h_2 + \frac{P_2}{\rho g} + \frac{v_2^2}{2g} = h_3 + \frac{P_3}{\rho g} + \frac{v_3^2}{2g}$$

Condition 1: $P_3 = 0$

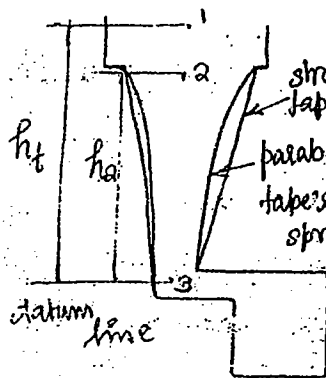
$A_2 v_2 = A_3 v_3$ (continuity eqn)

$$A_2 = v_3 \quad \therefore v_2 = v_3$$

$$\Rightarrow h_2 + \frac{P_2}{\rho g} = 0$$

$$\Rightarrow \frac{P_2}{\rho g} = -h_2$$

$$P_2 = -\rho g h_2 \quad \text{i.e., vacuum pressure.}$$



$$R = \frac{A_3}{A_2}$$

$$A_2 V_2 = A_3 V_3$$

$$\frac{V_2}{V_3} = \frac{A_3}{A_2} = R$$

$$h_2 + \frac{P_2}{\rho g} + \frac{V_2^2}{2g} = h_3 + \frac{P_3}{\rho g} + \frac{V_3^2}{2g}$$

$$P_2 = P_3 = 0 \text{ (gauge)}$$

— For avoiding the aspiration effect, all along the length of the sprue, pressure must be greater than or equal to P_{atm} .

As a worst condition, the $P_2 < P_3$ can be taken as zero gauge pressure.

$$h_2 + \frac{V_2^2}{2g} = \frac{V_3^2}{2g}$$

$$\frac{V_3^2 - V_2^2}{2g} = h_2$$

$$V_3^2 - R^2 V_3^2 = 2gh_2$$

$$V_3^2 (1 - R^2) = 2gh_2$$

$$1 - R^2 = \frac{2gh_2}{V_3^2}$$

$$R^2 = 1 - \frac{2gh_2}{V_3^2}$$

$$= 1 - \frac{2gh_2}{2gh_t}$$

$$R = \sqrt{1 - \frac{h_2}{h_t}}$$

— From the above, parabolic tapered sprue is used to ensure that the pressure all along the length of sprue is equal to zero gauge pressure or P_{atm} eliminating aspiration effect.

- But parabolic tapered sprue is difficult to manufacture.
- Hence straight tapered sprue is used. $(C.S.A.)_{\text{straight taper sprue}} > (C.S.A.)_{\text{parabolic taper sprue}}$
- The C.S.A of straight tapered sprue is greater than that of parabolic tapered sprue. Hence the velocity is reducing.
- Pressure all along the length of the sprue is greater than zero gauge or atm. eliminating the aspiration effect always.

SOLIDIFICATION:

- The time taken for converting liquid molten metal into solid is called solidification time.
 - Heat to be removed for converting $L \rightarrow S$ } = mass of casting $\left(\begin{matrix} \text{sensible heat} \\ + \\ \text{latent heat} \end{matrix} \right)$
- $$= V \times \rho \{ (T_p - T_f) C_p + L \} \quad \text{--- (1)}$$
- Heat to be removed for solidification has to be transferred only through mold only taking the mechanism of unsteady state heat conduction with infinite wall thickness.

$$\text{Heat removed} = \left[\frac{k A_s (T_p - T_m)}{\sqrt{\pi \alpha \tau}} \right] \times \tau \quad \text{--- (2) } \checkmark$$

A_s - surface area of casting

T_p - pouring temp. T_m - mold temp.

τ - time taken

α - thermal diffusivity

From (1) & (2) $\Rightarrow (1) = (2)$

Heat is removed for casting $L \rightarrow S$
through the mold only.

$$\Rightarrow \frac{k A_s (T_p - T_m) \sqrt{\tau}}{\sqrt{\rho \alpha}} = \sqrt{V P} \{ C_p (T_p - T_f) + L \}$$

$$\sqrt{\tau} = \frac{\sqrt{V P} (C_p (T_p - T_f) + L)}{k A_s (T_p - T_m)}$$

$$\tau = \left(\frac{V}{A_s} \right)^2 \left[\frac{P C_p (T_p - T_f) + L}{k (T_p - T_m)} \right]^2 \rho \alpha$$

$$= \left(\frac{V}{A_s} \right)^2 k_1 \rightarrow \text{mould constant or solidification factor}$$

$$\tau = k_1 M^2 \rightarrow \text{modulus} = \frac{V}{A_s}$$

Q. A spherical drop of $r_1 = 2 \text{ mm}$ solidifies in 10 s. Another drop 10 mm solidifies in similar condition. Calculate solid time.

$$r_1 = 2 \text{ mm}$$

$$r_2 = 10 \text{ mm}$$

$$\frac{\tau_2}{\tau_1} = \left(\frac{k_1}{k_1} \right) \left(\frac{M_2}{M_1} \right)^2$$

$$= \left(\frac{M_2}{M_1} \right)^2 = \left(\frac{r_1/3}{r_2/3} \right)^2 = \left(\frac{r_2}{r_1} \right)^2 = \left(\frac{10}{2} \right)^2 = 14$$

$$\tau_2 = \tau_1 \times 14$$

$$= 10 \times 14$$

$$= 140 \text{ s.}$$

Q. C.S₁ = 200 x 100 x 80 mm $\rightarrow$ $\tau_1 = 10 \text{ min.}$

C.S₂ = 200 x 100 x 60 mm $\rightarrow$ $\tau_2 = ?$ Similar condition.

$$\phi = D = 200 \text{ mm}$$

$$K_1 = 0.94 \times 10^6 \text{ s/m}^2$$

$$C = K_1 M^2$$

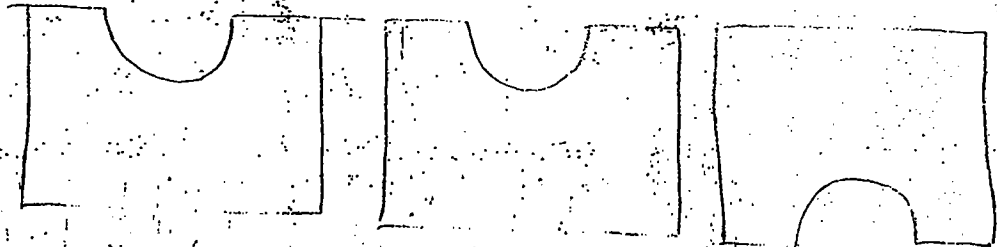
$$= K_1 \left(\frac{R}{2}\right)^2$$

$$= K_1 \left(\frac{D}{2}\right)^2 = 0.94 \times 10^6 \times \left(\frac{200}{2}\right)^2$$



SLUSH CASTING

- It is a special casting process, here liquid molten metal is poured into the cavity in open condition, allowing it to solidify for some time, immediately invert the mold, so that unsolidified metal is flowing down, retaining the solidified material inside the mold. By breaking the mold, casting is taken out.



- It is used for producing thin decorative parts like lamp shades (~1mm thickness)

$$M_{\text{thin}} = t$$

$$T \propto M^2 \propto t^2$$

$$T \propto \sqrt{t} \Rightarrow t = QT + C_0$$

Q, C_0 are found out through experiments

$$C_0 = \frac{t_0}{Q}$$

$$Q = \frac{t_0}{C_0}$$

$$Q_1 = 205, t_1 = 3 \text{ mm}$$

$$Q_2 = 50.5, t_2 = 4.5 \text{ mm}$$

$$Q_3 = 100.5, t_3 = ?$$

$$3 = Q_1 \sqrt{20} + C_2$$

$$4.5 = Q_1 \sqrt{50} + C_2$$

$$t_3 = Q_1 \sqrt{100} + C_2$$

$$Q_1 = 0.88$$

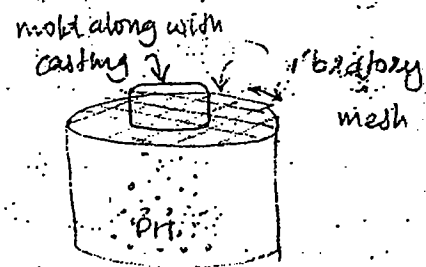
$$C_2 = -15.9$$

30.10

FETTLING

- It is the process of breaking the mold and taking the casting out.

- After solidification, the mold along with the casting is placed on the vibrating mesh so that due to the vibrational forces, the mold slowly breaks, broken pieces



falls into the pit leaving the casting and the mold box over the mesh.

- Once the mold is broken completely, the mold box can be sent for remolding and casting is sent for inspection.

INSPECTION $\begin{cases} \text{Dimensional} \\ \text{Defective} \end{cases}$

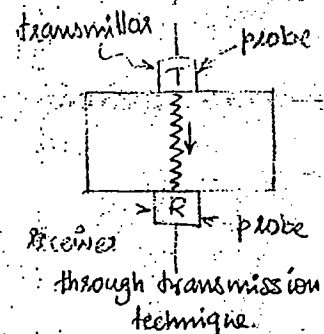
First one or two casting produced by the pattern is inspected dimensionally and qualify the pattern after no one need to be inspected, only random inspection is sufficient.

One the component is qualified dimensionally, the every component should be inspected for defects.

i) Com testing: is the cheapest and the fastest method of inspection but it needs experience of the inspector.

ii) Ultrasonic scanning/testing $\begin{cases} \text{TT} \\ \text{PET} \end{cases}$

where the ultrasonic sound is produced by the transmitter and transmitted through the solid test piece and the signal received by the receiver is compared

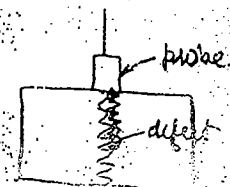


with the signal transmitted and determine the loss of sound.

If the loss is $\leq 5\%$, it is assumed that the defect may be present in the casting as the size of defect is negligible.

Based on the wave pattern received by the receiver we can estimate the type of the defect.

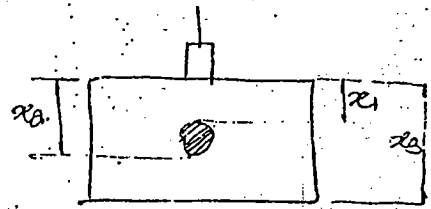
By using through transmission technique, we cannot locate the defects. So we use pulse echo technique (PET), in which initially the probe acts as both transmitter and receiver and produces signal such that whenever it find a variation is density of



ultrasonic backscattered signal.

- Now the probe is measuring the time interval b/w transmitted sound signal —

α_1



$$x_1 = \frac{V_{sound} \times T_1}{2}$$

$$x_2 = \frac{V_s \times T_2}{2}$$

$$x_3 = \frac{V_s \times T_3}{2}$$

- PET will give the approximate size and location of the defect but cannot give the type of the defect.

III) X-ray radiography

- After radiography the X-ray film is taken. If the film is having uniform colour indicates that no defects are present in the casting. If pure white coloured patch is observed ^{it} indicates the blowhole present in the casting. Pure black coloured patch indicates the high density inclusion and so on.
- By measuring the size of the patch divided by the magnification factor (MF) gives the exact size of the defect.
- Using this, it is easy to determine the size, height and location of the defect.
- It is very costly method.
- X-rays are highly carcinogenic (cancer prone).

RISER DESIGN

- Riser is acting as a reservoir for supplying molten metal to the casting cavity to compensate the liquid shrinkage taking place ^{during} the solidification.

Conditions: $\frac{\text{shrinkage volume of casting}}{V_c}$

$a = \%$ shrinkage of the material

V_c - volume of the casting

eg. $V_c = 1000 \text{ cc}$

$a = 6\%$

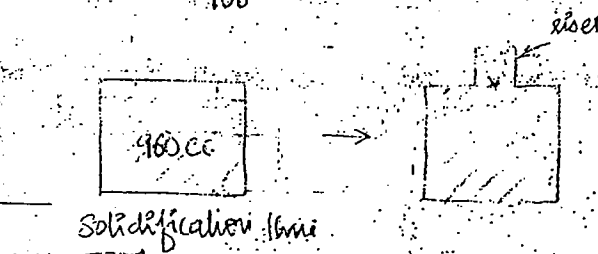
$$V_{sc} = \frac{6}{100} \times 1000 = 60 \text{ cc}$$

$$V_{sc} = \frac{a}{100} \times V_c$$

Necessary condition is that

$$V_{\text{riser}} \geq 3 V_{sc} \text{ so that}$$

one third is transferred to casting and remaining solidifies in the riser simultaneously



$$a. \tau_r \geq \tau_c$$

- To ensure that the molten metal can be supplied to the casting by the riser, the solidification of riser should be greater than or equal to that of casting.

- This is called sufficient condition.

3. Location of the riser

- For uniform CS, A casting riser is provided at the top.

- For non uniform CS, riser is provided at the thickest portion.

4. Shape of riser

$$\tau \propto \left(\frac{V}{A_s}\right)^2$$

V - is fixed.

A_s - is selected such that heat transfer is min.

It is selected so that surface area exposed to the environment

is minimum as possible to minimize the solidification time.

Heat transfer Q_{cyl} $Q_{spherical}$ $Q_{cubical} = 0.1439 : 0.81 : 1$

⇒ cylindrical riser are best preferable

$$\text{Volume}_{riser} = \frac{4}{3} \pi R^3 \text{ (for spherical)} = \pi R^2 H \text{ (for cylindrical)}$$

As determine the dimension of a cylindrical riser, it is necessary to know, the optimum relationship b/w the dia. and height of the cylindrical riser. For this there are 2 type of risers.

i) Top riser

$$V = \frac{\pi}{4} D^2 H$$

$$H = \frac{4V}{\pi D^2}$$

$$A_s = \pi D H + \frac{\pi}{4} D^2$$

$$= \pi D \left(\frac{4V}{\pi D^2} \right) + \frac{\pi}{4} D^2 = \frac{4V}{D} + \frac{\pi}{4} D^2$$

For min A_s $\frac{d(A_s)}{dD} = 0 \Rightarrow \frac{-4V}{D^2} + \frac{\pi}{2} D = 0$

$$\frac{\pi}{2} D = \frac{4V}{D^2} \Rightarrow D = \sqrt[3]{\frac{16V}{\pi/2}}$$

$$\Rightarrow \frac{D}{2} = \frac{RV}{\pi D^2} = H$$

$$\text{So } D = 2H$$



ii) Side riser

$$V = \frac{\pi}{4} D^2 H$$

$$H = \frac{4V}{\pi D^2}$$

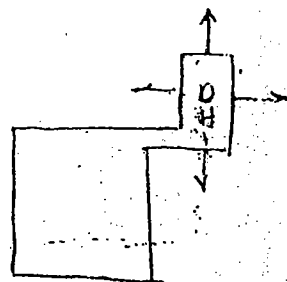
$$A_s = \pi D H + \frac{\pi}{4} D^2$$

$$= \pi D \left(\frac{4V}{\pi D^2} \right) + \frac{\pi}{4} D^2$$

$$= \frac{4V}{D} + \frac{\pi}{4} D^2$$

For min A_s , $\frac{d(A_s)}{dD} = 0 \Rightarrow \frac{-4V}{D^2} + \pi D = 0$

$$\pi D = \frac{4V}{D^2} \Rightarrow D = \sqrt[3]{\frac{16V}{\pi/4}} \Rightarrow D = H$$



$$\text{Modulus of Riser} = \frac{\text{Volume}}{\text{Surface area}}$$

For top riser, $M_T = \frac{\pi/4 D^2 H}{\pi D H + \pi/4 D^2} = \frac{D}{6}$

For side riser, $M_S = \frac{\pi/4 D^2 H}{\pi D H + \pi/4 D^2} = \frac{D}{6}$

For spherical riser, $M_R = \frac{4/3 \pi R^3}{4 \pi R^2} = \frac{D}{6}$

i.e., for every riser modulus, $M_R = \frac{D}{6}$

Methods of riser design: 4 methods

1. Chvorinov's method:

Freezing ratio indicates how molten metal of riser is freezing or solidifying compared to casting.

Freezing ratio, $X = \frac{(V/A)_R}{(V/A)_C}$ — (1)

$X = \frac{a}{y-b} - c$ — (2), a, b, c are constants dependent on the type of metal to be cast.

a, b, c values are taken from casting data book.

Y - volumetric ratio = $\frac{V_R}{V_C}$

(1), (2) $\Rightarrow \frac{a}{y-b} - c = \frac{D/6}{M_C \text{ modulus of casting}}$

$y = \frac{V_R}{V_C} = \frac{\pi/4 D^2 H}{V_C}$

D can be calculated.

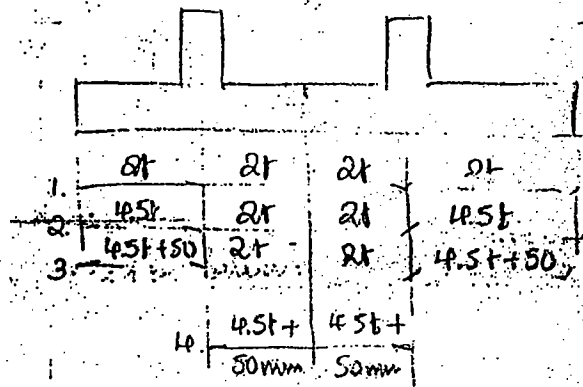
2. Modulus method:

$\tau_R \geq \tau_C$

$M_R^2 \geq M_C^2 \Rightarrow M_R \geq M_C$

Increase 2 when air used.

1. W/o e.w.e. $L = 8t$
2. With e.w.e. $L = 13t$
3. W. end chills $L = 13t + 100$
4. With end & central chills
 $L = 13t + 200 \text{ mm}$



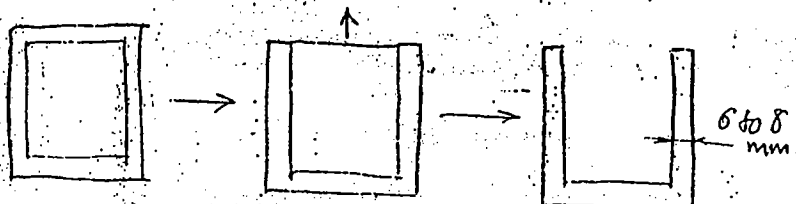
Special casting

1. Shell casting:

2. ~~Shell~~ Shell mold casting: Here, the material of the mold is phenolic resin (thermosetting plastic). with coeff. of viscosity $M = 1500$ to 2000 cent poise. Here the pattern is dipped in the phenolic resin, keep it for 1 to 2 minutes so that the complete surface of the pattern is wetted by the P.R. Then take out the pattern. A layer of P.R. will stick around the pattern.
3. Keep the taken out pattern in a furnace at 250 to 300°C so that the P.R. will get solidified within 2 to 3 minutes.

4. Take out the pattern along with solid P.R.

5. Remove the top layer of P.R. from the pattern.



6. Remove the pattern:

- In shell mold casting, the ceramic slurry is also used in place of P.R. as a mold material called ceramic mold.

+ The total time taken for producing one mold is 5 to 6 min.
Hence the production rate is very high.

+ Since P.R. is of low density, and this layer of the mold, the wt. of the mold will be very less hence easy to handle.

~~This is used for producing symmetrical and circular cs. castings~~
Only up to medium size castings can be produced.

eg Used for producing cylinders and cylinder heads of I.C.E.,
crankshafts, gear blanks, bevel gear.

3. Investment castings:

— Wax ^{can be} used as a pattern material. (+ any complex shapes can be produced, + easy removal of wax by heating, - max size that can be produced is 5kg)

— Cement concrete mould ^{can} be used (+ same mold can be used for producing a few no. of casting. So it is also considered as semi permanent, + No post casting process like machining, chamfering etc as the surface finish is very good.

+ When compared to sand mold, cement concrete has higher thermal conductivity is higher. Therefore the surface hardening heat treatment takes place on casting. i.e., investment casting will always have hard surface on soft materials.)

eg used for producing complex shapes of the components like turbine blades, gold and silver ornaments, handicrafts.

also ways of radar system, shuttle eyes for weaving technology

2.11

DIE CASTING

- metallic mould is used in die casting
- die steel or tool steel is used as the material for making the mould

Advantages of metallic mould

- + Excellent surface finish is possible on the mould. Hence the casting also has a good surface finish. Thus no machining is required after the casting
- + The mould can be used for producing infinite number of castings. Hence die casting is also called permanent mold casting

Limitation

- D.C. can not be used for casting of high M.P. materials.

Reason: Steel $\rightarrow$ MP $\approx 1500^{\circ}\text{C}$

The chances of melting are high.

So D.E. can only be used for low M.P. mat's like Al, Pd, Sn, Cd etc

- The chances of adhering of molten metal onto the die is very high during die casting. To avoid this silicon powder is sprinkled over the mold surface before filling of molten metal into the mold cavity

Types of die castings

a. Gravity die casting GDC

- In GDC the flow of molten metal into the casting cavity is due to acceleration ^{due to} gravity

- The molten metal cannot be filled into each and every corner of a cavity under gravity. Thus G.D.C. is used for producing

only simple shape components.

— Used for producing I.C.E. piston made by Al alloys.

b. Pressure die casting: PDC

Here the flow of the molten metal into the cavity is due to external pressure, due to which the molten metal can flow

into each and every corner of a complex shape cavity.

Thus PDC can be used for producing complex shapes

eg. carburetor of ICE made of Al alloys.

c. Centrifugal casting

Here the centrifugal force produced due to the rotation of the metal mold is used for distributing the molten metal around the circumference of the mold.

The rotation of the mould is continued till the molten metal gets solidified.

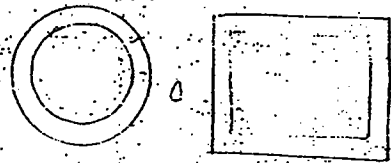
— Used for producing large hollow casting, where using a core is impractical.

Eg → producing a pipe of outside dia 5m. Here the core is required to have a dia say 4.8m which is difficult to handle.

— For producing a sound casting, the acceleration of the mould required is 65 to 75g.

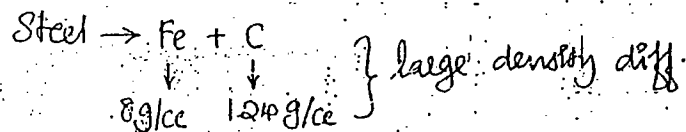
— Due to this rotation, the centrifugal force distributes the molten metal.

$$F_c = ma = m\omega^2 r$$



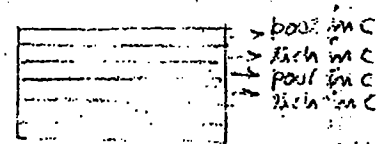
— The centrifugal force produced on the low density inclusions in the molten metal is low. Thus the low density inclusions are collected at the centre of the cavity.

— In general, centrifugal casted components have poor machinability. This is because of segregation or separation.



Centrifugal force on Fe is higher and on C is lower.

— During cc, when the mold is rotated, the centrifugal force acting on the high density elements is higher and low density elements



Heterogenous (alternating layers)

is lower. Therefore the elements present in the alloy try to separate. Before they are completely separated, the molten metal gets solidified producing heterogeneous material which has poor machinability.

Centrifugal force, $F_c = ma = mr\omega^2$

$$a = r\omega^2 = \frac{v}{r} \left(\frac{2\pi N}{60} \right)^2$$

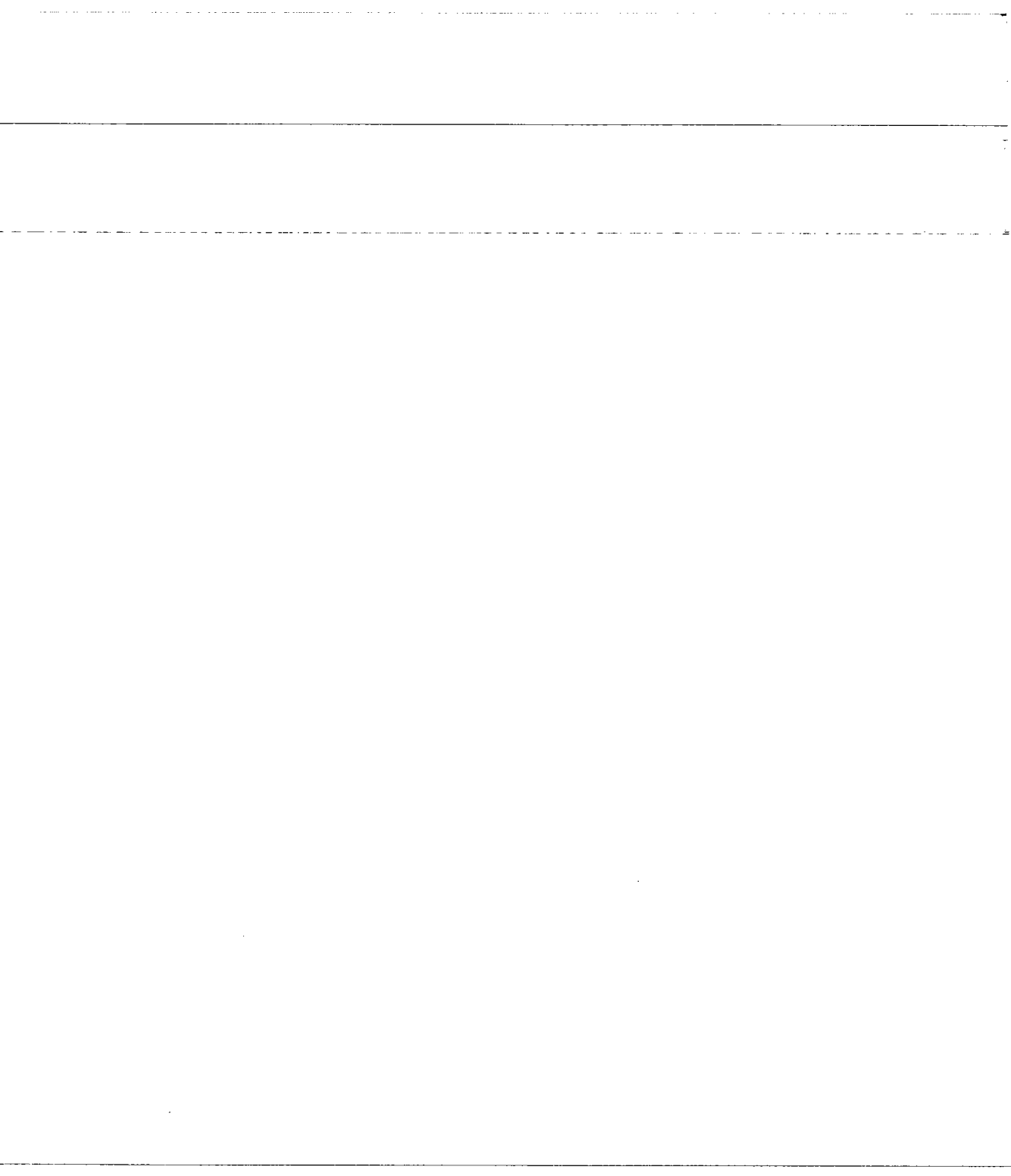
$$\Rightarrow N = \sqrt{\frac{a \times 2 \times 60^2}{4\pi^2 r}} \text{ rpm at which the mold has to be}$$

rotated to produce a sound casting.

— In general, the axis of rotation of the mold in cc. is horizontal because in case of rotation about vertical axis, for producing sound casting, the acceleration of the mould required is

1500g to 2000g. Producing such a very high acceleration is

very difficult. Hence it is preferred to rotate the mould with



arc welding is the heat required for melting of the plate
 obtained by means of electrical arc.
 Chemical heat required for melting of the plate is obtained
 by exothermic reaction.

DCSP - direct current straight polarity
 DCRP - direct current reverse polarity

TIG - Tungsten inert gas welding

Organic: Here joining of materials at a temperature less than -183°C .

-183°C is the boiling point temp of oxygen. At a height of more than 100 km, the temp is less than -183°C where no air or oxygen is present.

B.P.
 $\text{O}_2 \rightarrow -183.93^{\circ}\text{C} \approx -183^{\circ}\text{C}$
 $\text{N}_2 \rightarrow -195.8^{\circ}\text{C}$
 organic components $\rightarrow -185.7^{\circ}\text{C}$

At temp less than -183°C , air becomes liquid. No air is present.

Thus for an engine working in this condition, oxygen has to be provided. Such an engine is called organic engine.

WELDING

Welding is a process of joining two or more similar or dissimilar metals with or without the application of heat

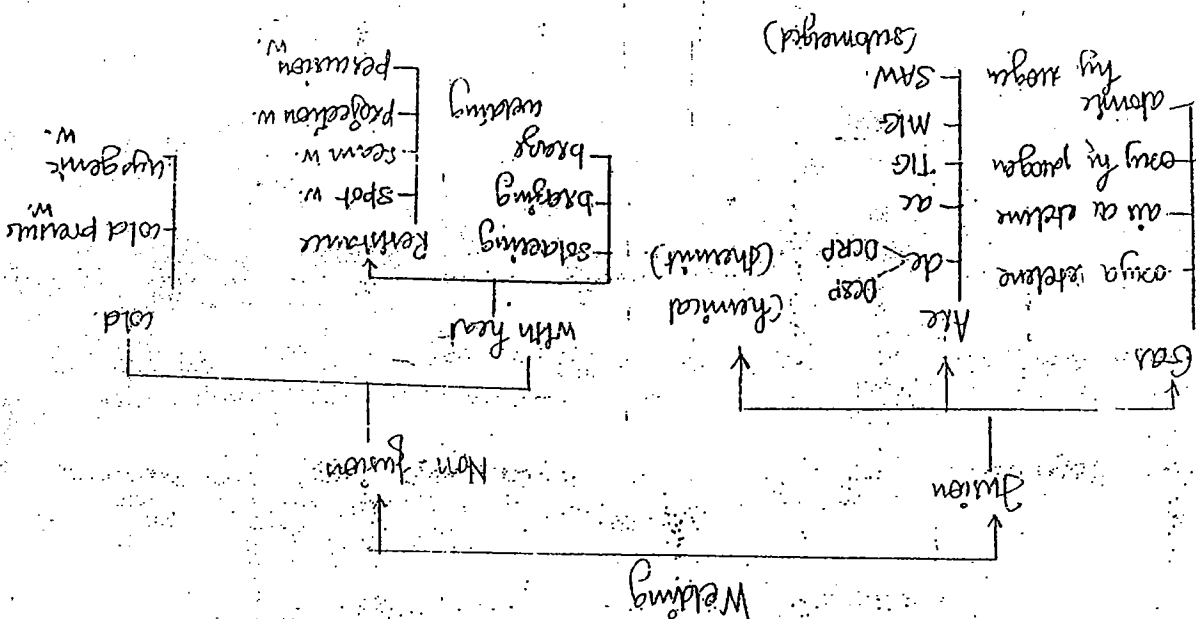
1. heat
2. filler material
3. pressure

Classification

1. Fusion welding: joint produced with the melting of parent material
2. Non-fusion welding or pressure welding: joint produced with the application of pressure, no melting of parent material

Fusion welding

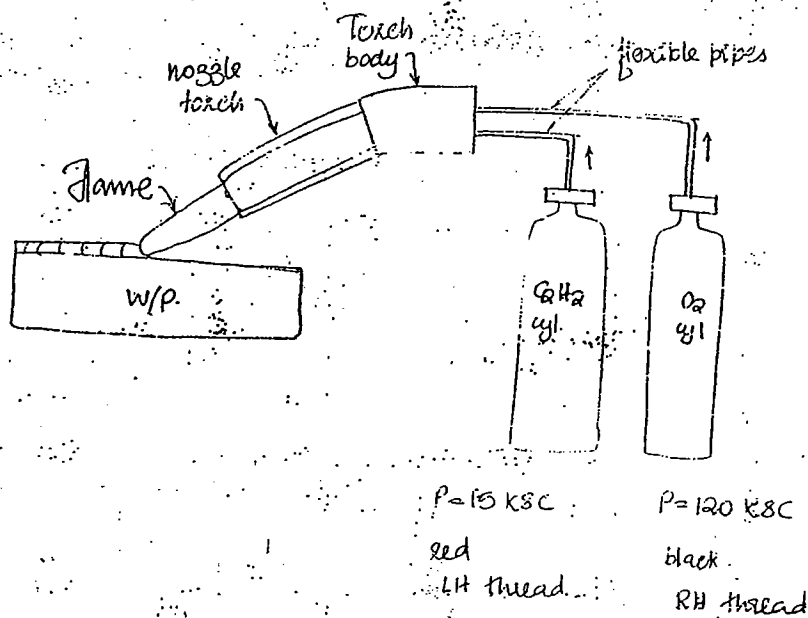
always done with the application of heat



— Cold pressure welding and explosive welding are used for joining of materials in explosive areas.

- for each process has to be explained
1. Preheating and post heating in welding
 2. Weldability
 3. Defects in welding

Oxy acetylene gas welding



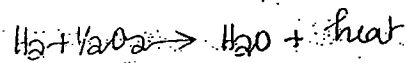
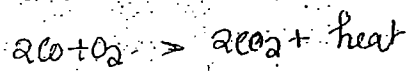
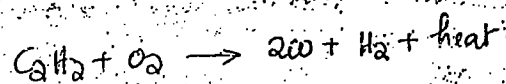
— The O_2 and C_2H_2 from the respective cylinders are taken through a flexible hose pipes into a torch body and mixed together.

The mixture possesses high pressure.

— When this high pressure mixture passes through a converging nozzle, the pressure energy is converted into velocity.

Again the mixture is directed towards the workpiece.

- If this high velocity mixture is given an initiation for burning, a continuous flame is produced and the heat available in the flame can be used for melting and joining of the plates.



- For one complete combustion of one unit volume of acetylene, total oxygen required is 2.5 units. Out of which one unit volume of O_2 is obtained from O_2 cylinder and 1.5 units is obtained from the atmosphere.
- Flexible hose pipes are required for easy movement of the torch for welding at different places.

ksc $\rightarrow$ kg per square centimeter kg/cm^2

O_2 hose pipe has to withstand higher pressure. Thus metallic hose pipes are used. (Cu, Al, Ag etc.)

- Cu is the matl used ~~for~~ commonly used for connecting O_2 cylinder because it has flexibility and can withstand high pressure.
- Aluminium reacts with O_2 (Al_2O_3 formed)
- Ag (Gold) is very expensive and has high density

CO_2 cylinder

- hose pipe is used. They can be interchanged.
- If Cu hose pipe is used, Cu reacts with acetylene producing a paste. Thus Cu hose pipe is not used.

Thus interchangeability is not possible.

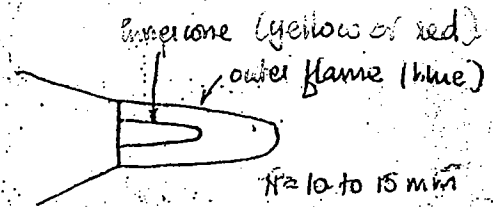
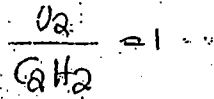
- If Cu hose pipe is used for connecting CO_2 cylinders. Whenever Cu is exposed to acetylene, it chemically reacts producing a paste like material. Hence it fails very easily. Therefore rubber or plastic pipe is used for connecting CO_2 cylinders.

- If accidentally, the 2 hose pipes are interchanged, both the pipes will fail. Hence it should be always ensured that the pipes are not interchanged. For this, colour, size and thread distinctions are provided on the cylinders.

- Based on the amount of oxygen, consumed from the oxygen cylinder, the flames produced in the oxyacetylene gas welding are divided into 3 types.

- Neutral flame
- Oxidising flame
- Carburising/reducing flame

1. Neutral Flame



— The red or yellow coloured flame indicates

incomplete combustion and blue coloured flame indicates ^{complete} combustion.

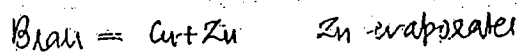
— The temp is maximum at the interface of the inner and outer cone.

$$T_{max} = 3200^\circ C$$

$$T_{avg} = 2000 \text{ to } 2100^\circ C$$

— During the process of complete combustion of acetylene, large quantity of water is produced and a large amount of heat is being carried away. Then the T_{avg} is less than T_{max} by $\frac{1}{3}$.

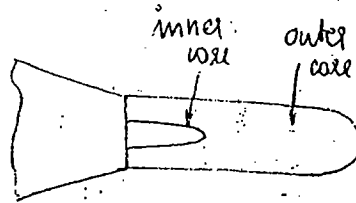
— The neutral flame is used for the joining and cutting of all ferrous and non ferrous materials except brass.



During joining of brass, Zn present in the brass gets evaporated. Hence neutral flame is not preferred for it w/r.

2. Oxidising flame

$$\frac{O_2}{C_2H_2} = 1.15 \text{ to } 1.5$$



At the inner cone, maximum

temp. T_{max} will be induced ($3380^\circ C$)

$T_{max} = 3380^\circ C$
 $\frac{1}{3}$ to $\frac{1}{2}$ N. $T_{avg} = 2100$ to $2700^\circ C$

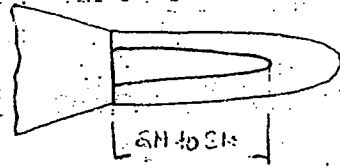
In case of S.I.F. A/F ratio is 16 to 16.5:1

- C.I.F. A/F ratio is 75:1

- Because of higher T_{avg} of flame, high m.p. materials can be joined by using this method.
- Because of excess amount of O_2 supplied, there is a possibility of free oxygen present in the flame, which may combine with metal during welding forming metal oxide. Hence it should not be used for joining of highly reactive metals like Al, Mg etc. It can be used for joining all other ferrous and non ferrous metals including Brass.
- Doing joining of Brass w/p using oxidising flame, because of excess O_2 in flame, O_2 combines with some quantity of Zinc present in the flame forming zinc oxide also called Tenacious oxide which floats over the weld bead not allowing remaining zinc to evaporate.

3. Carburising / Reducing flame.

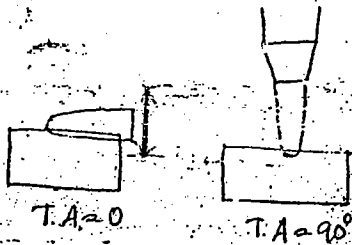
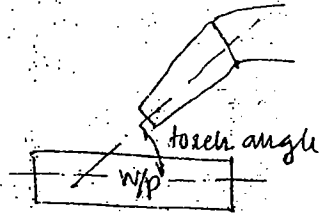
$$\frac{O_2}{C_2H_2} = 0.85 \text{ to } 0.95$$



- Short supply of oxygen is taken.
- 5 to 5.5% low amount of O_2 is supplied from O_2 cylinder. Remaining O_2 reqd for complete combustion is taken from the atmosphere.
- Because of considerable heat transfer by convection and radiation, max temp. at the interface is about $3000^\circ C$.
- Because of lower Temp of flame (1800 to $1400^\circ C$) it can be used for joining low to medium MP materials.
- Because of short supply of oxygen, the free carbon present in the flame during welding of ferrous materials, combines with iron and increases the brittleness and reduces the toughness of material. Hence this shouldn't be used for joining of ferrous materials.
- This method is most commonly used for joining of high carbon steels.
- In case steel, with increase of carbon content, the M.P. of steel reduces, hence H.C. steel will have low M.P. and also ^{thus} already saturated with carbon, no further absorption of carbon will occur.

Torch angle

- The angle made by the axis of torch w.r.t. that of W/P is called torch angle.



Torch angle can be varied from 0 to 90°.

$$\text{Flame density} = \frac{\text{heat supplied}}{\text{unit area}} \quad (\text{J/mm}^2)$$

As $A \uparrow$ area supplied $\downarrow$ flame density $\uparrow$

Factors influencing T.A.

1. M.P. of metals to be joined

M.P. $\uparrow$ T.A. $\uparrow$ (Heat required for unit area weld piece increase)

2. Thickness of plate

$t \uparrow$ T.A. $\uparrow$

3. Thermal conductivity (k) of plate

$k \uparrow$ T.A. $\uparrow$ ($k \uparrow$, heat lost by plate increase becoming difficult to raise the plate to M.P.T.)

4. Place of welding

The selection of T.A. based on the above 3 factors, is done at the middle of weld ^{bead}. But irrespective of above 3 factors, always large

T.A. is used at the beginning at torch returning to the end.

At the beginning of welding, since the

plate are at room temp, to raise the

plate to the M.P.T. large heat per unit

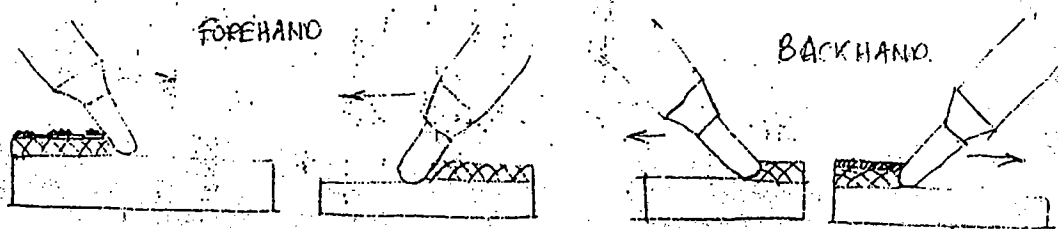
area is to be supplied which is possible by increasing T.A.

At the end of welding, if large T.A. is used, because force of flame, molten metal will over flow producing defect. With the use of smaller T.A., the force of flame obstructing the force of metal. Hence the crackee defect is eliminated.

WELDING TECHNIQUES

1. Forehand or L.H. W.T.
2. Backhand or R.H. W.T.

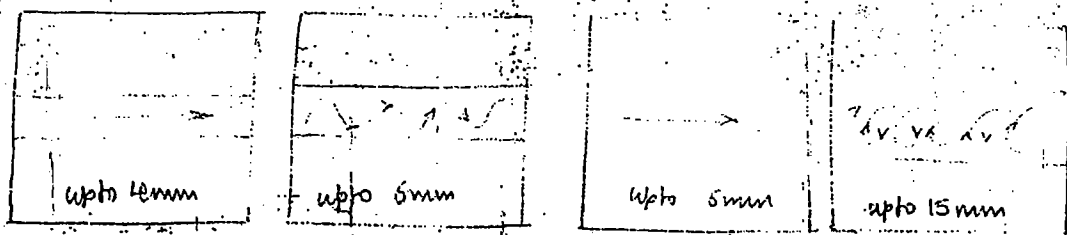
— The welding techniques can be classified based on motion of focusing of flame on to the weld bead. If the flame is focused to the non welded portion then it is called forehand or left hand W.T. If the flame is focused to the already welded portion then it is called backhand or R.H. W.T.



— Most of the welders found that forehand W.T. is more efficient if it is done from right to left direction.

— In forehand W.T. since the flame is focused towards the non welded portion, preheating of welding edge occurs whereas that happens

- Since in forehand W.T. flame and slag are in opposite direction, the slag particles are pushed back to the weld pool forming slag inclusion in weld bead which reduces the strength of the weld bead and also it forms non uniform slag layer in the weld bead.
- The molten metal weld present in front of the arc is called weld pool.
- In backhand W.T. the force of flame is pushing the molten slag particles in upward direction. Hence no slag inclusion are forming and uniform slag layer is produced. Hence the strength of joint is improved and it is perfectly protected from atmospheric contamination.
- The forehand W.T. can be used for joining of upto 4mm thickness with single piece welding with straight movement of torch. Upto 6mm thickness plate can be joined with modified movement of torch.



FOREHAND W.T.

BACK HAND W.T.

||ly with straight movement of torch, upto 6mm thickness of welding can be done using backhand W.T. and upto 15mm can be welded using modified movement of torch.

WELDING POSITIONS

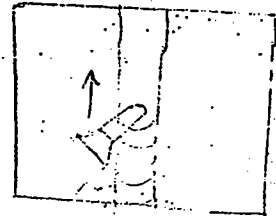
1. Horizontal / flat w.p.
2. Vertical w.p.
3. Horizontal vertical w.p.
4. Overhead w.p.

Horizontal / flat w.p.

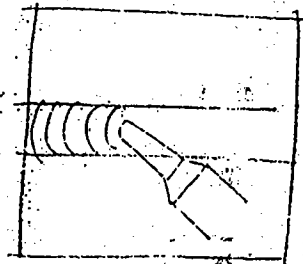
1. If $t \leq 10\text{mm}$, FH or BH with straight movement of torch.
2. If $t = 10$ to 6mm , FH with modified movement or BH with straight m.
3. If $t = 6$ to 5mm , BH with modif. m.
4. If $t > 15\text{mm}$, multipass.

— Vertical w.p.: Here the welding is always done from bottom to top. ^{since the} joint is vertical.

The molten metal particles try to fall down. To obstruct this, forehand w.T. can be used for the force of flame is obstructing the flow of molten metal in the downward direction.



— Horizontal-vertical w.p.: Here, the backhand w.T. will give additional force for holding the molten metal particles w/o falling.



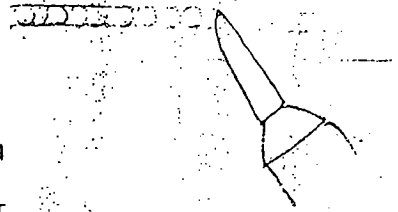
— Overhead w.p.: Here the molten metal particles are in position because of surface tension.

b/w surface and the liquid molten metal

So that the force of flame have to give additional force for

holding the molten metal particles.

This additional force will be given by the backhand W.T. only. Hence non-uniform weld bead is produced with forehand W.T. and uniform weld bead is produced with backhand W.T.



FLUX

— During gas welding operation, the welder takes out the filler rod frequently and dips in some powder called flux powder.

— Functions

1. To deoxidize the melt.
2. To absorb the gases present in the weld pool.
3. To form slag layer over weld bead (to protect W.B. from atmospheric contamination).

— Properties in addition to its functions.

1. density must be as low as possible for easy separation of molten slag from the weld pool.

flux $\rightarrow$ melt $\rightarrow$ molten slag

2. Its M.P. should be less than the M.P. of parent material.
3. It should not produce any harmful gases like SO_2 .

(Though sulphur present in flux is the best deoxidizer.)

— Applications

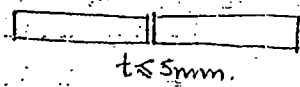
1. During gas welding of Carbon or Nickel alloys, no flux is required (because of C or Ni in the alloy).

2. Borax can be used as common flux during gas welding of all other materials.

FILLER RODS:

— Filler rods are used to supply the additional molten metal to the weld piece.

- If $t \leq 5\text{mm}$ can be joined by using square joint which does not require any additional molten metal



— Gas welding w/o any filler rod material is called puddling op/n.

- Whenever the thickness of plates to be joined is greater than 5mm, some type of joints like V (or) U (or) J joint is produced. With joint preparation, some amount of gap is present at joint to fill this filler rod is required.

Properties

1. Density of filler rod material must be nearly same as that of the parent material so that they can be mixed easily

2. $(M.P.)_{\text{filler rod}} \leq (M.P.)_{\text{parent material}}$

3. The molten metal of parent and filler rod materials can be easily mixed together and the mixture can be retained w/o any separation. (like water and milk)

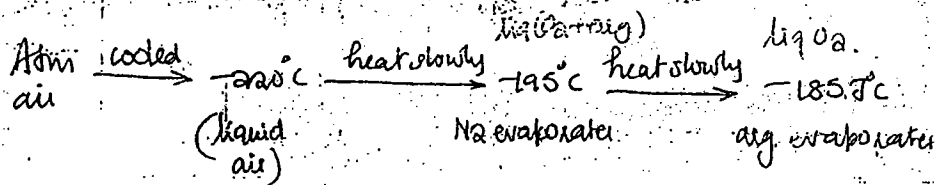
Application

1. Commonly used filler rods are made by using LC steel, ME steel, brass etc.

O₂ production

- Oxygen is always produced from atmospheric air. Since it is cheaper and safer than hydrolysis.

Atmospheric air	N ₂ 78.7%	B.P. -195.8°C
	O ₂ 21%	-182.97°C
	organic compounds 0.3%	-185.7°C

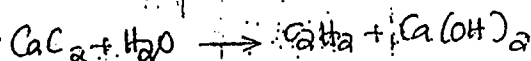


- The above method is always used for producing oxygen because it gives the purest form of oxygen.
- O₂ is always preferable to store in liquid form because specific volume of O₂ is very low.
- By using Charles law, at P ↑, B.P. ↑

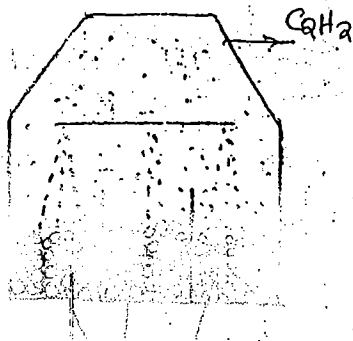
At 120 kSC pressure, B.P. of liquid O₂ is 40 to 50°C.

Hence O₂ can be stored at room temp. easily.

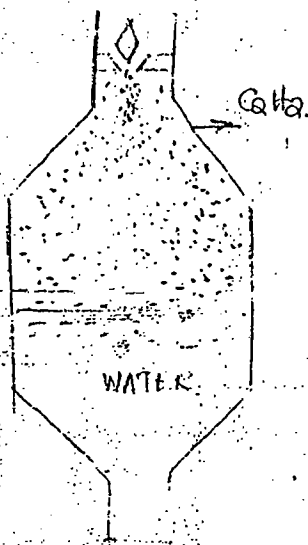
Acetalene production (C₂H₂) 2 methods



1. Water to carbide type.
2. Carbide to water type



When water falls on CaC₂ granules, C₂H₂ is produced which is at low pressure and small production rate. The equipment is



Here low pressure acetylene is produced.

Using this type, high production rate is obtained and the equipment is large sized.

To have the powder form of CaH_2 , a rolling mill is attached to carbide $\rightarrow$ water type equip.

because, as soon as or whenever CaH_2 powder is needed it can be made and used hence

the size of the equipment is large.

No direct methods are available for producing high pressure acetylene so the low pressure acetylene is compressed and used.

- Acetylene is always stored in acetone cylinders.

Acetone is a liquid at RT. and its properties are similar to kerosene.

1 l Acetone $\rightarrow$ 25 l of CaH_2 @ 1 ksc.

As the pressure of acetone increases, its absorbing capacity also increases.

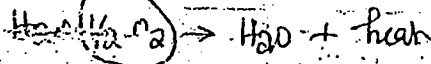
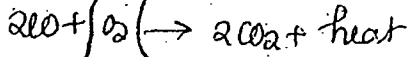
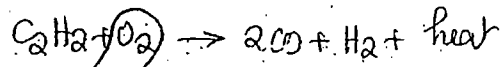
i.e. 1 acetone can absorb 25 l of CaH_2 @ 25 ksc

- But the safe storage pressure of acetone is 15 ksc, above which acetone can get exploded.

8.11

Air-C₂H₂ gas welding

Complete combustion takes place in 3 steps.



For complete combustion of 1 unit of acetylene, 2.5 units of O₂ is req'd.

If the oxygen required for complete combustion of acetylene is obtained only from the atmosphere, it is called air acetylene gas welding. Thus only acetylene cylinder is sufficient.

Bulson burner

Whenever a gas is burned by taking oxygen only from atmosphere, it is called Bulson burner principle.

The flame has to travel for a longer distance, due to which the heat energy lost by convection and radiation is high. The avg. temp. of flame,

$$T_{avg} = 500 \text{ to } 700^\circ\text{C}$$

Since the total oxygen has to be taken from atmosphere, a longer distance, the heat losses by convection and radiation are high.

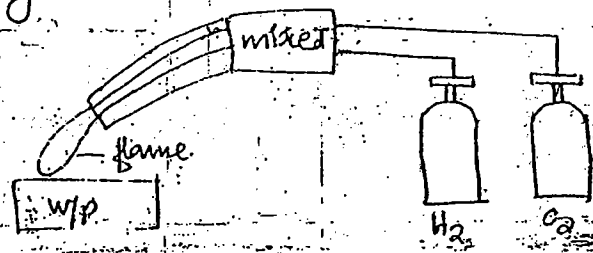
Hence the T_{avg.} of flame is about 500 to 700°C.

Application

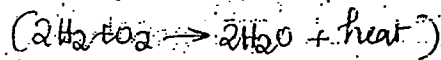
1. Because of lower T_{avg.} of flame, it can be used for joining of only low m.p. materials like Pd, Sn, Zn, Cd etc.
2. It can be used as a heat source for soldering operation.

Oxyhydrogen Gas Welding

- Similar to oxyacetylene.
- Practically $\frac{H_2}{O_2}$ ratio varies from 2.5 to 6 i.e. Excess hydrogen is used. which



moves away from the welding zone and acts as a shielding gas for protecting the weld pool from atmospheric contamination.



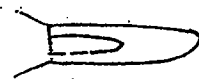
Thus this can be used for the joining of highly reactive metals.

- The flame produced has 2 cores, with T_{max} induced at the intersection of the cores of $2880^\circ C$.

- In the process of oxy- H_2 welding large quantity of water is produced.

To evaporate this, nearly $\frac{2}{3}$ rd of the

heat is expended. Therefore the T_{avg} of the flame is only $\frac{T_{max}}{3}$.



$T_{max} = 2880^\circ C$

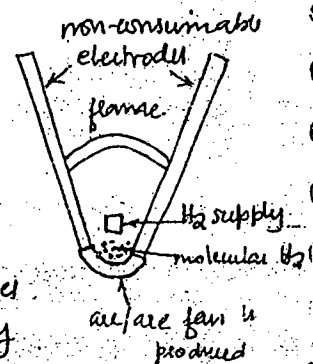
$T_{avg} = 800 \text{ to } 900^\circ C$

Application:

1. It is used for joining of low m.p. materials upto Al (eg. Pb, Sn etc).
2. It can ^{also} be used as a heat source for brazing and bronze welding.

Atomic hydrogen gas welding

- It is a special gas welding process.
- It is the combination of gas & arc welding processes.
- The 2 electrodes are connected to a terminal of power supply.
- When the optimum is maintained b/w the tips of the



electrodes and power is turned on, an arc is produced.

- When the molecular hydrogen is supplied, into the arc fan,

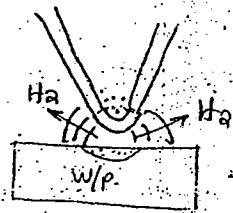
endothermic reaction results producing atomic hydrogen, which is unstable. Atomic hydrogen atoms reunite to form molecular hydrogen which is an exothermic reaction. The heat of the exothermic reaction can be used for melting and joining of plate of the molecular hydrogen produced burns by taking $\frac{1}{3}$ of the atmosphere giving out heat to the W.B. Remaining $\frac{2}{3}$ moves away and acts as a shield gas, thereby protecting the weld pool from atmospheric contamination.

The heat required for the endothermic reaction is obtained from the arc fan.

Thus the heat required for melting of the plates and joining is obtained from exothermic reaction and by burning of $\frac{1}{3}$ of hydrogen.

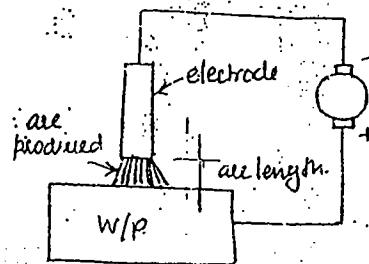
Applications:

1. mainly developed for the joining of highly reactive metals.
 2. can be used for the joining of stainless steel.
- After the invention of TIG welding, the atomic H₂ became obsolete.



ARC WELDING

- When the power supply is given and an optimum gap is maintained, an arc is produced b/w the tip of the electrode and W.P. Heat available

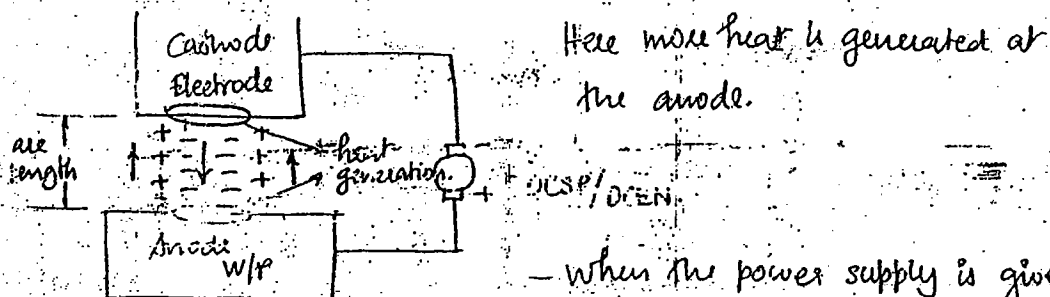


in the arc is used for melting of the plate and electrode & joining.

- When the power supply is given and the negatively charged electron are forced out of the electrode.

They are attracted by the positively charged

The KE. of electrons gets converted to heat energy. Heat is generated at the anode.



Here more heat is generated at the anode.

— When the power supply is given, and simultaneously the freely charged ions are generated at the anode, which possess high velocity. They are attracted by the cathode and move towards it and impinge, whereby KE. of ion gets converted to heat energy. Therefore heat is generated at the cathode also.

In practice, the velocity of the electrons is much higher than the velocity of the ions. Hence the heat generated at the anode is about 67% and that at cathode is 33%.

$$\text{i.e., } \frac{\text{heat generated at anode}}{\text{heat generated at cathode}} = \frac{2}{1}$$

— During actual welding operations, the ions and electrons are moving in mixed flow condition. Therefore if an ion and an electron are getting whirled in between, the KE. possessed by both is spontaneously converted into heat energy.

∴ The temp. induced at this energy rich point is 5000 to 6000°C and it is observed as spark.

— Because of sparking and high temp at the arc zone, ultraviolet rays are generated in the arc zone. Hence severe pain will be felt if arc welding is seen with naked eye. So safety goggles are inevitable.

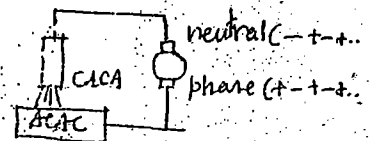
The above process is said to be

1. DCSP - Direct current straight polarity (OR)
2. DCEN - Direct current electrode negative

If the electrodes are interchanged with polarity, then it becomes Direct current reverse polarity.

$$\text{Heat generated at } H_{w/p} : H_{\text{electrode}} = 1 : 2$$

- Thus the heat can be controlled by changing the terminals. The +ve and -ve terminals are changing continuously when AC is used.



AC - alternating current
high frequency

For India, 50 Hz power supply

$$\text{cycle time} = \frac{1}{50} = 0.02 \text{ s}$$

i.e., after every 0.02 s, the terminals are changing from anode to cathode.

	+ve	-ve
w/p	more heat	less heat
Electrode	more heat	less heat

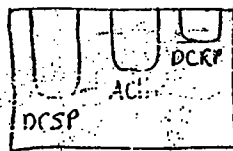
Since the w/p and electrode are changing continuously, heat generated at the w/p & electrode are in ratio 1:1.

Features of arc welding processes:

1. In DCSP, because of higher heat generated in w/p, high M.P. materials and higher thickness plates can be joined easily, and high depth of penetration is achieved.
2. Because of lower heat generation at the electrode, the melting rate of electrode is low, deposition rate is low. Hence only low melting speeds are possible.
3. In DCEN, because of lower heat generation at the w/p, only low M.P. materials and lower thickness plates can be joined. Also, the depth of penetration is low. Because of higher heat generated

at the electrode, melting rate of electrode is high, deposition rate is high. Hence high welding speeds are possible.

3. The characteristics of ACHF are in b/w that of DCSP & DCRP.



depth of penetration

On ACHF, heat generated is 1:1, the features of ACHF is in b/w DCSP & DCRP.

Arc recovery time

- It is the time taken to establish the arc between the electrode tip and W/P.

DCRP - permanently fixed terminals.

- In DCRP, welding the arc recovery time is not an important factor, because the terminals are always fixed. Once the arc is established the joining will be continuous.

- To establish the arc b/w the electrode and W/P, the recovery time must be less than the cycle time. Otherwise arc will not be produced.

For best performed, $ART < CT$

Eg. $ART = 0.008 \text{ s}$ $CT = 0.02 \text{ s}$

$$Diff = 0.02 - 0.008$$

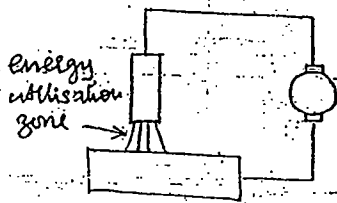
$$= 12 \text{ milli s.}$$

- In actual practice of AC arc welding, the ART must be less than half of the cycle time. Hence the arcing time is greater than the time taken for establishing the arc.

- In arc welding the cycle time is fixed. Therefore to ensure the above condition the voltage of power supply has to be increased.

to reduce the recovery time.

- To ensure that $ART < \frac{CT}{6}$, the minimum voltage used is 30V. The maximum voltage that can be used is limited to the voltage that a common human being can withstand w/o electric shock.
- The max. voltage which a human being can withstand w/o electric shock is 50V. Therefore the voltage range used for arc welding is 30 to 70V.

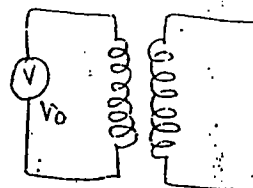
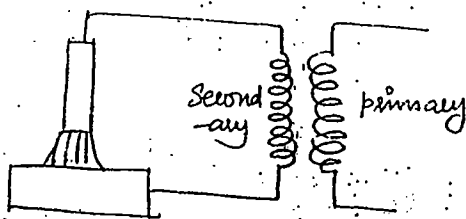


For maintaining the stable equilibrium conditions for welding equipments, whatever the energy supplied by the power supply unit, only has to be

utilised at the arc point or arc zone. For this, it is required to maintain optimum arc length at the arc point and power source has to be set for optimum voltage & current.

L - arc length

Power source } Electrical transformer
or
DC generator.



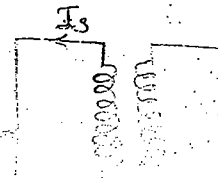
V_0 - open ckt voltage.

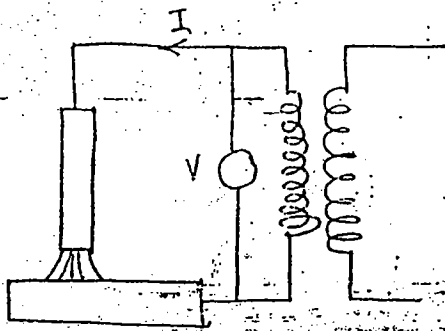
I_s - short ckt'd current

$$V_0 = I_s \times R_s$$

$$R_s = \frac{V_0}{I_s}$$

secondary
resistance



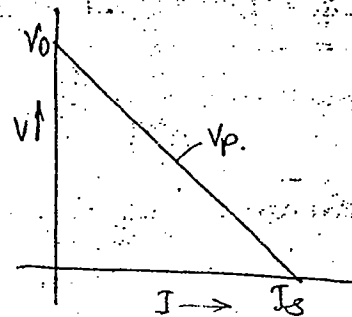


V & I - voltage and current in the secondary winding of the welding equipment during actual welding

V_0 - actual emf generated in the secondary

$$V_{\text{power source}} = V_0 - V_{\text{drop}} \\ = V_0 - R_s I$$

$$V_p = V_0 - R_s I \quad \text{power source characteristic}$$



At the arc

If $L \approx 0$ (short circuiting)

$$I \approx I_s \approx I_{\text{max}}$$

If L is large, $I \approx 0$.

as L increases, I decreases, R increases.

where $R \rightarrow$ resistance of the arc.

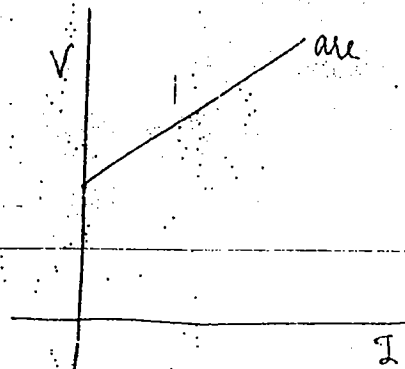
As L increases, V increases.

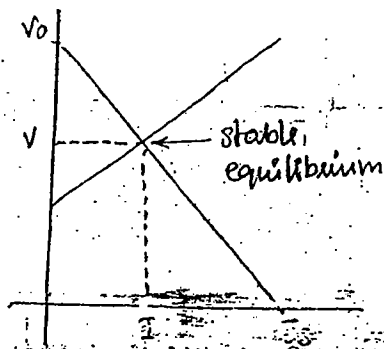
For a given change in the arc length (L), the reduction in I is very small, but the increase in R is very large. Hence the voltage V increases with increase of arc length.

$$V_a = a + bL$$

V_a - voltage in arc

a, b - constants





$$V_p = V_0 - R_s I \quad \text{--- (1)}$$

$$V_0 \pm a + bL \quad \text{--- (2)}$$

For stable equil. (1) = (2)

$$\text{i.e., } V_0 - R_s I = a + bL$$

$$V_0 - \frac{V_0}{I_s} I = a + bL$$

$$\frac{V_0}{I_s} I = V_0 - a - bL$$

$$I = \frac{I_s}{V_0} (V_0 - a - bL)$$

$$\text{Power, } P = VI = (a + bL) \frac{I_s}{V_0} (V_0 - a - bL)$$

in term of L

For minimum power supply.

$$\frac{dP}{dL} = 0 \Rightarrow L =$$

$$V = a + bL$$

$$I = \frac{I_s}{V_0} (V_0 - a - bL)$$

Q. Suppose $V_0 = 80V$, $I_s = 2000 A$

$$V_a = 20 + 100L$$

L - are length in cm

Optimum are length and settings of the power source?

$$V_p = 80 - \frac{80}{2000} I$$

At equil. $V_a = V_p$

$$20 + 100L = 80 - \frac{80}{2000} I$$

$$I = \frac{2000}{80} (60 - 100L)$$

$$P = VI = (20 + 100L) \frac{2000}{80} (60 - 100L)$$

$$\frac{dP}{dL}$$

$$\text{i.e., } P_T = \frac{2000}{80} [1200 + 1600L - 1600L^2]$$

For optimum power $\frac{dP}{dL} = 0$

$$1600 - 2 \times 1600L = 0$$

$$L = 0.5 \text{ cm}$$

$$V_a = 20 + 140L = 20 + 140 \times 0.5 = 90 \text{ V}$$

$$I = \frac{2000}{80} [60 - 120L] = \frac{2000}{80} (60 - 140 \times 0.5) \\ = 1000 \text{ A}$$

Q. $V_a = 20 + 140L$; L are length in cm

$$L = 3 \text{ to } 5 \text{ mm}$$

$$I = 1000 \text{ to } 5000 \text{ A}$$

$$V_0 = ? \quad I_s = ?$$

Equip. $V_a \approx V_p$

$$V_0 = \frac{V_p}{I_s} I$$

NOTE: Lower dr. are length, higher dr. current.

$$L = 3 \text{ mm} = 0.3 \text{ cm}$$

$$I = 500 \text{ A}$$

$$V_a = 20 + 140 \times 0.3 = 32 = V_0 - \frac{V_0}{I_s} \times 500$$

$$\text{/// } L = 5 \text{ mm} = 0.5 \text{ cm}$$

$$I = 1000 \text{ A}$$

$$V_a = 20 + 140 \times 0.5 = 90 = V_0 - \frac{V_0}{I_s} \times 1000$$

$$\frac{V_0}{I_s} = \frac{8}{100} = 0.08 \Rightarrow \frac{V_0}{I_s} \times 100 = 8$$

$$32 = V_0 - \frac{V_0}{I_s} \times 500 \Rightarrow 32 = V_0 - \frac{8}{100} \times 500$$

$$V_0 = 32 + 40 = 72 \text{ V}$$

$$\frac{V_0}{I_s} = \frac{8}{100}$$

$$I_s = V_0 \times \frac{100}{8} = 900 \text{ A}$$

Duty cycle

It is the % of time during which the arc is on w/o overheating the vital elements of welding equipment ^{windings of transformer/generator}

$$Duty\ cycle = \frac{\text{arc-on time}}{\text{total welding time}} = \frac{\text{arc-on time}}{\text{arc-on time} + \text{rest time}}$$

Arc-on time - during which

rest time - switching off arc

$$Q_g = H.G = I^2 R_s$$

$$Q_d = H.D = h A (T_s - T_{\infty})$$

If $Q_g \leq Q_d$ continuous welding

$$Q_g > Q_d \Rightarrow Q_{acc} = Q_g - Q_d$$

Here rest time is provided, during which $Q_g = 0$ but Q_d contin.

eg $I = 2000A$, $Q_g = 10\text{ kW}$, $Q_d = 6\text{ kW}$ Duty cycle = ?

$$Q_{acc} = 10 - 6 = 4\text{ kW}$$

$$(Q_{acc})_{max} = 1000\text{ kJ given}$$

$$\text{Arc-on time} = \frac{1000\text{ kJ}}{4\text{ kW}} = 250\text{ s}$$

$$\text{Rest time} = \frac{1000\text{ kJ}}{6\text{ kW}} = 166.6\text{ s}$$

$$\text{Duty cycle} = \frac{A.O.N}{A.O.N + R.T} = \frac{250}{250 + 166.6} = 0.6 \quad 60\%$$

$$Q_g \propto I^2$$

$$\propto \frac{1}{b}$$

$$I^2 \propto \frac{1}{b}$$

$$I^2 D = \text{constant}$$

$$I^2 D = \text{constant}$$

$$I^2 D = \text{constant}$$

$$I^2 D = \text{constant}$$

I_d, D_d - desired $I \neq 0$

taken based on I and D

$$D_d = \left(\frac{I_r}{I_d} \right)^2 D_1$$

- During the calculation of duty cycle, whenever D becomes greater than 100%, take it as 100% only so that rest time is zero and continuous welding can be done.

ELECTRODES

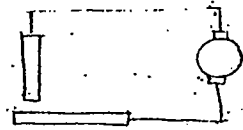
- Functions

→ It should act as an electrical element for closing the circuit. ↗ if only, → non consumable

→ Sometimes electrodes will get melted and

supply additional molten metal to the

weld bead. ↘ consumable



- The material used for manufacturing of non consumable electrode is selected such that i) the material should have high electrical conductivity and ii) high melting point temperature.

eg. carbon, graphite, tungsten → used with any power supply.

↙ ↘
only with DSSP power (low heat generated)

All non consumable electrodes are made as a bare wire electrodes only. w/o any coatings.

- The material used for manufacturing consumable must be

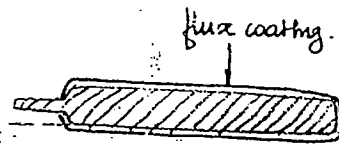
i) density nearly equal to ρ_{parent} .

ii) melting point $T \leq MPT_{parent}$.

iii) molten metal of the material can be easily mixed with molten metal of parent material.

eg. low carbon steel, m.s. steel, brass etc.

Consumable electrode $\begin{cases} \text{bare wire} \\ \text{coated.} \end{cases}$ $\begin{matrix} - \\ + \end{matrix}$



ADVANTAGES

- + It can deoxidise the melt.
- + It can absorb gases present.
- + It can form slag over W.B.
- + It can stabilise the arc. It demagnetise the electron and ion.
- + It can produce shielding gases like H_2, CO_2 etc. (prevent condensation).
- + It can supply alloying elements for improving the mech properties.

The types of coating given on the electrode are

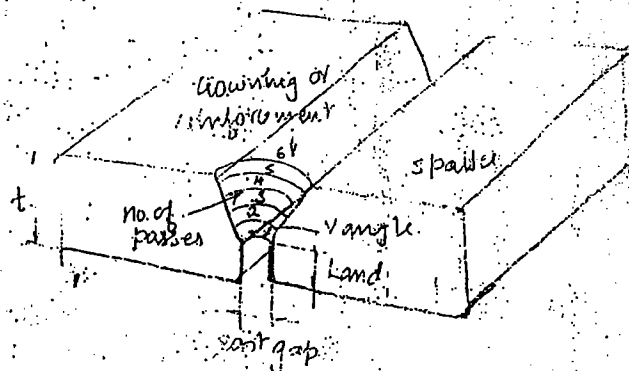
1. Ferro silicon or ferro manganese coating - deoxidise the melt, absorb gases.
2. Rutile/ TiO_2 coating for producing slag.
3. Potassium compound coatings for stabilisation of arc.
4. Cellulose coating - for producing shielding gases.
5. Small quantities of V, Mn, Mg, Cr, Al, Ni etc. are added in coating.

DESIGN OF WELD BEAD: 4 parameters

1. total no. of electrodes required.
2. welding speed.
3. welding time.
4. no. of passes req.

Root gap: The gap present in b/w 2 plates at the bottom most point of the weld bead.

Root gap is provided to ensure that complete thickness of the plates can be fused.



Land: the straight portions provided w/o preparing the joint at the bottom. If land is not provided, during welding, if the flame or arc is directly hitting the bottom of the weld, the burning through of the edges will occur because a very small quantity of material is present at the edges. The maximum land provided by 5mm.



burning through take place

V angle: standard V angle $60^\circ, 90^\circ, 120^\circ$. Whenever the thickness of the plate to be joined is greater than 5mm, it is necessary to prepare some type of joint. Most commonly used is V or U or J out of which V joint is most common. During preparation of

No. of passes: the most commonly. Whenever t is higher, it is not possible to join the plate in single pass welding. In such cases, use as ^{minimum} no. of passes as possible except T fillet welding.

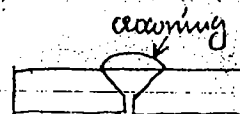
When many of passes are used, distortion of plate occurs. Here



the plates cannot be fixed but because it induces residual stresses leading to cracking in weld.

In case of T welding for minimization of distortion, it is preferable to use as many no. of passes as possible.

Crowning/reinforcement: excess material provided above the surface of the weld bead. Crowning is provided to ensure that the ~~resistance~~ resistance area



available at the joint is at least equal to the resistance area of

plates even though the surface of W.B. is not smooth.

Crowning provided is to 15% of volume of W.B.

Spatter: During welding, some of the molten metal particles jump ^{from} the weld pool and falls on other areas of the plate. Spatter is the loss of the material of W.B. and it damages the surface finish of the plates.

Amount of spatter = 5 to 10% of W.B. volume.

$$\text{Total no. of electrodes} = \frac{\text{total volume of W.B.}}{\text{volume/electrode}}$$

$$\begin{aligned} \text{total volume of W.B.} &= \text{vol. of W.B.} + \text{crowning} + \text{spatter} \\ &= 1.15 \text{ to } 1.25 (\text{volume of W.B.}) \end{aligned}$$

$$\text{Volume of W.B.} = A \times \text{length of W.B.}$$

$$A = A_1 + 2A_2$$

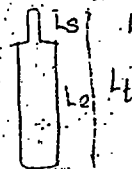
$$A_1 = t \times \text{root gap}$$

$$A_2 = \frac{1}{2} \times \text{base} \times \text{height}$$

$$\text{Volume/electrode} = \frac{\pi}{16} d^2 \times L_e$$

$$L_e = L_t - L_s$$

L_s = stub loss or holding loss



WELDING TIME

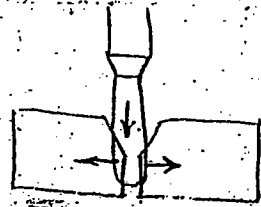
$Q = H.S.$ by welding process.

$= Q_{\text{loss}}$ by cond + H.

By considering 3D heat loss, heat loss

$$Q = \frac{5}{10} \pi k w \theta_m \left[\frac{\pi}{3} + \left(\frac{u w}{10 \alpha} \right) \right]$$

thermal conductivity $\rightarrow$ M.P.T. of plates
width of plates joint



u - welding speed.

α - thermal diffusivity.

- But if the length of the plate is very high, the heat lost by conduction along the length direction is very small. Therefore it is neglected.

- By considering only 2D heat loss,

$$Q = 8 k \theta_m t \left[\frac{1}{5} + \frac{u w}{10 \alpha} \right]$$

$$\therefore \text{Welding time} = A.O.T = \frac{\text{length of w.B.}}{u}$$

$$\text{Total welding time} = \frac{A.O.T}{\text{duty cycle}}$$

Let x = length of weld bead welded by using one electrode

This is taken from the welding data book corresponding to the size of the electrode, to the size of the electrode and welding current used.

$x = 200$ to 500 mm length of WB/electrode.

$$\text{No. of electrodes/pass} = \frac{\text{length of w.B.}}{x}$$

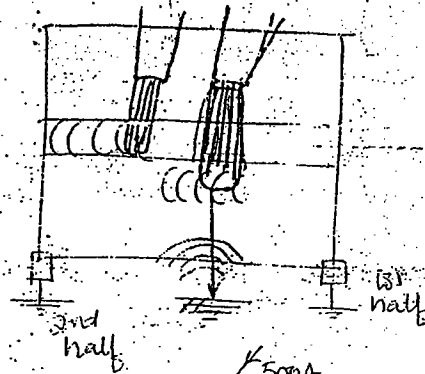
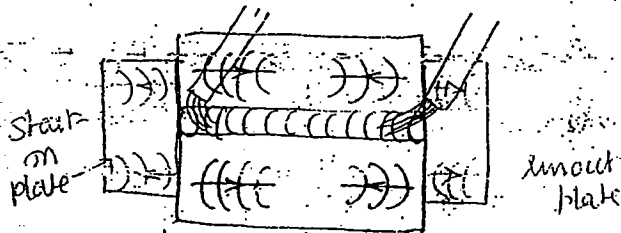
$$\text{No. of passes} = \frac{\text{total no. of electrodes}}{\text{no. of electrodes/pass}}$$

MAGNETIC ARC BLOW OR ARC BLOW.

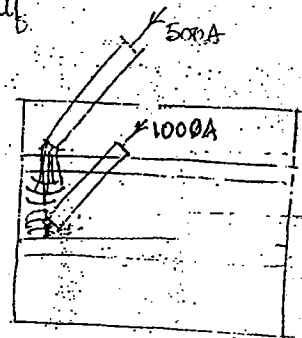
- The magnetic force created by the electric current will tend to draw the arc from its shortest line of action and making the arc fluttering called magnetic arc blow or simply arc blow.

Reasons:

- Welding near to the earth connection.
- Starting and ending arc blow.



- Simultaneous welding of 2 electrodes at 2 places which are nearby, using different current conditions.



Remedies

- Welding away from the earth connection: Give the earth connection at one end and welding is started at other end. After half of the W.B. has been completed, stop the welding operation and change the earth connection to the other end.

- By providing an additional plate at the starting, it is possible to create the magnetic force in the opposite direction also since it can be able to concentrate the arc wherever required. Pulling welding in section and mount plates ought to be joined to the main plate. Some suggestions are given below.

separated by hammering or machining.

→ By using same current conditions in the multiple electrode welding, it is possible to eliminate the arc blow.

— The arc welding is mainly taking place after the power supply. Whereas in ac, since the direction is changing for the +ve and -ve terminals, direction of magnetic fields are changing for every fraction of a second. Hence it is possible to concentrate the arc wherever required.

— Even though ac eliminates the arc blow, in general, dc is preferable because, the heat generation is controllable in dc arc welding by changing the polarity.

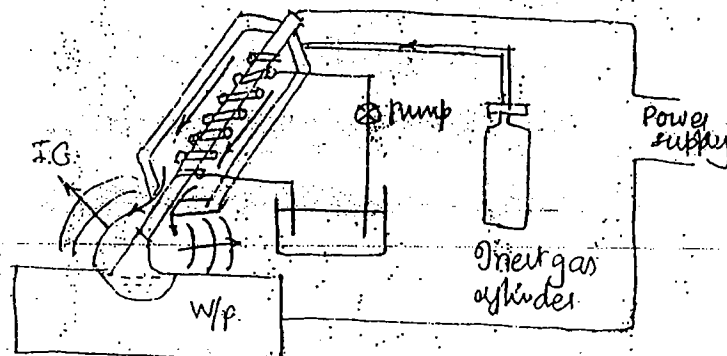
TIG/GTAW/AAW

TIG - Tungsten Inert gas welding

GTAW - Gas Tungsten Arc welding

AAW - Argon Arc welding

— Non-consumable electrode (tungsten) is used.



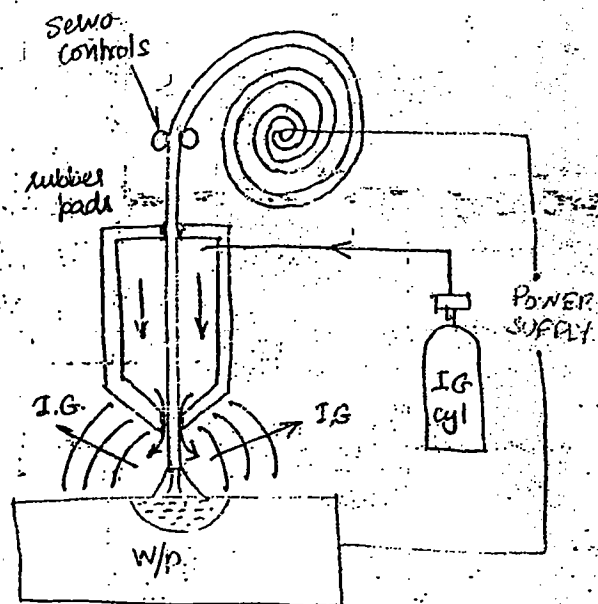
- For protecting the weld pool from atmospheric contamination inert gas is used as shielding gas ~~and~~ (eg. Argon)
- To avoid the electrode melting it is cooled continuously by supplying the coolant through a pipe which is wrapped around ~~the~~ electrode.
- This is developed mainly for the joining of highly reactive metals like Al, Mg etc.
- When compared to the atomic H₂ welding, TIG welding is more efficient.

DISADVANTAGES

- Because of non consumable electrode welding, the additional molten metal is not supplied to W.B. Hence upto 5mm thickness plates can be joined. To join ^{plate having} more than 5mm thickness using TIG-W, additional filler rod must be used. But while doing so, the air particles which are sticking to the surface of filler rods is going along with the filler rods contaminating the weld pool.
- Since the usage of inert gas, coolant, pump etc, the cost of TIG-W equipment on TIG-W process is high.
- Even though the electrode is not melting but at high temp, the atoms of Ti may get diffused from the tip of electrode and enter the weld pool which increases the brittleness of W.B.

MIG W GMA W METAL INERT GAS W. / GAS METAL ARC WELDING

- MIG W uses continuously consumable electrode which is wound on to the spool and fed by using servo controls. Here
- The inert gas supplied as the shielding gas protects the weld from atmospheric contamination.



- It is used in joining of highly reactive metals Al, Mg, etc even thickness $> 5\text{mm}$ also
- By the electrode through the rubber pads, the air particles sticking to the electrode surface can be squeezed out.
- Because of complete elimination of coolant and coolant pump, the cost of MIG W is less than TIG W.
- Because of consumable electrode presence, (other than Tn) the diffusion (as in Tn) can be eliminated.

DISADVANTAGES

- In MIG W because of continuous electrode wound on the spool, the maximum size of the electrode will less than or equal to 5mm .
- ② While using this, for joining of large thickness plate, the welding speed must be low at which the size of weld pool produced in front of the arc is very large and due to the force

Of all, many molten metal particles and fumes from weld pool and spatter loss become very high. To reduce it to less than 10% maximum thickness of plate which can be joined by using MAW in single pass welding is 30mm.

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But the presence of large quantity of flux product on the weld pool, it is not allowing molten metal particles to jump. Hence the start spatter loss can be minimized.

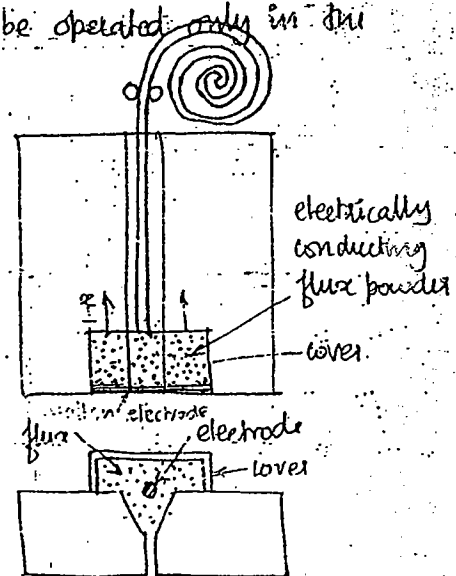
- SAW is used for joining of 75mm plate in single pass welding beyond which it is not economical.

flux → arc → heat → molten flux submerged electrode (molten) → no arc
← medium

ELECTROSLAG WELDING

- is a pressure welding process. It can be operated only in the vertical position.

- When the power supply is given, an arc is produced by the tip of electrode & W.P. The heat generated through the arc is used to melt the flux powder forming molten slag so that the tip of the electrode is submerged inside the molten slag and the arc is



put off. Now the current is passing from electrode to the W.P. through electrically conducting molten slag. Due to the resistance of the molten slag, the heat gets generated which can be used for melting of the plates and the electrode and joining occurs.

- As the molten metal is forming, it settles at the bottom of W.B.

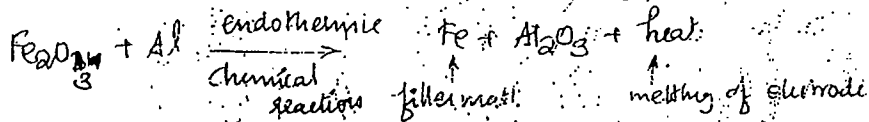
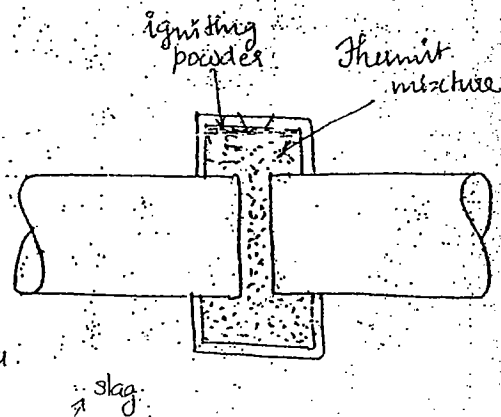
pushing the molten slag upward, therefore as the welding is

proceeding, the cover moves upward so the same slag can be used from the beginning to the end of the welding.

- Because the heat required for welding is due to electrical resistance of the molten slag, the name electroslag welding. If this
- If this done in horizontal weld position, as soon as the molten slag is forming, it is distributed over the w.B. so that the immersion of the tip is not possible so it can be used only in the vertical position.
- It is used for ^{joining of} above 75mm thickness plates.
- Silicon base flux powder can be used.

THERMIT WELDING

- In this the heat is generated due to exothermic chemical reaction of thermite mixture ($\text{Fe}_2\text{O}_3 + \text{Al}$ powder) is used for melting and joining of plates.



- The maximum temperature induced will be 3750 to 4000°C
- The exothermic C.R. is initiated by igniting powder (Mg powder or Barium peroxide powder) which can be initiated for burning using a match box so that the heat generated is used for initiating the chemical reaction of the thermite mixture.
- The reaction produces three things - i) Fe produced is used as filler metal ii) Al_2O_3 is used as slag iii) heat can be used for the melting of plates.

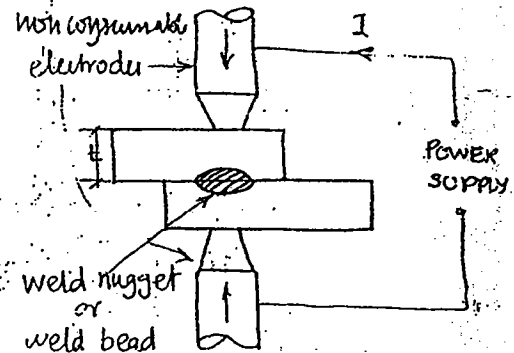
- This has been developed mainly for joining of railway tracks for remote applications rails like forest area where electricity is not available for arc welding and gas cylinders cannot be carried.
- This can be used for joining of thick plates.

RESISTANCE WELDING (Spot welding)

- It is not a non fusion welding process. It is a fusion-pressure welding process.

- The heat required is obtained through electrical resistance of the circuit - so name resistance.

Heat generated $HG = Q = I^2 R T$



- For 1mm thickness, $I_{req} \approx 10000 A$

eg. $I_1 = 10000 A$, $t_1 = 1.5 mm$ MP ≈ 11400 (Steel)

$t_2 = 5 mm$. $\therefore I_2 = ?$

$HG \propto I^2$
 $\propto t$

$I^2 \propto t$

$\left(\frac{I_2}{I_1}\right)^2 = \frac{t_2}{t_1}$

$I_2 = I_1 \sqrt{\frac{t_2}{t_1}}$

$I_2 = 10000 \sqrt{\frac{5}{1.5}}$

eg. $t_1 = 1.5 mm$. Al. Plate MP ≈ 660

$HG \propto I^2 \propto MP$

$\frac{MP_2}{MP_1} = \left(\frac{I_2}{I_1}\right)^2$

$I_2 = I_1 \sqrt{\frac{MP_2}{MP_1}}$

$\approx 10000 \sqrt{\frac{660}{11400}}$

eg. $t_2 = 5 \text{ mm}$, Cu plate $MP_2 = 1100^\circ \text{C}$

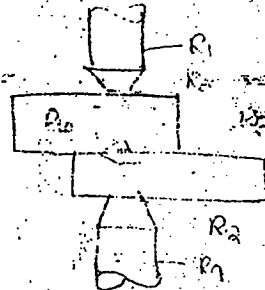
$$\frac{I_2^2}{I_1^2} = \frac{t_2 \times MP_2}{t_1 \times MP_1}$$

$$I_2 = I_1 \sqrt{\frac{t_2 \times MP_2}{t_1 \times MP_1}}$$

$$= 10000 \sqrt{\frac{5 \times 1100}{1.5 \times 1400}}$$

$$2.17 \times 10000$$

$$14000$$



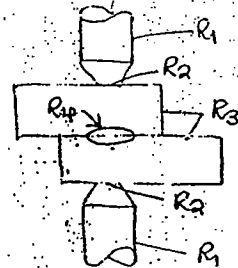
$$H_2 = Q_2 = I^2 R t$$

R - total resistance of the resistance welding ckt.

$$R = 2(R_1 + R_2 + R_3) + R_4$$

R_1 - ele. resistance of electrode metal.

As min. as possible so that the heat generated within the electrode is min. eliminating chance of electrode melting.)



- The material for electrode shall be selected so that it has high electrical conductivity, high strength for withstand the loads (Cu, In or Cu-In alloys are used).

R_2 - contact resistance b/w electrode & w/p. (should be as min. as possible to avoid melting of electrode) It depends on the roughness and cleanliness of the contacting surfaces.

R_3 - ele. resistance of the plate to be joined. (should be as min. as possible to avoid the melting of complete thickness of the plates)

Resistance to be avoided

Res contact resistance b/w the joining surface as facing surfaces or as plates b/w the facing surfaces. (should be as max. as possible, because here we need the heat to be generated to join the plates). It can be made max. by making the contacting surfaces rough and clean.

Total resistance $R = 200$ to $500 \mu\Omega$ or $200 \square \Omega$ also

τ - time during which current is passing through the ckt.
 $\tau < 0.2 \text{ s}$

$T_{\text{max induced}} = 9000$ to 12000°C

In Resistance welding, since very high temp. are induced, if the time duration is longer, the heat transfer by conduction will occur. Due to this the complete thickness of the plate may get melted. Hence $\tau < 0.2 \text{ s}$

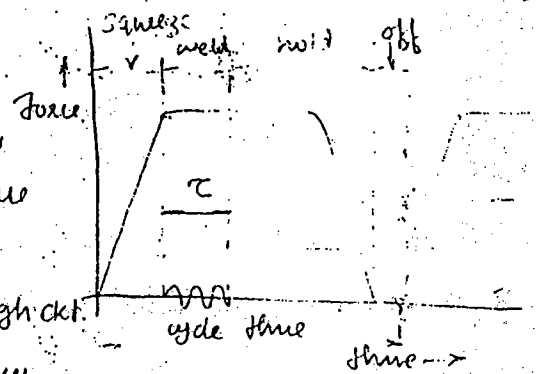
This short duration of power supply can be achieved by using relay with an ac power supply. In this we use no. of cycles, whenever the power supply is given, it will allow only corresponding no. of cycles only.

→ Squeeze time: during which the air present at the joining surface is driven out.

→ Weld: current is passing through ckt.

→ Hold time: during which the forces

are continued to hold until the molten metal produced will get solidified.



→ Off time: total setup is switched off. This is to account for

i) set time in the duty cycle of w. equip.

ii) time needed for slipping of electrode to another position

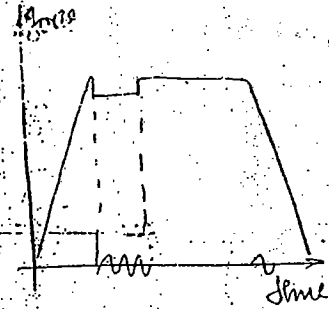
Modifications to improve the efficiency of resistance welding cycle are

i) during weld time, the force applied on the

plates can be reduced slightly so that the elastic deformation of the plates is reduced

and the time to regain the contacting surface which increases the resistance R_p . Hence the

heat generation increases.

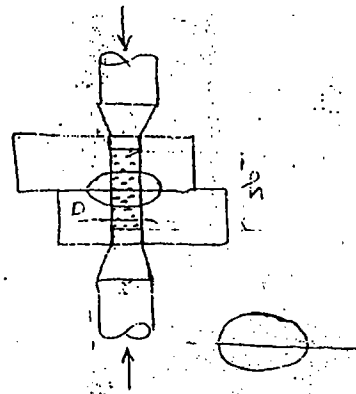


ii) Just before the reduction of force in the hold time, one or 2 cycles of power supply are given again so that the heat generated here can be used for the post heating of the W.B. for reducing the brittleness and increasing toughness.

Heat required = mass of nugget $\times$ Heat req./gram

$$= \text{volume} \times \rho \times (H.R/g)$$

Since practically it is not possible to measure the volume of nugget, theoretically it is assumed to the volume of elliptical nugget is equal to the volume of cylindrical nugget forming after the elastic deformation.



D - dia. of cyl. nugget

$=$ dia of tip of the electrode

$$\text{Volume of nugget} = \frac{\pi}{4} D^2 h$$

h - height of nugget

$$\eta_{heat} = \frac{\text{Heat required}}{\text{Heat generated}} = 85 \text{ to } 95\%$$

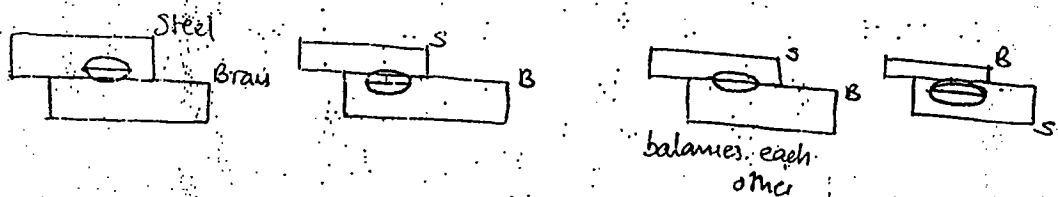
$\eta_{h.1} = 45 \text{ to } 55\%$ for Arc welding.
 $= 55 \text{ to } 65\%$ for gas welding.

- To have the maximum load carrying capacity or maximum strength of joint, major axis of the nugget must coincide with the axis of joint formation.

- To ensure the above condition, the total resistance above joint must be equal to total resistance below the joint.

- The resistance above and below plates may be different due to the resistance above and below plates may be different due to:

- i) during joining of same thickness plates using of diff. mat.
- ii) During joining of diff. thickness plates by using same mat.
- iii) During joining of diff. thickness plates by using diff. mat.



- The resistance above and below can be balanced by changing the resistance R_1 of the electrodes. R_1 can be changed by

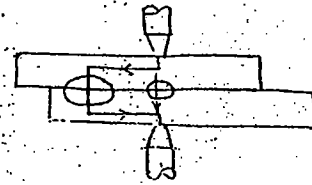
- i) changing the electrode mat. i.e., whichever the side, R_3 is higher in that side use carbon electrode and whichever the side, R_3 is lower, use Tungsten electrode.

- ii) By changing dimensions of electrode by increasing of length

change in dia only. Changing the resistance in and increase in length may cause failure of electrode in buckling. One method of increasing the strength of joint. Other methods

a) By increasing the overlap b/w plates and making use more or less one weld nugget. In the formation of multiple nuggets, during second & subsequent nugget

welding, shunting or bypassing of electricity will be taking place.

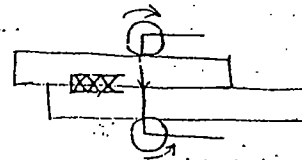


This reduces the size of the nugget. (Shunting is the property of electricity that it always tries to pass through the continuous material if it is available nearby) So the min. spot spacing is provided ($\geq 1.25t$).

b) By doing continuous resistance welding.

Called Seam welding. Here shunting

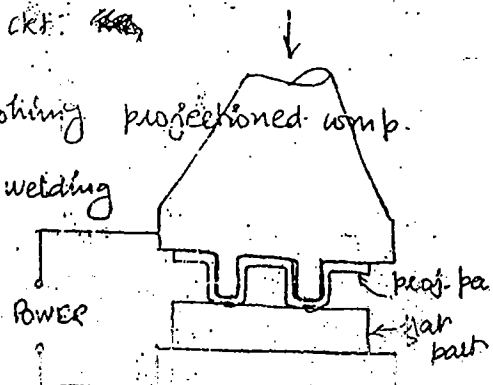
is more severe because there is no distance b/w already produced and present joint. This can be eliminated by increasing the current through the ckt.



c) Projection welding: is the method of joining projectioned comp. on to a flat comp. using resistance spot welding.

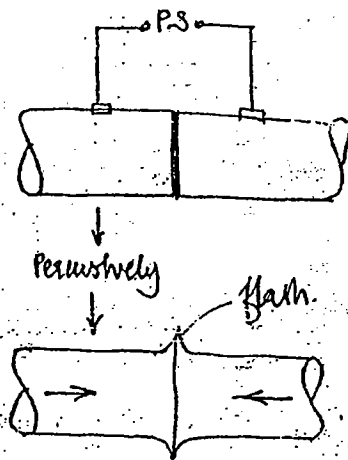
d) Percussion welding / flash butt welding

Earlier resistance welding will join only lap joint. The percussion welding is used to join butt joint.



- In percussion welding, no separate electrodes are required - w/p itself acts as electrodes. It is non fusion welding operation.

In this, the power supply will be given first, heat is generated at the joint due to the resistance, this



heat is sufficient to raise the temp of plates very near to the m.p. temp. Then stop the power supply and apply the force percussively (suddenly) due to ^{this} and due ^{to} high temp, atoms ^{at} both the surfaces ^{is} trying to share the energy thus form the joint.

- During this process, the material is produced like flash at the joint and the type of joint is a butt joint.
- It is used for joining of shafts end to end.

Applications

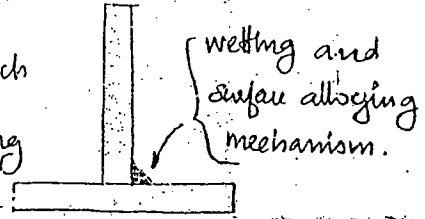
1. Whenever the increase in wt of system is not allowed due to joining. eg. aircraft, cycles, ^{frame} etc to reduce weight.
2. Whenever the leak proof joint is to be produced.
eg. pressure vessels, boilers, attaching fuel tank to the automobile bodies etc.
3. Used for joining of throw away type of tool tips to the tool.

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SOLDERING, BRAZING & BRAZE WELDING } non fusion welding

Reason for development:

1. Whenever 2 materials are to be joined which have large difference in m.p. temp. so that before melting one material so that the other gets evaporated.



2. Whenever a very thin component is to be joined to a very thick comp. so that before melting the thick comp, large quantity of thin comp. ^{will be} melted and joint formation becomes difficult.

eg joining of electronic wires to the printed ckt. board.

3. Some metals can never produce liq. molten metals with whatever temp (eg Tungsten). They can be joined by non fusion welding process.

4. Melting and solidification causes change in the mechanical properties i.e. brittleness $\uparrow$ toughness $\downarrow$ so that during usage, the impart load acting can cause the fail the comp (eg attaching fins to Iceberg walls.)

1. Mechanism of joint formation
2. Temp of joint
3. Heat source
4. Filler rod
5. Applications

SOLDERING

1. Wetting and surface alloying

2. Temp. $<$ m.p. of joint $< 420^\circ\text{C}$

3. Air-Gas flame, electrical resistance heating.

4. Filler rod 1) 50:50 Pb:Sn alloy.

1-2% Bi

10-15% Cu

10-15% Zn

10-15% Ni

10-15% Fe

10-15% Co

10-15% Mn

10-15% Al

10-15% Si

10-15% B

10-15% P

10-15% S

10-15% O

Using 50:50 Pb:Sn alloy is also called soft soldering.

(ii) Lead: Sn: Silver $\rightarrow$ hard soldering (only for space applications)

3 : 3 : 4

10-15% of filler rod

used for joining of electrical & electronic parts to printed

Temp. $< 420^\circ\text{C}$

1 $\rightarrow$ 250 - 350

2 $\rightarrow$ 350 - 450

3 $\rightarrow$ 450 - 550

4 $\rightarrow$ 550 - 650

Soldering iron

general purpose commercial

BRAZING & BRAZE WELDING

2. 70-30 Cu alloy is used as filler rod ($MP_{\text{filler}} = 422^{\circ}\text{C} \sim 427^{\circ}\text{C}$)

500°C
1000°C
1500°C
2000°C
2500°C
3000°C
3500°C
4000°C
4500°C
5000°C
5500°C
6000°C
6500°C
7000°C
7500°C
8000°C
8500°C
9000°C
9500°C
10000°C

1. The first part of the document is a list of names and titles, including the names of the members of the committee and the names of the members of the subcommittee. The list is organized in a table with two columns: the first column contains the names of the members of the committee, and the second column contains the names of the members of the subcommittee. The names are listed in alphabetical order.

$$= (50.63) \left(\frac{2}{0.1} \right)$$

$$= P \cdot \frac{2}{d}$$

$$T = F_{xy}$$

$$= 5065 \text{ N/mm}^2$$

$$F = (83.8) (0.000001)$$

and

$$= 8.63 \text{ Nm}$$

$$\text{Power} = \frac{80 \text{ Nm}}{80}$$

$$= 80 (0.010) (8.63)$$

$$= 65.8 \text{ W}$$

8.12. c

13. a

14. a

15. c

20. b

N/m

$$(8) 0.0125$$

11. c

Q9.

$$T = F = \frac{A}{A} = \frac{W \sin \theta}{A} = \frac{mg \sin \theta}{A}$$

$$T = \frac{mg \sin \theta}{A}$$

$$F = \frac{W}{A}$$

Acceleration

$$V = At$$

$$T = \frac{P \Delta t \sin \theta}{A} = P \sin \theta$$

Q10. ~~Water~~

$$1. \text{ Force} = \frac{\text{dyne-cm}}{\text{second}}$$

$$N = 10 \text{ force} = \frac{1N}{10^{-5}}$$

$$II. \gamma = m/s$$

$$\text{shake} = cm/s$$

$$N = 0.5 \text{ force} = 0.05 \text{ kg/m}^2$$

$$3 = 0.5$$

$$\gamma = ? \text{ shake}$$

$$\gamma = \frac{N}{A} = \frac{0.05 \text{ kg/m}^2}{0.05 \text{ m}^2}$$

$$= 1 \text{ m/s}$$

$$= 10^4 (60 \text{ cm})^2$$

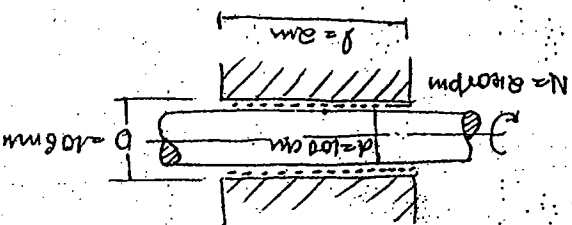
$$= 10^4 \times 10^4 \text{ cm}^2/s$$

$$= 1 \text{ cm/s}$$

$$= 1 \text{ shake}$$

$$S = 0.5$$

$$P = 500 \text{ kg}$$



$$\gamma = \frac{a}{d} = \frac{2}{8 \text{ mm}} = 0.25 \text{ mm}$$

$$N = 0.8 \text{ force} = 0.8 \text{ N}$$

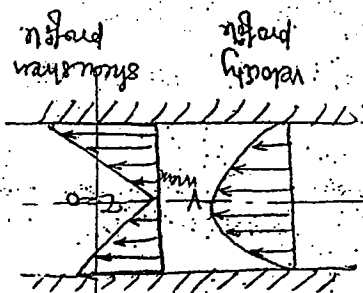
$$M = 0.8 \text{ force} = 0.8 \text{ N}$$

$$T = M \gamma = 0.8 \text{ N} \times 0.25 \text{ mm} = 0.2 \text{ mm}$$

$$= \frac{0.2 \text{ mm}}{1000} = 0.0002 \text{ m}$$

$$= 0.2 \text{ mm}$$

$$= 83.8 \text{ mm}$$



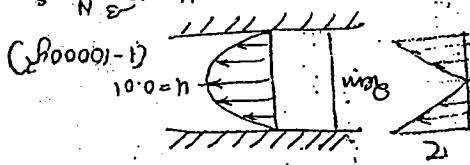
Q8.

→ opposite to fluid flow
 → against the flow → drag stress exert
 → we sign → a dragging force acting

$$\frac{du}{dy} = - \text{velocity gradient}$$

$$u = 0.01 - 10y^2$$

$$N = 10^3 \frac{N}{m^2}$$



$$= -0.002 \frac{m}{s}$$

$$= -10^3 \frac{N}{m^2}$$

$$= 10^3 \times 200 \times 0.0002$$

$$= 200 \frac{N}{m^2}$$

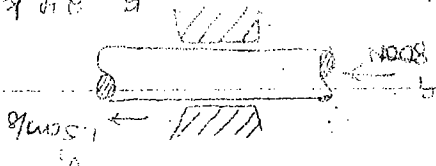
$$= 2 \frac{N}{m^2}$$

Q5.

$$u = \frac{21000 \times 1.5}{800} = 39.375 \frac{m}{s}$$

$$= 4.5 \frac{cm}{s}$$

$$R = 2.4 \text{ kN}$$





Q8. $u = 5 \sin(5\pi y)$

$M = 5 \text{ pole} = 0.5 \text{ N} \cdot \text{s}$

$T_y = 0.05 \text{ m}$

$\tau = 0.05 = M \left(\frac{du}{dy} \right)$

$= (0.5) (55.58) = 27.79 \text{ N/m}^2$

- Q5. b
- Q4. c
- Q3. c
- Q2. b
- Q1. a
- Q8. a
- Q7. a
- Q6. a
- Q5. c
- Q4. a
- Q3. c
- Q2. b
- Q1. c

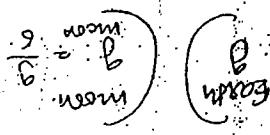
$\frac{du}{dy} = 5 \cos(5\pi y) (5\pi)$
 $\left(\frac{du}{dy} \right)_{y=0.05} = 25 \pi \cos(5\pi \cdot 0.05)$
 $= 25 \pi \cos(0.785) = 25 \pi (0.707) = 55.53 \text{ s}^{-1}$

$m = \frac{892}{9.8} = 110 \text{ kg}$

Q1. $W = 392 \text{ N} = mg$

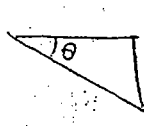
$F = ma$
 $800 = 110 \times a$
 $a = 7.27 \text{ m/s}^2$

the same on force is applied horizontal g is not affecting a .



Q6. $m = 100 \text{ N}$
 $\theta = 30^\circ$
 $y = 2 \text{ mm} = \frac{2}{1000} \text{ m}$
 $s = 0.8$
 $M = 10 \text{ pole} = 1 \text{ N} \cdot \text{s}$
 $A = 0.1 \text{ m}^2$
 $v = ?$

$P = 800 \text{ kg/m}^3$
 $F = M A \frac{g}{u}$
 $W \sin \theta = M A \frac{g}{u}$
 $100 \times 9.81 \times 0.5 = (0.1) \left(\frac{g}{u} \right)$
 $u = 1 \text{ m/s}$



$$\frac{20}{11} \text{ hole} = 11 \text{ hole} = 10 \text{ times the tool to}$$

$$20 \times 300 = 50 \text{ minutes}$$

$$226. \quad p = \frac{1}{0.2} = 5 \text{ mm taken}$$

$$227. \quad \text{Time/hole} = \frac{L}{fN} = \frac{45 \pm 0.5 \times 1000 \times 0.2}{0.2 \times 15} = 0.618 \text{ min}$$

$$\text{No. of holes} = \frac{100}{\text{Time/hole}} = 161 \text{ holes}$$

$$\text{Time} = \text{Time/hole} + \text{all time + tool changes}$$

$$= 0.618 \times 60 + 20 + \frac{161}{800} = 58.9 \text{ c}$$

228. Best is three rolling b and c

$$229. \quad b \quad 50 \text{ d}$$

$$51. \quad \frac{fN}{c}$$

$$52. \quad \frac{fN}{c} = \frac{300 \times 12}{200} = 0.056 \text{ (a)}$$

$$L = 500 + 2 + 1R$$

$$= 500 + 2 + \sqrt{2(0-d)}$$

$$= 600 + 0.2(50-d)$$

$$= 51.89 \text{ mm}$$

$$\frac{\text{Time/lot}}{\text{Time/lot}} = \frac{fN}{c} = \frac{800}{0.01124} = 8.55 \text{ min}$$

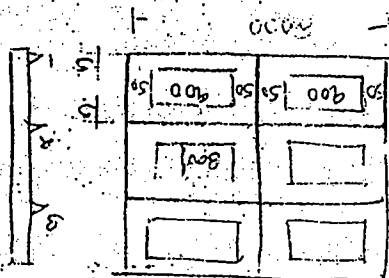
$$53. \quad c \quad 54. \quad d$$

$$55. \quad A\text{-value} \quad R\text{-value}$$

$$56. \quad b \quad 57. \quad a \quad 58. \quad c$$

$$59. \quad a \quad 60. \quad c \quad 61. \quad c$$

38. RPM_{bank} = $\frac{V}{L(t+M)}$ = $\frac{18000}{2000(1+0.43)}$ = 5.4 rpm



Time of / cut = $\frac{B}{L} \cdot \frac{1}{(1+M)}$ = $\frac{810}{810} \cdot \frac{1}{2000} (1+0.5)$ = 930 s (2 pieces)

Time / piece = $\frac{980}{2} = 490$ s = 465 s

B = 300 + 515 = 810

H1. a Beam is soft

H2. i) Time / cut = $\frac{L}{B} \cdot \frac{1}{Z}$ = $\frac{0.1 \times 12 \times 160}{880} = 1.193$ s

ii) $AP_1 = \frac{1}{2} (10 - \sqrt{10^2 - 80^2})$

$M_0 = W + 20g$

$\approx 80 + 2 \times 5 = 90$

$L = 238.2$

$\Rightarrow$ Time / cut = 1.239 s

H3. i) Time / piece = $\frac{L}{B} \cdot \frac{1}{N}$ = $\frac{586}{0.2 \times 1144} = 80$ minutes

$V = \frac{Q \times 100 \times 1144}{1000} = 45.3$

ii) $T = \left(\frac{V}{35}\right)^{1/0.75} = 1.96$ min

$$G_{\text{bet}} = \frac{p_{A1} - p_{A2}}{2}$$

$$= \frac{0.015625 \times 180}{2} = 0.8$$

$$G_{\text{bet}} = \text{dopa/mm} \times \text{total length}$$

$$35 \quad \text{dopa/mm} = \frac{10 - 7.5}{2 \times 80} = \frac{2.5}{160} = 0.015625$$

$$= 0.5 \times 20 = 10 \text{ mm}$$

$$34 \quad d = AP = 0.5 D$$

33. A-True R-True but Adrenomedullary A

32. A-True R-False

30. d

31. b

$$= 1 - \frac{3}{4} \times \frac{4}{7} = \frac{1}{7} = \frac{1}{21} \text{ available in plate 8}$$

$$(b) \quad = 1 - \frac{3}{4} \times \frac{3}{3} = \frac{1}{4} \text{ available in plate 8}$$

$$= 1 - \frac{10}{3} \times \frac{3}{7} = \frac{1}{7}$$

$$29 \quad CR = \frac{100}{28}$$

28. b

$$= \frac{1}{3} \times \frac{1}{3} = \frac{1}{9} \quad (c)$$

$$= \frac{3}{4}$$

$$CR = \frac{100}{34} = \frac{100}{34}$$

13. i) 14. c

$$GR = \frac{NLS}{Njob} = \frac{P.L.S.}{P.job} = \frac{60}{9}$$

14. c

$$NLS = \frac{P.L.S.}{9} = \frac{6}{9} \times 60$$

16. c

$$Time\ of\ wt = \frac{B}{L} \cdot \frac{1}{V} \cdot (1+M)$$

$$= \frac{80}{0.3} \times \frac{1000}{1000} (1+25) = 14\%$$

$$= 13.5\%$$

18. d: 19. b

20. Time of wt = $\frac{L}{B} \cdot \frac{1}{V} = \frac{80}{0.1 \times 1000 \times 0.5} = 0.51$

No. of pieces = $\frac{1000}{\text{time per piece}} = 4$

21. 1 = addendum + dedendum

$$= 1m + 1.25m = 2.25 \times 3 = 6.75$$

22. d

23. 100 km a. b.

24. d

25. $\frac{NLS}{B} = \frac{NLS}{B}$

$$= \frac{1000}{2000} = 0.5m$$

$$= \frac{1}{2} \times \frac{0.5}{1} = 0.25 \text{ mm}$$

$$= \frac{800}{0.3} \times \frac{1}{10} = 2666.67 \text{ mm}$$

Q9. d. already done

Q10. Hign spots / mm = $\frac{360}{800} = 0.45$

Hign spots / second = $12 \times 60 = 720$

$$= 12 \times \frac{500}{60} = 100$$

Q11. $L = 1 + A_1$

$$= 300 + \frac{1}{2} (10 - \sqrt{10^2 - 300^2})$$

$$= 300 + \frac{1}{2} (75 - \sqrt{5625 - 90000})$$

$$= 209$$

Q11. Grinding rate = Material removed in v.p

wheel wear:

$$= \frac{2000 \times 8.5 \times 5}{\frac{0.1}{10} (300^2 - (299.46)^2 \times 0.25)}$$

$$= 53.05$$

$$\text{Q12. } \alpha = 1.50$$

$$\text{Offset} = 150 \text{ mm} \times 1.5$$

$$= 225 < 10$$

Ans. the 3 methods can be used

OH
8

$$\text{mm } 091 = 7$$

$$d = 4.5 \text{ mm}$$

$$g = g_H$$

$$9d \times 9u + s_d \times s_u + i_d \times u_u =$$

2. Last min.

$$\frac{5500}{3} = \frac{4}{p} = 11$$

$$1 - i_2 + i_1 = 1$$

$$\text{Time of hot} = \frac{h}{k} = \frac{1}{1 + \frac{h}{k}}$$

Qa b Q d Q T Q down

८५१२

$$= 2.0 \text{ mm/dec}$$

!! 505 82 N

57 (1) 25

100.4

0.8

0.00

0.00

W 20.949 W
(N) 1.544

III) 0.1814 m/L

II) $2 = 51.41 \text{ N/mm}^2$

16. I) $\phi = 80.135 \quad \rho = 89.28$

III) d

II) c

18. I) a

51. a

50. c

49. c

48. a

47. c

46. c

45. c

44. d

Metal removal rate = 10vc

43. b

42. a

41. a

40. d

39. a

38. b

37. d

36. a

35. b

34. a

33. a

$$V_c = \frac{1000}{\pi D N} \approx 8.14$$

52. a
53. c
54. a
55. a
56. b
57. c
58. d (a)
59. d
60. c
61. b
62. d
63. a
64. c
65. a
66. c
67. c
68. a
69. c
70. b
71. a
72. c
73. a
74. c
75. a
76. c
77. a
78. c
79. a
80. c
81. a
82. c
83. a
84. c
85. a
86. c
87. a
88. c
89. a
90. c
91. a
92. c
93. a
94. c
95. a
96. c
97. a
98. c
99. a
100. c

81. C - 38. C

=

$$\Rightarrow \frac{1}{81} = \sqrt{K \times 81} = \sqrt{0.005 \times 8 \times 1.8}$$

$$R_f = \frac{1}{81}$$

$$T_2 = 0.7 T_1$$

$$\frac{T_1}{T_2} = \frac{\tan \alpha_2}{\tan \alpha_1} = \frac{\tan 7}{\tan 10} = 0.7$$

$$T \propto \tan \alpha$$

$$T \propto \cot \alpha$$

$$T \propto \frac{\text{Bank}}{\text{weat}}$$

28.

27. C - 29. A

=

$$V_{opt} = C \left[\frac{1-n}{n} \cdot \frac{1}{T_c} \right]^n$$

$$C = 50 \times 10^5$$

$$n = \frac{\mu_{100/50}}{\mu_{145/10}}$$

$$\left(\frac{50}{100} \right) = \frac{50}{145}$$

28. $V_a V' = Q_0$

$n = 0.12$

$V_{T14} = C'$

$T' = \left(\frac{C'}{V'} \right)^{1/n}$

$= \left(\frac{143}{98} \right)^{1/0.12}$

$= 87.14 \text{ mm}$

23. i) V_T^{nec}

$V_T^{nec} = \frac{9.8 \times 30 \times 0.4}{0.4 \times 0.5}$

$= 60.2$

$\Rightarrow C = 60.2$

ii) $V_{opt} = C \left[\frac{1-n}{n} \right]^n \left[\frac{G}{L_m} \right]^n$

$= 60.2 \left[\frac{0.2}{0.2} \right]^{0.2} \left[\frac{100}{100} \right]^{0.2}$

$= 13.8 \text{ m/min}$

Q4.

$R_{Ti} = \frac{f}{b} = \frac{\tan \alpha + \cot \alpha}{b}$

$= 0.08 \text{ f}$

$\left. \begin{array}{l} R_{Ti} \text{ can be } \\ R_{Ti} \text{ put in } \end{array} \right\}$

$R_{Ta} = \frac{f}{b} = \frac{\tan \alpha + \cot \alpha}{b}$

$= 0.11 \text{ f}$

25. $P_2 = F_c = \text{sat } C_s (3 \sec r - \tan \delta + 1)$

$S_0 = 0.12$

$t = 0.0$

$S_0 = 400$

$r = 0$

$\frac{1}{S_0} = \frac{f}{b}$

$P = F_{Tc} = \frac{r}{V_f}$

$\frac{V_f}{V_c} = r$

$$r = \frac{1}{k}$$

$$\phi = \tan^{-1} \left(\frac{r \cos \alpha}{1 - r \sin \alpha} \right)$$

$$\therefore \alpha = 10^\circ$$

12.

$$\cos \alpha = 2\phi + b - \alpha$$

$$\phi = \tan^{-1} \left(\frac{r \cos \alpha}{1 - r \sin \alpha} \right)$$

$$\beta = \alpha + \tan^{-1} \left(\frac{F_T}{F_C} \right)$$

$$\alpha = 10^\circ$$

$$r = \frac{0.43}{0.135}$$

$$a_n. F_c = \text{spring force} \times A_n$$

$$= 800 \times 20 \times 2$$

$$= 3200 \text{ N}$$

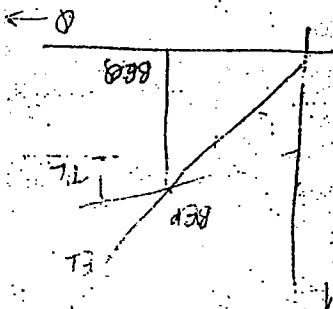
$$P = F_c V_c = 3200 \times 60 = 192000 \text{ W}$$

$$a_n. \text{ for } Q = \text{no. of parts}$$

$$(TC)_1 = \frac{80}{80} \times 2 \times 80 = 1600$$

But

$$(TC)_{11} = \frac{60}{60} \times 6 \times 160 + 500 = 500 + 1600$$



$$\Rightarrow Q = 21$$

$$ii) T = \frac{f_s}{f_{smp}} \times 8 \text{ ms}$$

$$f_s = \frac{f_c}{\cos(\phi - \alpha)} \cos(\phi + \beta - \alpha)$$

$$\Rightarrow A_0 = L_1 \times b$$

$$= 0.06 \times 3.83 =$$

$$\Rightarrow C =$$

$$iii) V_f = V_c = 0.5 \times 0.223 \times 60$$

$$iv) \text{ shaft stress} = \sigma_t \phi + \tau_m (\phi - \alpha)$$

$$v) \text{ power for cutting operation } P = F_c \times V_c$$

$$= 363 \times 0.223$$

$$17) V_{T_{0.13}} = V_{A_{0.13}}$$

$$\Rightarrow T_0 = T_1 \left(\frac{V_0}{V_1} \right)^{1/0.13}$$

$$V_0 = 2V_1$$

$$T_1 = 60$$

$$T_0 = T_1 \left(\frac{V_0}{V_1} \right)^{1/0.13}$$

$$= 0.09 \text{ mm}$$

$$18) f_t = f_{us} \times$$

$$= f_{sm} \times$$

$$= 0.15 \times 8 \text{ ms}$$

$$\begin{aligned}
 v &= 0.823 \text{ m/s} \\
 t_1 &= 0.06 \text{ mm} \\
 b &= 8.83 \text{ mm} \\
 r &= 0.51 \\
 \alpha &= 20^\circ \\
 F_c &= 363 \text{ N} \\
 F_t &= 127 \text{ N}
 \end{aligned}$$

$$= 80 + \tan^{-1} \left(\frac{12.4}{8.63} \right)$$

$$p = \alpha + \tan^{-1} \left(\frac{F_t}{F_c} \right)$$

$$\phi = \tan^{-1} \left(\frac{r \cos \alpha}{1 - r \sin \alpha} \right)$$

$$\Rightarrow T_H =$$

$$n \ln \left(\frac{54}{14} \right) + p \ln \left(\frac{0.85}{0.82} \right) = \ln \left(\frac{120}{125} \right)$$

$$\Rightarrow \left(\frac{54}{14} \right)^n \left(\frac{0.85}{0.82} \right)^p = \left(\frac{120}{125} \right)$$

$$p =$$

$$(1) \text{ and } (2) \Rightarrow n =$$

$$n \ln \left(\frac{60}{54} \right) + p \ln \left(\frac{0.85}{0.8} \right) = \ln \left(\frac{125}{106} \right) \quad (3)$$

$$\text{and } \left(\frac{60}{54} \right)^n \left(\frac{0.85}{0.8} \right)^p = \ln \left(\frac{125}{106} \right)$$

$$n \ln \left(\frac{110}{60} \right) + p \ln \left(\frac{0.85}{0.8} \right) = \ln \left(\frac{106}{80} \right) \quad (4)$$

$$\left(\frac{110}{60} \right)^n \left(\frac{0.85}{0.8} \right)^p = \frac{106}{80}$$

$$= 130 \times T_H \times 0.82$$

$$130 \times 54 \times 0.82 = 120 \times 54 \times 0.85$$

$$T_H = 1.16$$

$$18. i) \beta = \alpha + \tan^{-1} \left(\frac{F_T}{F_C} \right) = 35 + \tan^{-1} \left(\frac{800}{80} \right)$$

$$M = \tan \beta$$

$$> 1$$

So according to d'Alembert's theorem

$$M = \tan(\gamma) = \tan(72 - \alpha)$$

$$L_2 = 60 \quad \tan L_2 = \frac{60}{80 \times 32} = 0.59$$

$$ii) \text{ Shear plane angle } \phi = \tan^{-1} \left(\frac{1 - \mu \tan \alpha}{\mu \tan \alpha} \right)$$

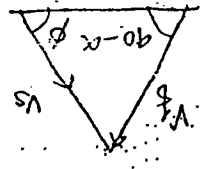
$$\approx \tan^{-1} \frac{1 - 0.59 \tan 35}{0.59 \tan 35}$$

$$= 36.4^\circ$$

$$iii) V_f = r V_c = 0.59 \times 10 = 5.9$$

$$\frac{V_s}{V_f} \cos \alpha = \frac{V_f \sin \phi}{V_f}$$

$$V_s = V_f \cos \alpha \sin \phi$$



$$t_{max} = 2 \sqrt{\frac{N_2}{d}} \sqrt{\frac{d}{2}} = \frac{2 \times 100}{500 \times 8}$$

$$= 0.011$$

10.10

8. $T_c = 15$

$$V_{opt} \propto \left[\frac{\frac{1}{1-n}}{T_c} \right]^n$$
$$= 100 \left[\frac{1}{1-0.8} \times \frac{1}{15} \right]^{0.8}$$

$$n \approx 45 \text{ m/min}$$

10. $\alpha_n = \tan^{-1} (\tan \alpha \cdot \cos i)$

$$= \tan^{-1} (\tan 12^\circ \cos 10^\circ)$$

$\approx$

$$\alpha_n = \tan^{-1} \left(\frac{\tan \alpha}{\cos i} \right)$$

$$= \tan^{-1} \left(\frac{\tan 7^\circ}{\cos i} \right)$$

11. $V_0, T_0 = \text{original}$

$$V_1 = 1.2 V_0$$

$$T_1 = 0.5 T_0$$

$$V_2 = 0.8 V_0$$

$$T_2 = ?$$

$$V_0 T_0^n = V_1 T_1^n$$

$$\left(\frac{T_0}{T_1} \right)^n = \frac{V_1}{V_0}$$

$$n \ln \left(\frac{T_0}{T_1} \right) = \ln \left(\frac{V_1}{V_0} \right)$$

$$n = \frac{\ln(V_1/V_0)}{\ln(T_0/T_1)}$$

$$= \frac{\ln 1.2}{\ln 2} =$$

$$V_0 T_0^n = V_2 T_2^n$$

$$T_2 = ?$$

$$T_2 = ?$$

$$T_1 = T_2 \quad) \quad \frac{V_2}{V_1} = \left(\frac{f_2}{f_1} \right)^{0.5} \left(\frac{d_1}{d_2} \right)^{0.15}$$

$$f_2 = f_1/2$$

$$d_2 = 2d_1$$

$$= 2^{0.5} (V_1)^{0.15}$$

$$\Rightarrow V_2 = 1.11 V_1$$

$$\frac{V_2 - V_1}{V_1} = 11\%$$

ii) Productivity $\propto MRR$

$$\% \text{ change} = \frac{MRR_2 - MRR_1}{MRR_1} = \frac{f_2 d_2 V_2 - f_1 d_1 V_1}{f_1 d_1 V_1}$$

$$= 11\%$$

5. $\alpha = 6^\circ, V_c = 0.5$

$t_1 = 1, b = 3, t_2 = 1.5$

$2\phi + \beta = 90^\circ$ (min. energy condition)

$$r_2 \frac{t_1}{t_2} = \frac{1}{1.5} = \frac{2}{3}$$

$$\phi = \tan^{-1} \left(\frac{r \cos \alpha}{b - r \sin \alpha} \right) = 35.48^\circ$$

$$\beta = 90^\circ + \alpha - 2\phi = 26^\circ$$

$$\mu = \tan \beta = 0.4887$$

ii) $V_f = r V_c = \frac{1}{1.5} \times 0.5 = 20 \text{ m/min}$

iii) $A_s = l_s b = \frac{t_1}{\sin \phi} b = \frac{1}{\sin 35.48^\circ} \times 3 = 5.2 \text{ mm}^2$

6. $T_{op} = \left[\frac{1-n}{n} \cdot \frac{C_s}{L_m} \right] V^{1.1} = 1000$

$$= \left[\frac{1-0.1}{0.1} \cdot \frac{3}{25/60} \right]^{1.1} = 56 \text{ min.}$$

7. $V \propto \frac{C}{T^n}$ $V_A = \frac{100}{180^{0.22}} = 35$ $V_B = \frac{120}{180^{0.25}} = 32$

Tool A has higher cutting velocity

Q1. Orthogonal cutting $V_c = 30$ $V_f = 15$ $\alpha = 10^\circ$ $r = \frac{V_f}{V_c} = 0.5$

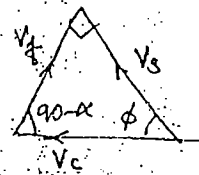
Shear angle, $\phi = ?$

$$\phi = \tan^{-1} \frac{r \cos \alpha}{1 - r \sin \alpha} = \tan^{-1} \left(\frac{0.5 \cos 10}{1 - 0.5 \sin 10} \right) = 28.33$$

$$\frac{V_s}{\sin(90 - \alpha)} = \frac{V_f}{\sin \phi}$$

$$V_s = \frac{15 \sin(90 - 10)}{\sin 28.33}$$

$$= 31 \text{ m/min}$$



Q2. Orthogonal cutting

$$t_1 = d = 2$$

$$b = w = 15$$

$$V_c = 0.5$$

$$\alpha = 0$$

$$F_c = 900$$

$$F_T = 600$$

$$\phi = 30$$

$$M = ?$$

$$\tan(\beta - \alpha) = \frac{F_T}{F_c}$$

$$\beta = \alpha + \tan^{-1} \frac{F_T}{F_c}$$

$$\beta = 0 + \tan^{-1} \frac{600}{900}$$

$$= 33.69$$

$$M = \tan \beta$$

$$= \tan 33.69$$

$$= 0.66$$

Cutting power

$$P = F_c V_c = 900 \times 0.5$$

$$= 450$$



Length of shear plane L_s

$$L_s = \frac{t_1}{\sin \phi}$$

$$= \frac{2}{\sin 30} = 4$$

3. For minimum shear strain

$$\phi = \alpha = 20^\circ$$

$$\phi = \alpha = 20^\circ$$

$$V_1 T_1^{0.3} f_1^{0.3} d_1^{0.5} = V_2 T_2^{0.3} f_2^{0.3} d_2^{0.5}$$

21. b

30. c

21. b

32. b

33. c

34. b

35. d

$$36. \quad F_{max} = 0.10 \times 3 \times 1000$$

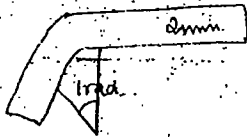
$$= 37.7 \text{ kN}$$

$$F = \frac{F_{max} \times k t}{k t + 1}$$

$$= \frac{37.7 \times 4 \times 3}{6.4 \times 3 + 2}$$

$$= 22.2$$

37



$$\theta = m \cdot \theta$$

$$= (r + k t) \theta$$

$$= (100 + 0.5 \times 2) \cdot 1$$

$$= 101$$

38. a

$$103 = \sigma_y = \frac{\sigma_4}{2}$$

14. d.

15. a

16. a

$$17. D = \sqrt{d^2 + 4edn}$$

$$= \sqrt{35^2 + 4 \times 25 \times 15}$$

$$= 108 \text{ mm.}$$

$$18. k = 0.5$$

$$I = t$$

$$F(kt + I) = F_{\max}$$

$$F = \frac{F_{\max} \times 0.5t}{0.5t + t}$$

$$= \frac{F_{\max} \times 0.5}{1.5}$$

$$= \frac{F_{\max}}{3}$$

19. b

20. a

21. b

22. d

$$23. DS = BS = 30 \text{ mm} //$$

$$C = 5\%$$

$$PS = DS - 2C$$

$$= \frac{6}{100} \times 30 = 0.6$$

$$= 30 - 2 \times 0.6$$

$$= 28.8 //$$

24. d

25. c

$$26. DS = BS = 20 \text{ mm}$$

$$PS = 20 - 2 \times \frac{3}{100}$$

$$C = \frac{3}{100} \times 2$$

$$= 19.88 \text{ mm}$$

27. a

28. b

$$1. \quad v_k = \frac{d_1}{D}$$

0.6 $\rightarrow$ 1st draw.

0.8 for 2nd and subsequent.

$$\begin{aligned} D &= \sqrt{d^2 + 4 \times 50 \times 150} \\ &= \sqrt{30^2 + 4 \times 50 \times 150} \\ &= 137.47 \text{ mm} \end{aligned}$$

$$d_1 = DR_1 \times D = 0.6 \times 137.47 = 82.48 > 30$$

$$d_2 = DR_2 \times D = 0.8 \times 82.48 = 65.98 > 30$$

$$d_3 = 65.98 \times 0.8 = 52.78 > 30$$

$$d_4 = 0.8 \times 52.78 = 42.22 > 30$$

$$d_5 = 0.8 \times 42.22 = 33.78 > 30$$

$$d_6 = 33.78 \times 0.8 = 26.99 < 30 \quad \text{not}$$

$$11. \quad \frac{d}{r} = \frac{100}{6} = 16.67 \quad R = 25 \text{ mm}$$

$$D = \sqrt{d^2 + 4 \times 25 \times 100} = 138.42 \text{ mm}$$

$$P_{\text{total}} = D + 2 \times T \times A$$

$$= D + 2 \times 3$$

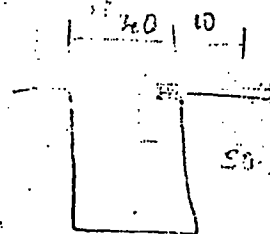
$$= 141.42 \text{ mm}$$

13.

$$D = \sqrt{d_0^2 + 4 \times 10 \times 10}$$

$$=$$

$$P_{\text{total}} = D + 2 \times 10$$



$$I = \frac{83.6 \times 0.4 \times 2}{20} = 0.4 \text{ m}^2$$

$$= 1.98 \text{ mm} \approx 2 \text{ mm}$$

$$7. D = \sqrt{d^2 + 4dh} \approx 20.2 \text{ mm}$$

$$d = 12 \text{ mm}$$

$$h = 16 \text{ mm}$$

$$= \sqrt{12^2 + 4 \times 12 \times 16}$$

$$= 30.2 \text{ mm}$$

$$d_1 = D (1 - 0.4)$$

$$= 30.2 (1 - 0.4) = 18 > 12$$

$$d_2 = 18 (1 - 0.25) = 13.5 > 12$$

$$d_3 = 13.5 (1 - 0.25) = 10.125 < 12 \quad \text{na3.}$$

$$\sigma_{\theta 1} = \frac{P_1}{\pi [(d_3^2 - (d_1 - 2t)^2)]}$$

$$= \frac{\sigma_{\theta 1} \sigma_{\theta 2}}{\sigma_{\theta 1} [(18)^2 - (18 - 8 \times 2)^2]}$$

$$= 66 \text{ MPa}$$

~~part~~ (ii) $LDR = 1.8$

$$PR_1 = \frac{P}{d_1}$$

$$d_1 = \frac{13.2}{1.8} = 7.33$$

$$d_2 = \frac{8}{1.8} = 4.44 < 5 \quad n=2$$

(iii) $P = \sigma_d t \sigma_y \left(\frac{P}{d_1} - C \right)$

$$= \sigma_d t \sigma_y$$

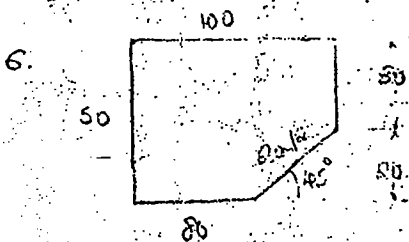
$$= 8 \times 13.2 \times 1.5 \times 315$$

$$= 195.94 \text{ k}$$

$$D = \sqrt{a_1^2 + 4d_1^2}$$

$$= \sqrt{7.33^2 + 4 \times 7.33 \times h_1}$$

$$h_1 = \frac{13.2^2 - 7.33^2}{4 \times 7.33} = 1.773$$



$$P = 50 \times 100 + 30 \times 20 \times 2 + 80$$

$$= 280$$

$$F_{max} = P \times t_c$$

$$= 83.6 \text{ kW}$$

$$t = 2 \text{ mm}$$

$$t_c = 145 \text{ MPa}$$

$$W_p = F_{max} \times t$$

$$= 83.6 \times 0.4 \times 2$$

$$= 66.6 \text{ J}$$

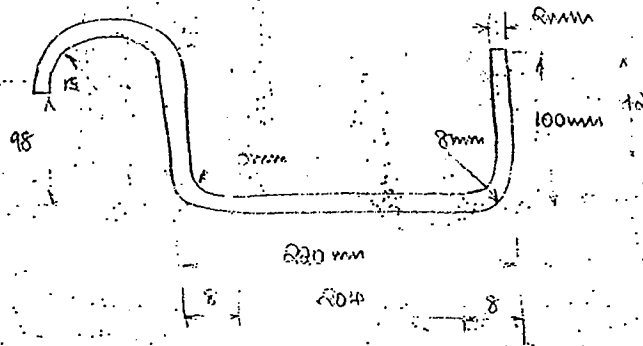
$$F_{max} \times t = P (t_f + t)$$

$$J = \frac{F_{max} \times t}{P} - t$$

$$\begin{aligned}
 3. \quad F_{bmax} &= P \times t \times T_c \\
 &= 317.5 \times 1 \times 420 \\
 &= 133 \text{ kN}
 \end{aligned}$$

$$\begin{aligned}
 F_{pmax} &= Q \times D \times t \times T_c \\
 &= 2 \times \pi \times 12.5 \times 420 \\
 &= 32 \text{ kN}
 \end{aligned}$$

14.



$$L = 98 + 204 + 192 + B_1 + B_2$$

$$B_1 = r \times \theta$$

$$= \left(15 + \frac{1}{2} \times 2\right) \times 180 \times \frac{\pi}{180}$$

$$= 50 \text{ mm}$$

$$B_2 = \left(6 + \frac{1}{2} \times 2\right) \times 90 \times \frac{\pi}{180}$$

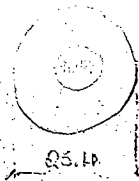
$$= 10.99 \text{ mm}$$

$$L = 466 \text{ mm}$$

$$5. \quad D = \sqrt{d^2 + 4e^2}$$

$$= 13.2 \text{ cm}$$

SHEET METAL OPERATIONS



a) Piercing $D.S. = D.S. = 12.7$

$$D.S. = P.S. + 2C$$

$$= 12.7 + 2 \times 0.04$$

$$= 12.78$$

b) Blanking

$$D.S. = B.S. = 25.4$$

$$P.S. = D.S. - 2C$$

$$= 25.4 - 2 \times 0.04$$

$$= 25.32$$

c) Compound die $F_{max} = F_{pmax} + F_{bmax}$

$$= \pi d t +$$

$$= \pi (12.7)(1.25)(800) + \pi (25.4)(1.25)(800)$$

$$= 200000$$

$$= 120 + 80$$

$$= 120 \text{ kN}$$

d) Progressive die $F_{max} = \max(F_{pmax}, F_{bmax})$

$$= 80 \text{ kN}$$

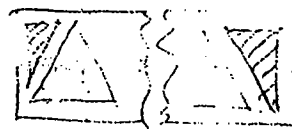
e) When progressive die and shear provided,

$$F = F_p + F_b$$

$$= \frac{F_{max} \cdot k t}{k t + 1}$$

i) 84%

ii) $n = \frac{1}{S} = \left(\frac{220}{54} \right) \times 2 = 8.1$
 $= 8 - 1$
 $= 7$



39. $AC = R \times$

$$= 300 \left(\frac{\Delta H}{R} \right) \frac{A}{180}$$

100. c

101. b

102. At max. load, $\epsilon = \frac{1}{3}$

$$\sigma = 1400 \left(\frac{1}{3} \right)^{0.93}$$

$$= 987.4$$

103

104. 1/2 and 4

105. A true R false

$$\begin{aligned}
 26. \quad (E_{\text{eff}})_{\min} &= \sigma_y \times A_0 \\
 &= 10 \frac{\pi}{16} \times 100^2 \\
 &= 95 \text{ ton}
 \end{aligned}$$

$$\begin{aligned}
 EF &= \frac{(EF)_{\min}}{0.4} \\
 &=
 \end{aligned}$$

27. d

28. a

29. c

30.

$$\begin{aligned}
 EF &= K A_0 \ln \frac{A_0}{A_1} \\
 &= 250 \times \frac{\pi}{16} (100)^2 \ln \left(\frac{100}{50} \right)^2 \\
 &= 2.72 \text{ MN} //
 \end{aligned}$$

31. Roll strip contact length = Arc length of contact
 = arc length of deformation zone

$$= R \alpha$$

$$= 300 \left(\tan^{-1} \sqrt{\frac{\Delta H}{R}} \right) \frac{\pi}{180}$$

$$= 24.5 \text{ mm} //$$

$$\Delta H = 380 \text{ mm}$$

$$R = 300 \text{ mm}$$

$$\alpha = \tan^{-1} \sqrt{\frac{\Delta H}{R}}$$

$$= \tan^{-1} \sqrt{2/300}$$

$$= 4.667$$

$$\beta = \alpha$$

$$\mu = \tan \beta = 0.08$$

32. b

33. a

34. a

35. d

36. d

37. d

38. b

39.

22. Whenever increase in yield strength $\Rightarrow$ the process is assumed to be cold working

$$A_0 L_0 = A_f L_f$$

$$L_f = L_0 \frac{A_0}{A_f}$$

$$= L_0 \left(\frac{d_0}{d_f} \right)^2$$

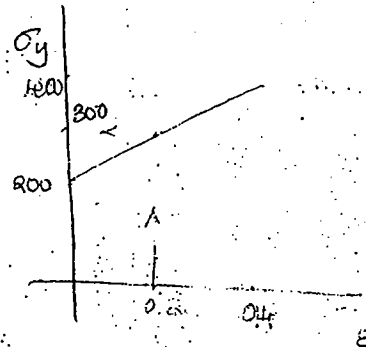
$$= 100 \left(\frac{12.214}{10} \right)^2$$

$$= 150 \text{ m.}$$

$$\epsilon = \ln \frac{A_0}{A_f}$$

$$= \ln \left(\frac{12.214}{10} \right)^2$$

$$= 0.4$$



23. $\sigma = 315 \epsilon^{0.54} \text{ MPa}$

$$\sigma = 315$$

$$= 315 \left(\frac{\sigma}{315} \right)^{0.54}$$

$$= 315$$

$$= 592 \text{ MPa}$$

$$\epsilon = \ln \frac{A_0}{A_f}$$

$$= \ln \left(\frac{d_0}{d_f} \right)^2$$

$$= \ln \left(\frac{25}{5} \right)^2$$

$$= 6.931 \cdot 3.2188$$

24. $d_0 = 100$

$$h_0 = 10$$

$$h_f = 40$$

$$\sigma_y = 80$$

$$d_f = d_0 \sqrt{\frac{h_0}{h_f}} = 100 \sqrt{\frac{10}{40}} =$$

$$R_{min} = \sigma_y A_0$$

$$R_1$$

20. $A_0 = 80 \times 5 = 400 \text{ mm}^2$

$$\frac{A_0 - A_1}{A_0} = 0.14$$

$$A = A_0 \sqrt{1 - 0.14}$$

$$M = 0.1$$

$$\sigma_y = 300 \text{ MPa}$$

$$\alpha = \frac{26.5}{3}$$

$$B = \mu \sigma \alpha$$

$$= 0.1 \text{ wt } (13.25)^6$$

$$= 0.48$$

$$\sigma_2 = \sigma_y \left(\frac{1+B}{B} \right) \left(1 - \left(\frac{A_1}{A_0} \right)^B \right)$$

$$\text{Drawing load} = \sigma_2 \times A_1$$

21. $d_0 = 6$

$$d_f = 1.34$$

$$M = 0.2$$

$$\alpha = 26^\circ$$

$$\sigma_y = 80$$

For maximum reduction/pass

$$B = 0.2 \text{ wt } 6^\circ = 1.9$$

$$\sigma_2 = \sigma_y$$

$$\frac{\sigma_2}{\sigma_y} = 1 = \left(\frac{1+B}{B} \right) \left[1 - \left(\frac{A_1}{A_0} \right)^B \right]$$

$$\frac{A_1}{A_0} = 0.58$$

$$\frac{d_1}{d_0} = 0.75$$

$$d_1 = d_0 \times$$

$$= 6 \times 0.75 = 4.5 > 1.34$$

$$d_2 = d_1 \times$$

$$= 4.5 \times 0.75$$

$$= 3.39 //$$

$$d_3 = 3.39 \times 0.75 = 2.54$$

$$d_4 = 2.54 \times 0.75 = 1.92$$

$$d_5 = 1.92 \times 0.75 = 1.44$$

$$d_6 = 1.44 \times 0.75 =$$

$$1.06 < 1.34$$

$$1.06 //$$

$$17. A_0 h_0 = A_f h_f$$

$$\sigma_{h_0} d_0^2 h_0 = \sigma_{h_f} d_f^2 h_f$$

$$d_f = d_0 \sqrt{\frac{h_0}{h_f}}$$

$$18. R.S.F = \frac{Q}{\sqrt{3}} \sigma_y (bL) \left(1 + \frac{ML}{4bH} \right)$$

$$\sigma_y = 1400 \text{ MPa} \quad R = \frac{250}{2} = 125 \text{ mm}$$

$$b = 450 \text{ mm}$$

$$M = 0.08$$

$$L = \sqrt{RAH} = \sqrt{125 \times 1} = 11.18$$

$$H = \frac{h_0 + h_1}{2} = \frac{3.5 + 2.5}{2} = 3.0$$

$$\Rightarrow R.S.F = \frac{Q}{\sqrt{3}} (1400) (450 \times 11.18) \left(1 + \frac{0.08 \times 11.18}{4 \times 3} \right)$$

$$= 833419.8 \text{ N} = 0.833 \text{ MN}$$

$$19. \frac{\sigma_2}{\sigma_1} = \left(\frac{1+B}{B} \right) \left[1 - \left(\frac{p_1}{p_0} \right)^B \right]$$

$$B = \frac{M_1 + M_2}{\tan \alpha - \tan \gamma}$$

$$M_1 = M_2 = 0.12$$

$$\alpha = 24/2 = 12^\circ$$

γ is negligible.

$$p_1 = 1.8$$

$$p_0 = 26$$

$$\Rightarrow B = 0$$

$$\sigma_2 = \sigma_1 \log_{10} \frac{p_0/p_1 - 1}{1}$$

$$\frac{\sigma_2}{\sigma_1} = \log_{10} \left(\frac{26/1.8 - 1}{1} \right) = 0.556 / \sigma_2 = 0.556 \sigma_1$$

$$16. H_0 = 20.$$

$$H_1 = 14$$

$$\sigma_y = 120 \text{ MPa}$$

$$R = 2140$$

$$\Delta H = 20 - 14 = 6.$$

$$\tan \alpha = \sqrt{\frac{\Delta H}{R}}$$

$$\alpha = \tan^{-1} \sqrt{\frac{6}{2140}}$$

$$L = \sqrt{R \Delta H}$$

$$= \sqrt{2140 \times 6}$$

$$= 38 \text{ mm}$$

$$\approx 9^\circ$$

$$\text{Max. red. at } \beta = \alpha = 9^\circ$$

$$\mu = \tan \beta = \tan 9^\circ$$

$$= 0.158$$

$$H_n = H_1 + 20 \text{ to } 30\% \Delta H$$

$$\approx 15.3 \text{ mm}$$

$$\text{Forward slip} = \frac{V_1 - V}{V}$$

$$= \frac{V_1}{V} - 1$$

$$= \frac{H_1}{H_0} - 1$$

$$= \frac{15.3}{20} - 1 = 9\%$$

$$\text{Backward slip} = \frac{V_2 - V_0}{V}$$

$$= 1 - \frac{H_n}{H_0}$$

$$= 1 - \frac{15.3}{20} = 23\%$$

$$\text{Vol. at Neutral P.} = \text{Vol. at edge}$$

$$H_n \times b \times r = H_1 \times b \times r_1$$

$$\frac{H_n}{H_1} = \frac{r_1}{r}$$

Maximum pressure at neutral point

H_n in leading zone or lagging zone pressure equation

$$\Rightarrow (P_x)_{\text{lag}} = \left[(n-1) \left(\frac{H_0}{H_n} \right)^n + 1 \right] \frac{\sigma_y}{n}$$

$$= \left[0.9 \left(\frac{20}{15.3} \right)^{1.9} + 1 \right] \frac{120}{1.9}$$

$$= 157.7$$

$$n = \frac{R \mu L}{\Delta H}$$

$$= \frac{2(0.15)(38)}{(6)}$$

$$= 1.9$$

$$3. \quad \epsilon = \frac{\delta L}{L} = \frac{2L - L}{L} = 1$$

$$\epsilon = \ln(1 + e)$$

$$= \ln 2 = 0.693$$

4. c 7. b 10. d

5. a 8. c 11. a

6. c 9. c 12. A - false R - true.

Assertion and reason standard multiple choice

a) A & B are true and R explains A.

b) " " " " R doesn't explain A.

c) A true R false

d) A is false R true

13. b

14. b

15. a

15 $d_0 = 6 \text{ mm}$

$d_f = 5.2 \text{ mm}$

$\alpha = 9^\circ$

$L = 4 \text{ mm}$

$\mu = 0.15$

$\sigma_y = 260 \text{ MPa}$

$B = \mu \cot \alpha$

$$= 0.947$$

$$\sigma_a = \sigma_y \left(\frac{hB}{b} \right) \left[1 - \left(\frac{A_1}{A_0} \right)^B \right]$$

$$= 260 \left(\frac{1.947}{0.947} \right) \left[1 - \left(\frac{5.2}{6} \right)^{0.947} \right]$$

$$= 193 \text{ MPa}$$

$$\sigma_t = \sigma_y + (\sigma_a - \sigma_y) e^{-\frac{2\mu L}{R}} = 260 + (193 - 260) e^{-0.45} = 178.5 \text{ MPa}$$

$$F_{0.1} = \sigma_t \times A_1$$

①

$$\mu = 0$$

METAL FORMING

$$B = \cot \alpha \cdot \mu = 0$$

$$\sigma_2 = \sigma_y \left(\frac{1+B}{B} \right) \left[1 - \left(\frac{A_1}{A_0} \right)^B \right]$$

$$= \frac{0}{0}$$

$$\sigma_2 = \sigma_y \cdot \log_{10} \left\{ \frac{1}{A_0/A_1 - 1} \right\}$$

For maximum reduction

$$\frac{\sigma_2}{\sigma_y} = 1 - \log_{10} \left\{ \frac{1}{A_0/A_1 - 1} \right\}$$

$$\log_b a = x \Rightarrow b^x = a$$

$$\Rightarrow 10^1 = \frac{1}{A_0/A_1 - 1} \Rightarrow \frac{A_0}{A_1} = 1$$

$$= 2.72$$

②

$$d_f = 0.1 \text{ mm}$$

$$d_0 = 15 \text{ mm}$$

$$\% \text{ red} = \frac{A_0 - A_1}{A_0}$$

$$\frac{A_1}{A_0} = 1 - \text{red.}$$

$$d_1 = d_0 \sqrt{1 - \text{red.}}$$

$$a) \quad d_1 = 15 \sqrt{1 - 0.8} = 6.7$$

$$d_2 = d_1 \sqrt{1 - 0.8} = 2.99$$

$$d_3 = d_2 \sqrt{1 - 0.8} = 1.34$$

$$b) \quad d_3 = 1.34$$

$$d_4 = 1.34 \sqrt{1 - 0.8} = 0.997$$

$$c) \quad d_2 = 2.99$$

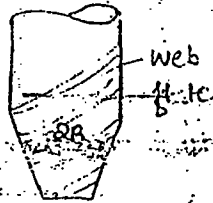
$$d_3 = 2.99 \sqrt{1 - 0.4} = 2.314$$

$$d_4 = d_3 \sqrt{1 - 0.4} = 1.79$$

$$d_5 = d_4 \sqrt{1 - 0.4} = 1.6$$

DRILLING

- produces holes in the component using multi point cutting tool.



α_h - min at centre to max at periphery.

$\alpha_h = \alpha_b = \text{min to max.}$

$\alpha_b = \text{point angle} \approx 118^\circ$ (standard)

$> 118^\circ$ (hard w/p)

$< 118^\circ$ (soft w/p)

- The min.

It is always preferable to

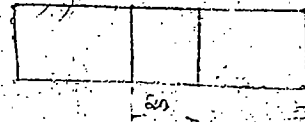
smaller size of the drill bit and

increase size of the hole in stages

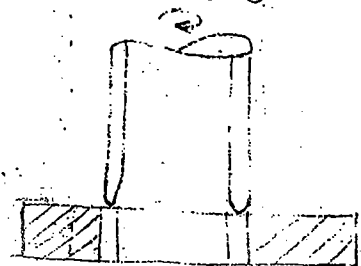
with different size of the drill bit until the required size of the hole

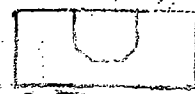
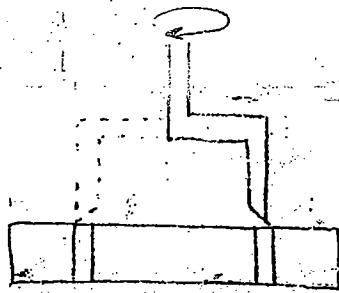
eg To produce 20mm hole,

first drill 5mm hole $\rightarrow$ then 8, 10, 12, 15, 20.

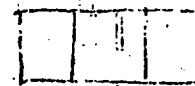


- Using the above method, the max. size of hole which can be produced is 50mm only. Beyond which the time taken for producing the hole becomes very large. Hence it is not preferable.
- Boring is the operation used for enlarging the existing hole by some amount.





Blind hole



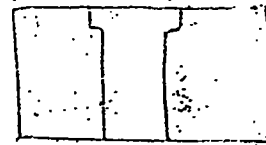
Through hole

- This method is used only for producing through holes and not for blind holes.

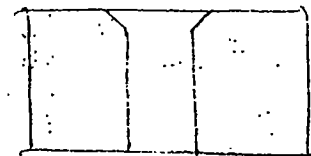
Reaming is the process used for sizing of the hole removing very small amount of materials.

Counter boring is the operation used for enlarging the end of the hole.

It is done by using boring operation i.e., internal turning.



Counter sinking is the method of enlarging the end of the hole by tapering. It can be done by a large size drill bit.

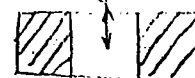
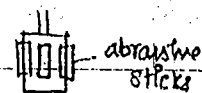


- The method removing left over chips on the surface of the hole for making the hole surface flat is called spot facing.

It is done by end mill cutter using milling machine.

- Honing is the operation used for making the hole highly polished surface.

eg finishing of I.C.E. cylinders.



Machining time in drilling operations.

— For calculation of machining time, the required size of the hole that can be produced by corresponding size of the drill ^{directly} by.

$$\text{Time/hour} = \frac{L}{f \cdot N} \quad \leftarrow \text{length of tool travel}$$

$$L = L_1 + AP_1 + AP_2 + OR$$

AP_1 - compulsory approach (or)

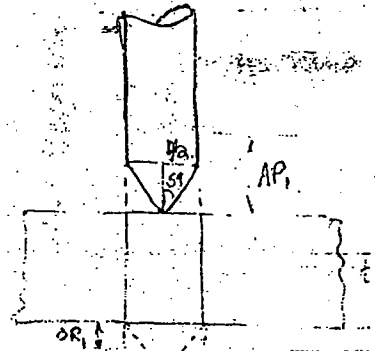
distance to be travelled by the tool for complete diameter of the hole is started producing.

AP_2 = conical length of drill bit.

= { 0.50 through holes
0.80 blind holes.

f - feed mm/rev.

$$N = \frac{1000 \text{ Vopt}}{SD}$$



$$\tan 59 = \frac{D/2}{AP_1}$$

$$AP_1 = D/2 \cot 59$$

$$= 0.30$$

MILLING

The operation used for producing slots in the component or removing a layer of material from complete surface of the w/p using multipoint cutting tool rotation is called milling.

2 types of mills are used

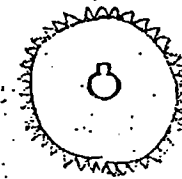
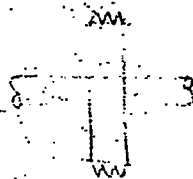
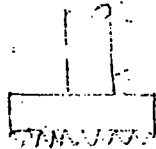
1. End mill cutter → cutting teeth at the end of a disc

2. Peripheral mill cutter

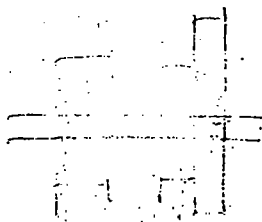
→ cutting teeth at the periphery of disc

End mill cutter can be used either for vertical drilling machine or milling while periphery m.c. is used only for milling m/c.

It is mounted on a shaft called Arbor.



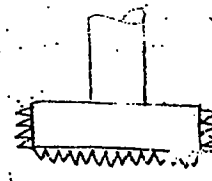
Peripheral m.c.



GANG MILL



STRADDLE MILLING CUTTER



SIDE MILLING CUTTER

Types of milling

1. Face milling operation

2. Slab/slot milling operation

— If a layer of material is removed from complete surface of the w/p, it is called face milling operation.

- If a slot is produced in the component using milling, it is called slab/slot milling operation.

- In milling, both the operation of milling can be done by using both the types of tools. But preferably face milling operation is done by using end m.c and slab/slot milling is done by using peripheral m.c.

11/10 Time of cut = $\frac{L}{f_m} = \frac{L}{f_t N} = \frac{L}{f_t Z N}$

$f_m = f_t N$
 $= f_t Z N$

where $f_t = \text{mm/min}$

$f_t = \text{mm/rev}$

$f_t = \text{mm/tooth}$

$Z = \text{no. of teeth}$

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

$D = \text{dia. of milling cutter}$

$L = l + AP_1 + AP_2 \text{ OR}$

AP_1 - distance to be travelled by the tool for complete width of the w/p starts machining.

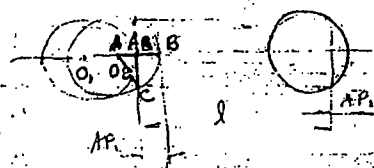
- AP_1 4 cases
- (1) Face milling with end mill cutter
 - (2) " " peripheral m.c
 - (3) Slab milling with end m.c
 - (4) " " peripheral m.c

Case 1. Face end m.c

$AP_1 = AB$

$= \frac{D}{2} - \frac{d}{2}$

$= \frac{D - d}{2}$



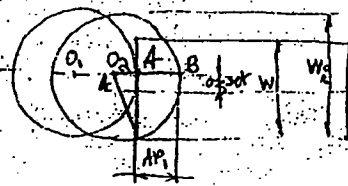
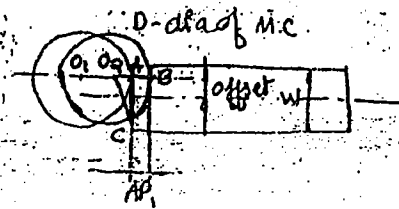
— If the centre of Wp of centre of M.C coincides, it is called as symmetrical milling operation.

— Asymmetrical milling operation:

W_1 — imaginary width of the Wp

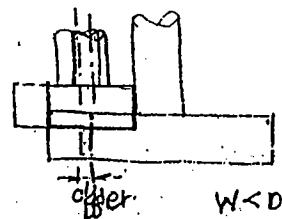
$$\begin{aligned} AP_1 &= AB = \sqrt{\frac{D^2}{4} - a_1^2} \\ &= \frac{D}{2} - \sqrt{a_2^2 - A_1^2} \\ &= \frac{D}{2} - \sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{W}{2} + \text{off}\right)^2} \\ &= \frac{1}{2} \{ D - \sqrt{D^2 - W_1^2} \} \end{aligned}$$

$$\text{Time} = \frac{l + AP_1}{f_m}$$

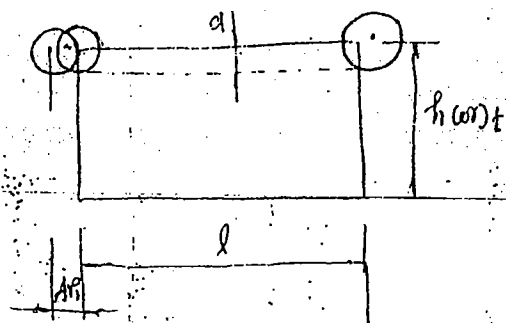
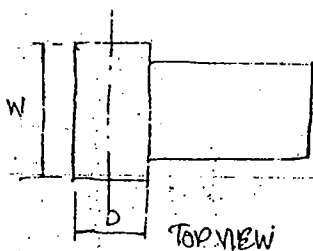


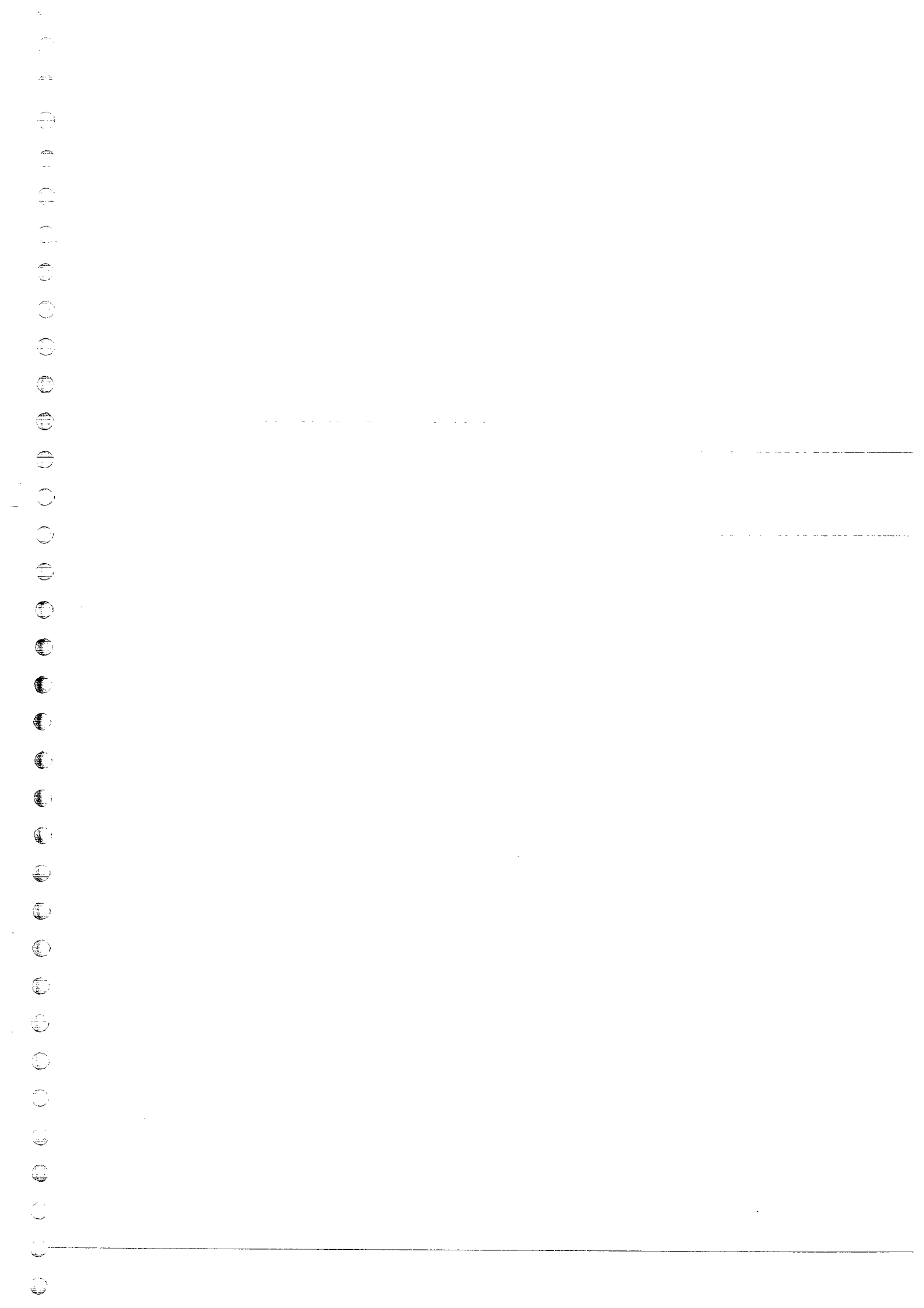
— In general symmetrical is the most preferable milling method because, it is giving lower machining time and it's more stable since the area of contact of the tool with Wp. is same from the centre.

— But whenever symmetrical milling is not possible to use, asymmetrical milling is used.



Case 2: Face milling with peripheral M.C.





1

2

3

4

5

6

7

8

As the machine is becoming old, the transmission systems like gears are experiencing wear and tear, causing no effect in the upmilling because of opposite direction of motions. Whereas in down milling because of same direction of movement, the w.p is experiencing fluctuation causes to induce impact loads on the tool tips or vibrations in the w.p and finally, resulting into either mechanical breakage of tool tips or poor surface finish.

As the machine is new, it is always preferable to use down milling and if the m/c is very old, use up milling.

Indexing:

It is the operation of rotating the job through required angle in b/w the successive cuts.

$$\begin{aligned} \text{Depth} &= \text{addendum} + \text{dedendum} \\ &= 1m + 1.25m \\ &= 2.25m \end{aligned}$$

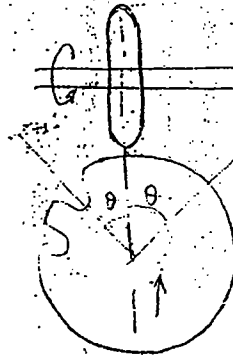
eg. During gear cutting using milling m/c, after every teeth has been cut the gear blank has

to be brought to downward and rotate through exact angle as required.

$$\text{eg. For 24 toothed gear } \theta = 360/24 = 15^\circ$$

To rotate the job through the exact angle, indexing mechanism is used. It consists of 2 devices. A device which can rotate the job through required angle called indexing crank.

(ii) A device which can ensure that the given rotation is correct called index plate.



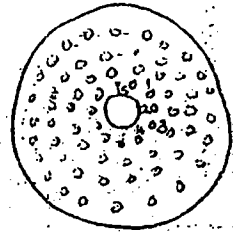
— Index plate:

a) Brown and sharp plates

Plate 1: 15, 16, 17, 18, 19, 20

Plate 2: 21, 23, 27, 29, 31, 33

Plate 3: 35, 37, 39, 41, 43, 47, 49



b) Parkinson plates.

Plate 1: 24, 25, 28, 30, 34, 37, 38, 39, 41, 42, 43

Plate 2: 46, 47, 49, 51, 53, 54, 57, 58, 59, 62, 66

— As per Indian standard, we are using only Brown and sharp plates.

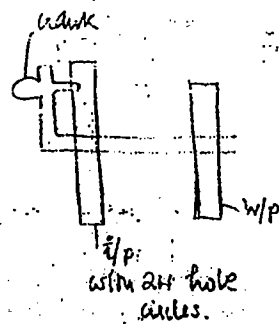
— Methods of indexing:

1. Direct indexing
2. Simple/plain ind.
3. Angular ind.
4. Compound ind.
5. Differential ind.

— In ~~simple/plain~~ ^{direct} indexing,

1 rev. of crank = 1 rev. of job

Since the crank has been directly connected to the job, it is called direct indexing.



The circumference of the job can be divided into

2, 3, 4, 6, 8, 12, 24 only

$$\text{Crank radius} = \frac{24}{T} = 6 \text{ holes}$$

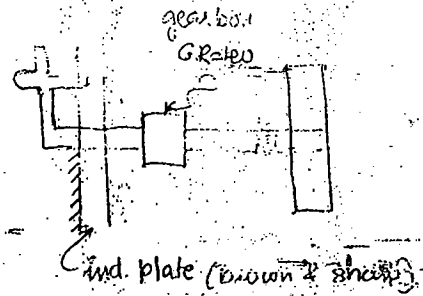
It is very simple and easiest methodology, but it can ^{not} divide the circumference into any other said number divisions only.

Simple/Plain indexing

$$1 \text{ rev. of crank} = \frac{1}{40} \times \text{rev. of job.}$$

$$= \frac{360}{40} = 9^\circ \text{ of job}$$

— The gear ratio b/w the crank and job is always taken as 40 because all



The indexing plates are designed based on the gear ratio of 40 only.

— To get this high G.R. with a compact size of the gearbox, the worm and worm gear can be used in the gearbox.

Crank rotation required in b/w 2 successive cuts. $CR = \frac{40}{N}$ where N. no. of divisions the circumference of the job to be divided.

eg. If $N = 27$,

$$CR = \frac{40}{27} = 1 \frac{13}{27}$$

= 1 rev. and 13 holes in 27 hole circle.

$N = 36$

$$CR = 1 \frac{4}{36} = 1 \frac{1}{9} \times \frac{2}{2} = 1 \frac{2}{18}$$

Angular indexing

$$1 \text{ rev. of crank} = 9^\circ \text{ of job}$$

$$CR = \frac{\theta}{9} \text{ where } \theta = \text{angle b/w 2 consecutive divisions}$$

eg $N = 24$

$$CR = \frac{40}{24} = 1 \frac{10}{24} = 1 \frac{2}{3} \times \frac{5}{5} = 1 \frac{10}{15}$$

$$\theta = \frac{360}{24} = 15$$

$$CR = \frac{15}{9} = \frac{5}{3}$$

LIMITATIONS OF SIMPLE OR ANGULAR INDEX

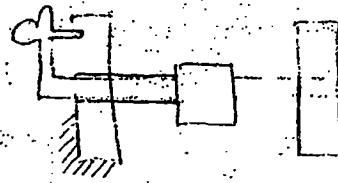
Using simple indexing, upto 120 no. of divisions, any no. of divisions is possible. But beyond 120, only few nos are possible and others are not possible.

eg. $N = 53$, $CR = \frac{120}{53} \rightarrow 53$ is not available.

To overcome this problem, compound indexing can be used.

Compound Indexing:

- In case of simple indexing, the index plate is always fixed but the crank is rotating to rotate the job with CR 120.



Whereas in case of compound indexing, the ~~can~~ I-plate is also connected to the gear box so that ~~the~~ whether the plate or crank is rotating, the job will always be rotated through a CR 120.

- In compound indexing, the required crank rotation is divided into 2 fractions, one of which is obtained by fixing the plate or rotating the crank and the other fraction of rotation is obtained by fixing the crank and rotating the plate.

eg. $N = 23$

$$\begin{aligned} CR &= \frac{120}{23} = \frac{8}{3} + \frac{22}{23} \\ &= \frac{8 \times 5}{8 \times 5} + \frac{22}{23} \\ &= \frac{10}{15} + \frac{22}{23} \end{aligned}$$

By fixing plate the crank will be rotated through

10 holes in 15 hole circle

By fixing the crank the plate can be rotated around on 22 holes in 23 hole circle

- During the usage of compound indexing, the hole circles required for both the fractions must be available in one plate itself otherwise it will be very difficult.

- With compound indexing, it is possible to produce any no. of divisions whether it is less or greater than 40.

Limitation:

- Unless the operator is strong in mathematics, it is not possible to divide the required crank rotation into 2 fractions.

Differential indexing

N - no. of divisions by which the circumference to be divided

n - a no. slightly larger or smaller than N .

$$CR = \frac{40}{N}$$

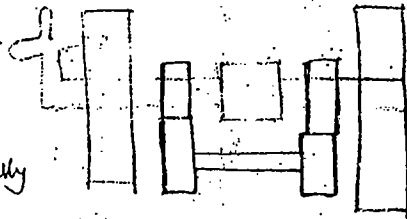
$$\text{difference} = \frac{40}{nN} \sim \frac{40}{N^2}$$

The difference in rotation is simultaneously given to the plate through an externally mounted gear train.

- In differential indexing, the crank is rotated by using the operator.

The plate will rotate simultaneously through external mounted

gear train either in the same direction or opposite direction of crank.



- In diff ind. In addition to the calculation of crank rotation it also requires the externally mounted gear train to be designed.

ie, the gear ratio

Eg $N=63$, Take $n=65$

$$\text{Gear ratio of gear train} = \frac{(50-53) \frac{100}{58} \times 8}{11} \\ = \frac{16 \times 2}{11 \times 2} = \frac{32}{23}$$

$$\text{or } \frac{2}{1} \times \frac{8}{11} = \frac{2 \times 20}{11 \times 20} \times \frac{8}{11} \times \frac{3}{3} \\ = \frac{40}{20} \times \frac{24}{33}$$

OR

$$n=50 \quad \text{G.R. of G.T.} = \frac{(50-53) \frac{100}{58} \times 8}{11} \\ = - \frac{3 \times 4}{5} \\ = - \frac{12 \times 5}{5 \times 5} \\ = - \frac{60}{25}$$

Take n as multiple of 5 to make problem easier.

$$\text{eg } n=137$$

$$n=140$$

$$CR = \frac{140}{140} = \frac{2}{7} \times \frac{3}{3} = \frac{6}{21}$$

$$\text{G.R. for G.T.} = \frac{(140-137) \frac{140}{140}}{11} = \frac{6 \times 5}{7 \times 5} \\ = \frac{30}{25}$$

$$\text{OR } \frac{3}{1} \times \frac{2}{7} = \frac{3 \times 20}{1 \times 20} \times \frac{2}{7} \times \frac{10}{10} \\ = \frac{60}{20} \times \frac{20}{70}$$

$$\text{If } n=136 \text{ taken, } CR = \frac{140}{136} = \frac{5}{17}$$

$$\text{G.R. for G.T.} = \frac{(136-137) \frac{140}{136}}{11}$$

$$= -1 \times \frac{20}{68}$$

$$= - \frac{20}{68}$$