KIIT POLYTECHNIC

LECTURE NOTES

ON

Mechanical Metallurgy

(6th Semester Metallurgy)

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CONTENTS

Chapter - 1

DISLOCATION

Dislocation:-

Line imperfections are commonly called as dislocations. It is the region of disturbance localised around a line. It can also be defined as the region of local lattice disturbance, separating the slipped and unslipped part of the crystal.

There are two types of dislocation.

(I) Edge dislocation

(II) Screw dislocation.

(I)Edge dislocation-

In a perfect crystal all the vertical planes of atom or horizontal planes of atom are parallel to each other. If one vertical plane of atom is incomplete one i.e it does not extends from the top to the bottom of the crystal but completes in the midway of the crystal. It gives rise to imperfection called edge dislocation.

Atoms just above the edge of the incomplete plane are in a state of compression and atoms below the edge of the incomplete plane are in a state of tension. Since the region of maximum disturbance extends around the edge of the incomplete plane it is called edge dislocation.

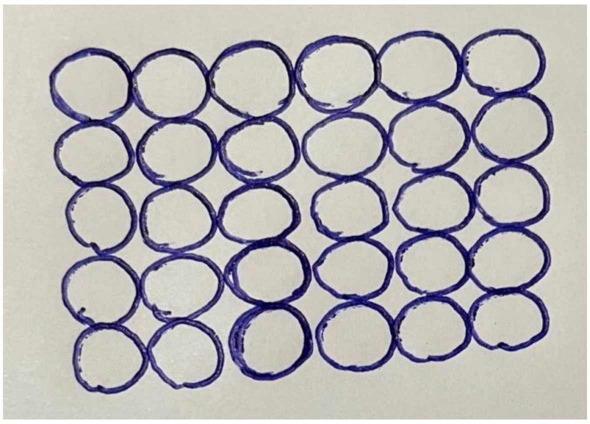
Again it is of two types,

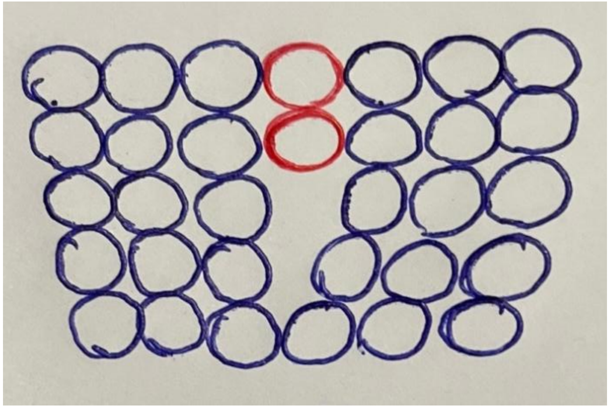
(a) Positive edge dislocation:-

When the extra plane of atom extend from top to the midway of the crystal it is called positive edge dislocation and is denoted by

(b) Negative edge dislocation.

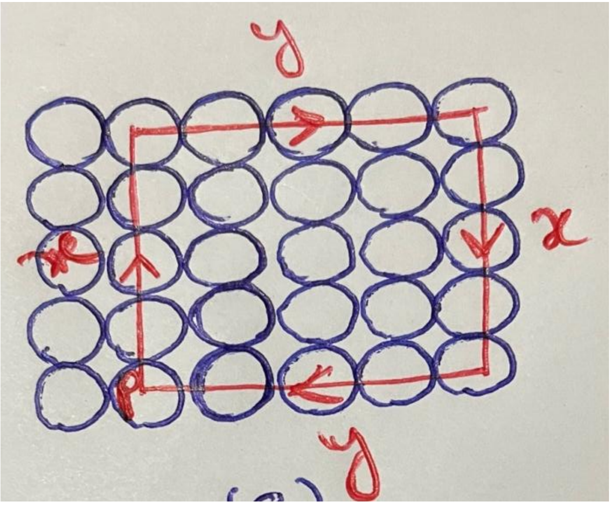
If the extra plane plane of atoms lies below the sliped plane or it extends from bottom to the mid way of the crystal, it is called negative edge dislocation and is donated by “ T ”

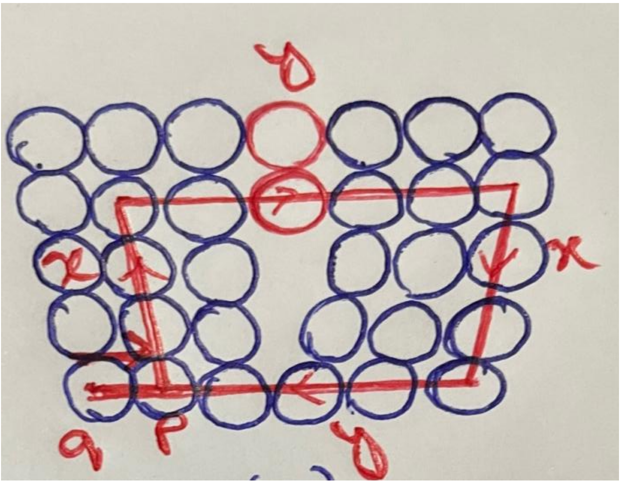




Fig(a) Fig(b)

Burger's Vector:-





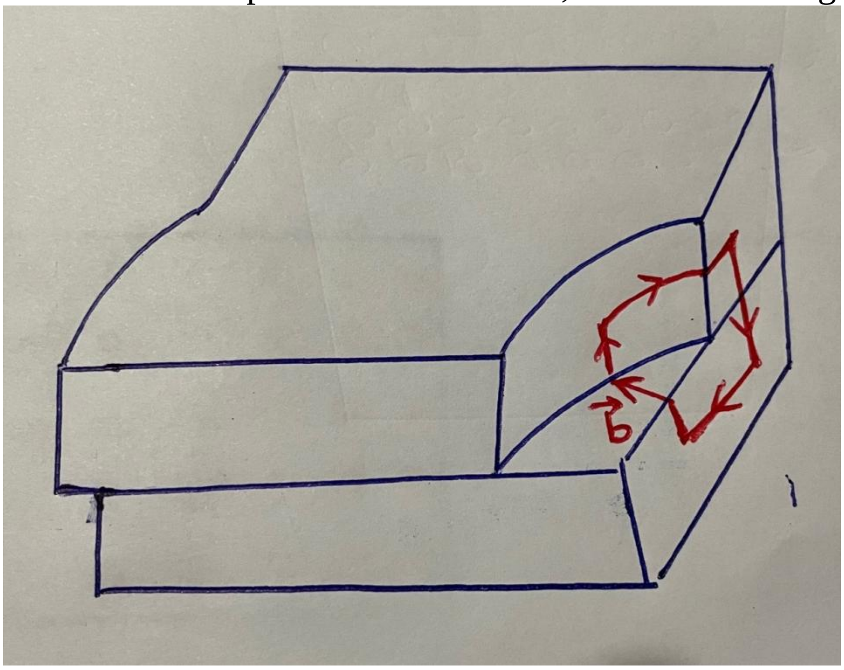
Fig(c) Fig(d)

The magnitude and direction of displacement or slip of the lattice is defined by burgers vector. It is denoted by symbol b. In a perfect crystal in a plane starting from point 'P' when we moves x-steps (inter atomic distance) up , y steps toward right , x-steps down and y steps towards left, we reached at the starting point p(fig-3) . This is called as burger circuit or burger loop. We reached the starting point because the region included by burger loop is perfect without any dislocation.

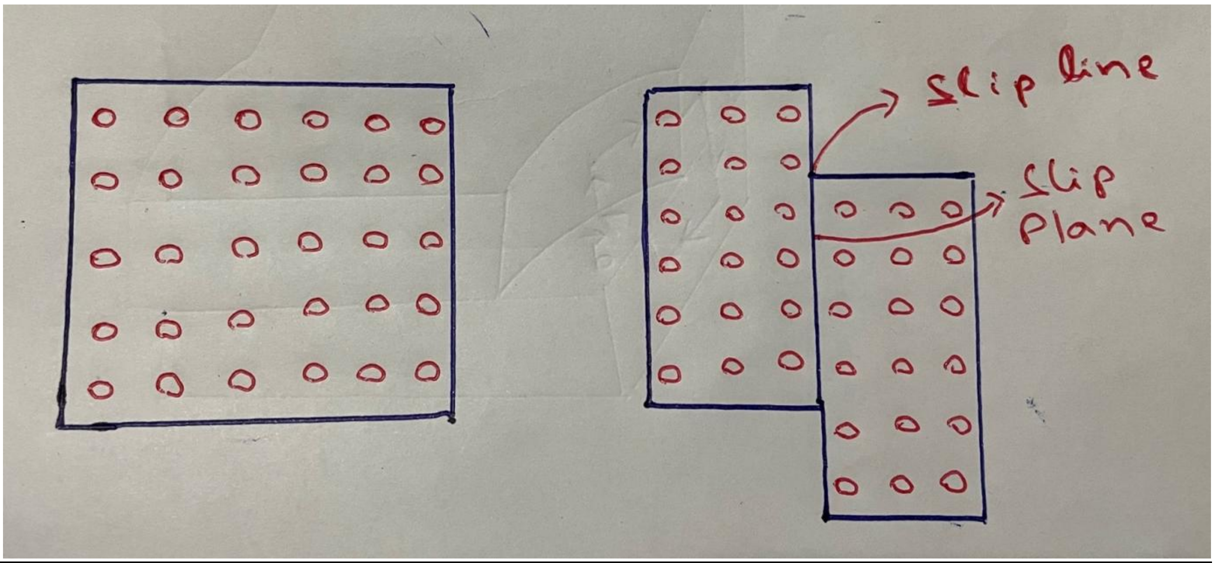
But in a crystal having dislocation we started from point ‘p’ and reached at ‘q’. Thus to complete the burgers circuit we need an extra step i.e q to p . The magnitude and direction of this vector defines the burger vector. The burger vector is always perpendicular to the edge dislocation line.

(2) Screw Dislocation-

A screw dislocation lies parallel to its burger vector. If both dislocation and burger vector are parallel to each other, it is called as positive screw dislocation and if both are anti-parallel to each other, it is called as negative screw dislocation.

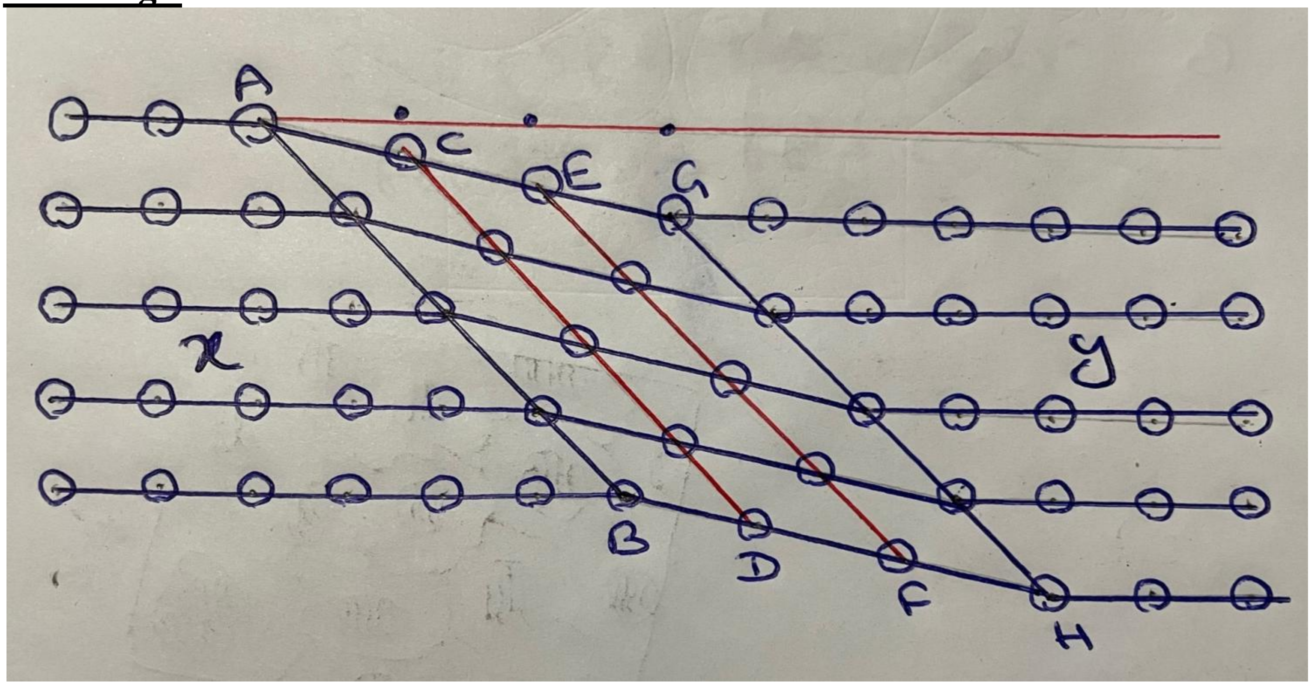


Slip:-



A slip can be defined as the distortion produced in a deck of cards when it is pushed from one end. By the application of shear stress to a metal cube with a top polished surface, slip occur when the shear stress exceed a critical value. Atom moves an integral number of atomic distances along the slip plane and a step is produced in the polished surface. By looking from top with a microscope the step looks up as a line and is called as slip line. If the surface is then re-polished after slip has occurred so that the step is removed, the slip line will disappear. Each atom in the slipped part of the crystal moves forward the same integral number of lattice spacing. Slip lines are produced due to change in surface elevation and that the surface must be suitably prepared for microscopic observation prior to deformation, if the slip lines are to be observed. The fine structure can be observed as high magnification by means of the electron microscope. Slip occurs most readily in specific directions on certain crystallographic planes. Generally the slip plane is the plane of greatest atomic density, since the resistance to slip is generally less for these planes than for any set of plane.

Twinning:-



When a block is subjected to stress instead of whole block of atoms moving various distances along the slip planes, in twinning each plane of atom moves in the same direction a definite distance such that the extent of movement of each plane is proportional to its distance from the twinning plane. The distance moved on each subsequent plane is greater by a fixed fraction of unit atomic spacing than that on the previous plane for example plane CD moves $1/3^{rd}$ of an inter atomic distance, the plane

EF movies 2/3rd of an inter atomic distance and plane GH moves by one inter atomic distance. The movement of these planes alters the direction of lattice and thus a twinned region forms. The twinned region separates the crystal into two regions X and Y oriented in such a way that both are mirror image to each other. Twinning appears as broad lines or bands under the micro scope.

There are two types of twins

(I) Deformation or mechanical twins produced after mechanical working.

(II) Annealing twins develops as a result of annealing after plastic deformation.

Chapter - 2

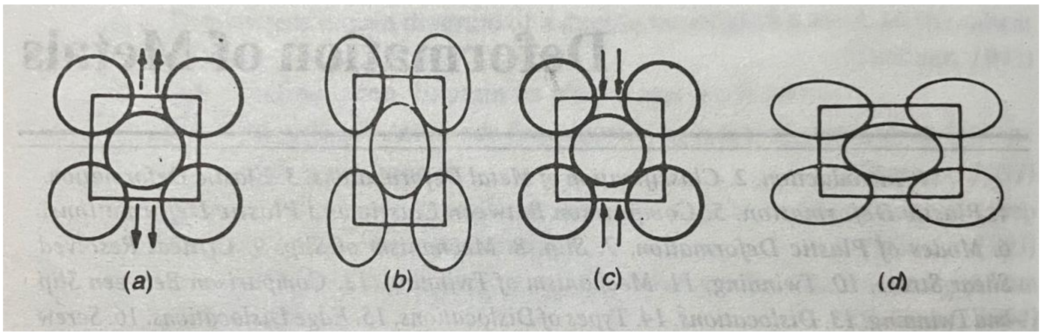
DEFORMATION OF METALS

The deformation of metal may be classified into the following two types depending upon the nature of strain produced during deformation:

1. Elastic deformation
2. Plastic deformation

1. **Elastic Deformation**-

The term elastic deformation may be defined as the process of deformation which appears and disappears simultaneously with the application and removal of stress. It has been observed that whenever a stress of low magnitude is applied to a piece of metal, it causes displacement of atoms from their original positions. But on the removal of stress, the atoms springs back occupy their original positions.



The above figure shows the effect of tensile and compressive loads respectively on the atoms of the unit cell respectively. Fig(a) represents the front face of the F.C.C unit cell before loading. In this figure, the circle represents the atoms of the metal specimen. Fig(b) shows a slight elongation of the unit cell in the direction of tensile load. Similarly Fig(c) represents the front face of the F.C.C unit cell before loading and fig(d) shows a slight contraction of the unit cell in the direction of compression load. The unit cell, after removal of the load, returns back to the normal positions as shown in fig (a) and (c).

It may be noted, from the above discussion, that whenever there is an elongation or contraction, in the crystal structure of a metal, in one direction, due to uniaxial load, produces an adjustment in dimensions at right angles to the force.

This type of change in dimension at right angles to the applied load is due to lateral strain. The ratio of lateral strain to the original strain is known as Poisson's ratio.

It has been experimentally found that the strain is nearly proportional to the applied stress. The ratio between stress and strain is known as Modulus of Elasticity or Young's Modulus.

Plastic Deformation-

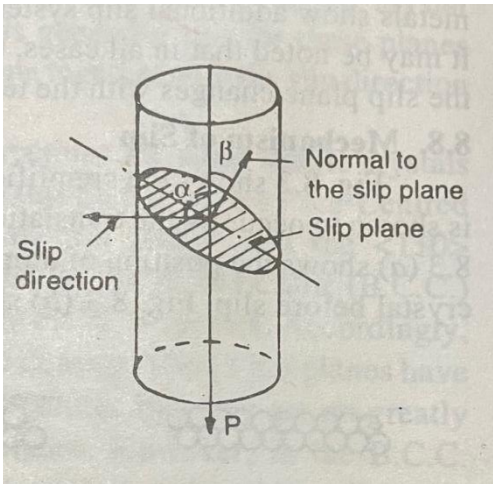
The term plastic deformation may be defined as the process of permanent deformation, which exists in a metal, even after the removal of the stress. It is due to this property, that the metals may be subjected to various operations like rolling, forging, drawing, spinning etc.

The plastic deformation in crystalline materials occurs at temperatures lower than $0.4T_m$. Where T_m is the melting temperature in Kelvin. In this temperature range, the amount of deformation, which occurs after the application if stress is very small and generally ignored? However the rate at which, the material is deformed plays some role in determining the deformation characteristics. The plastic deformation may occur under the tensile, compressive or torsional stresses. There are two basic modes of plastic deformation slip and twinning. The slip mode is common in many crystals at elevated temperature. But at low temperatures, the mode of deformation changes over to twinning in a number of cases.

Comparison between elastic and plastic deformations-

Sl. No.	Elastic deformation	Plastic deformation
1	It is a deformation which appears and disappears with the application and removal of stress.	It is a permanent deformation which exists even after the removal of stress.
2	The elastic deformation is the beginning of the progress of deformation.	The plastic deformation takes place after the elastic deformation has stopped.
3	It takes place over a short range of stress-strain curve.	It takes place over a wide range of stress-strain curve.

Critical Resolved Shear Stress- The slip in crystalline materials results from the action of a shear stress on the slip plane.



Consider a single crystal subjected to an axial load as shown in the above figure.

Let P = Load applied along the axis of the single crystal

A = Cross-sectional area of the crystal

As a result of axial load, let the slip takes place along the shaded plane as shown in the figure.

Now let α = Angle, which the slip direction makes with the tensile axis (i.e., in the direction of load)

B = Angle which the slip plane makes with the normal to the tensile axis.

We know that component of applied load acting in the slip direction = P cos α

Area of the slip plane = A/ cos β

So, resolved shear stress,

$$\tau = \frac{Load}{Area} = \frac{P\cos\alpha}{A/\cos\beta} = \frac{p}{A}\cos\alpha\cos\beta$$

$$= \sigma\cos\alpha\cos\beta$$

Where σ is the applied tensile stress (equal to P/A)

The stress required to initiate slip in a pure and perfect single crystal is called critical resolved shear stress

So, critical resolved shear stress,

$\tau_{cr} = \sigma \cos \alpha \cos \beta$

This equation is popularly known as Schmid's Law, and the term 'cos α cos β' as the Schmid's factor.

a) Ifthe slip direction is at right angle to the tensile axis (i.e., $\alpha = 90^o$), then $\cos \alpha = \cos 90^o = 0$. Therefore $\tau_{cr} = 0$
b) If the slip plane is parallel to the tensile axis (i.e., $\beta = 90^o$) then $\cos \beta = \cos 90^o = 0$. Therefore $\tau_{cr} = 0$
c) If both the slip plane and slip directions are inclined at an angle of 45^o to the tensile axis, then

$$\tau_{cr} = \sigma \cos 45^o \cos 45^o = \sigma \times \frac{1}{\sqrt{2}} \times \frac{1}{\sqrt{2}} = \frac{\sigma}{2}$$

If many slip planes and slip directions of the same type are possible in a crystal, then the active plane is the one on which the critical resolved shear stress is reached first as the specimen is subjected to increasing applied stress.

Deformation of polycrystalline Materials:

The deformation of a polycrystalline material is different than that of the single crystalline material. It is due to the reason that the deformation of a polycrystalline material takes place due to movement of dislocations. It has been observed that these dislocations move under the action of applied load. If the movement of dislocations dose not takes place, the stress required to produce deformation will increase.

In a crystalline material, the grains have random orientations. On the application of a force, the grains which have their slip planes parallel to the direction of the force, deform more easily. But their deformation is restricted by the adjacent grains having different orientation. As a result of this, the grains develop a complex state of stresses. The deformation of a polycrystalline material is also affected by the presence of grain boundaries. These areas act as physical barriers to the movement of dislocations. This results in piling up of dislocations at grain boundaries, which offer resistance to slipping. Thus a high stress is required to cause plastic deformation.

The greater the number of grain boundaries in a polycrystalline material, higher will be the resistance offered to the dislocation movement. Thus greater will be the stress required to produce plastic deformation. It is due to this fact, that a fine grained material possesses higher tensile strength and better mechanical properties as compared to a coarse grained material. The smaller the grains, closer are the grain boundaries and hence the strength is greater. The effect of grain size on the yield stress (σ_y) in steel can be represent by

$$\sigma_y = \sigma_i + \frac{k}{\sqrt{d}}$$

Where d = Mean grain diameter

K = A constant

σ_i = A measure of resistance of the material to dislocation motion due to effects other than grain boundaries.

The above relation is known as Petch equation.

Chapter – 3

STRENGTHENING MECHANISM

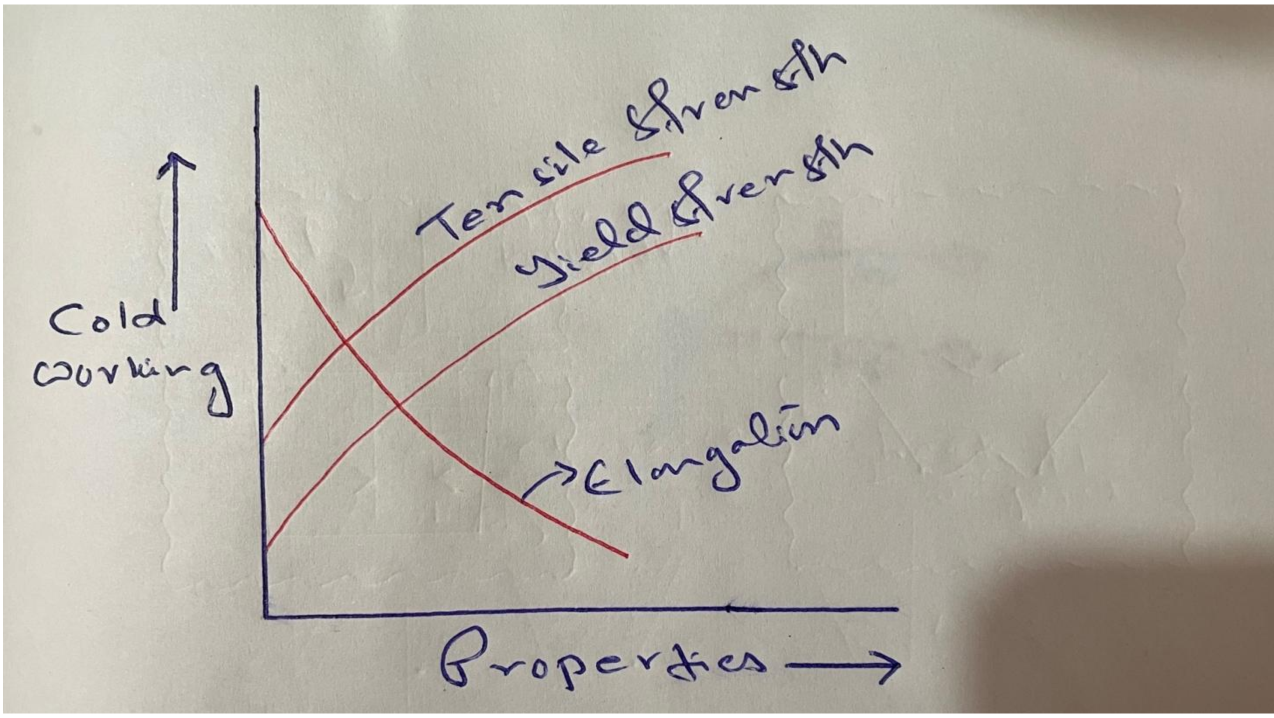
Martensite Strengthening :

The transformation of austenite to martensite is a diffusion less shear type due to sudden quenching from an elevated temperature. It is one of the most common methods of strengthening engineering materials. Although martensite transformation occurs in a numbers of metallurgical systems, only the alloy based on iron and carbon show such a pronounced effect of strengthening. The high strength of martensite is due to the very strong barrier to the dislocation motion in this structure. High strength is partly due to effective barrier to slip provided by the fine twin structure and partly due to the high dislocation density in the martensite. The second important contribution to the strengthening of martensite comes from the carbon atoms. There is a strong binding set up between dislocations and the carbon atoms on transformation. This restricts the motion of dislocations. The strengthening due to carbon atom and dislocation interaction increases approximately with carbon content.

Strain hardening :

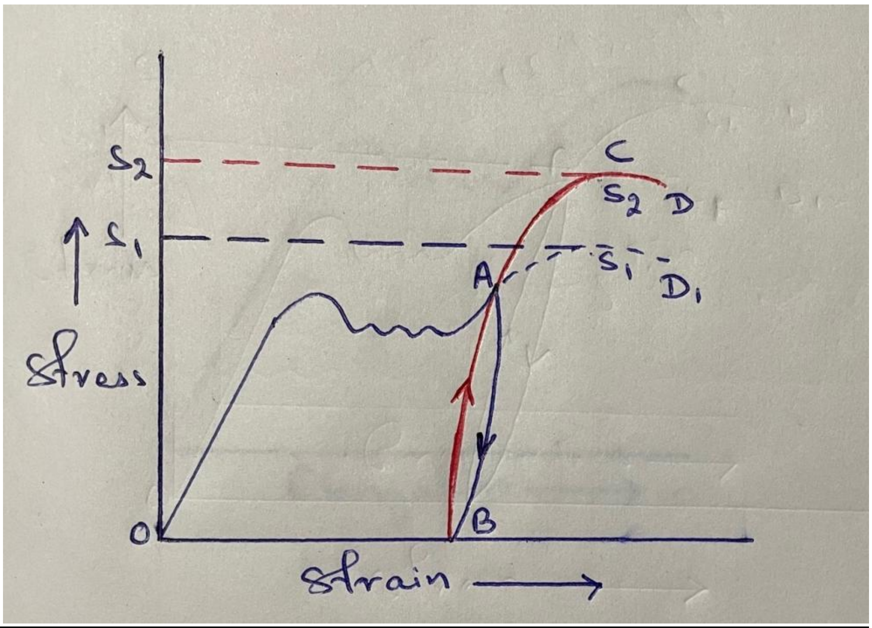
Strain hardening is a phenomenon which results in an increase in hardness and strength of a metal subjected to plastic deformation at temperature lower than the recrystallisation temperature. Strain hardening is an important industrial process that is used to harden metals or alloys that do not respond to heat treatment. The rate of strain hardening can be obtained from the slope of the flow curve.

Generally, the rate of strain hardening is lower for HCP metal than for cubic metals. The strain hardening rate depends heavily on temperature of working and alloy additions.



The above diagram shows typical variation of strength and ductility with increasing amount of cold working. The strain hardening is due to regeneration and multiplication of existing dislocation by Frank-Read mechanism. As the dislocation density increases, strength automatically goes up. Finally the yield strength becomes equal to the ultimate strength.

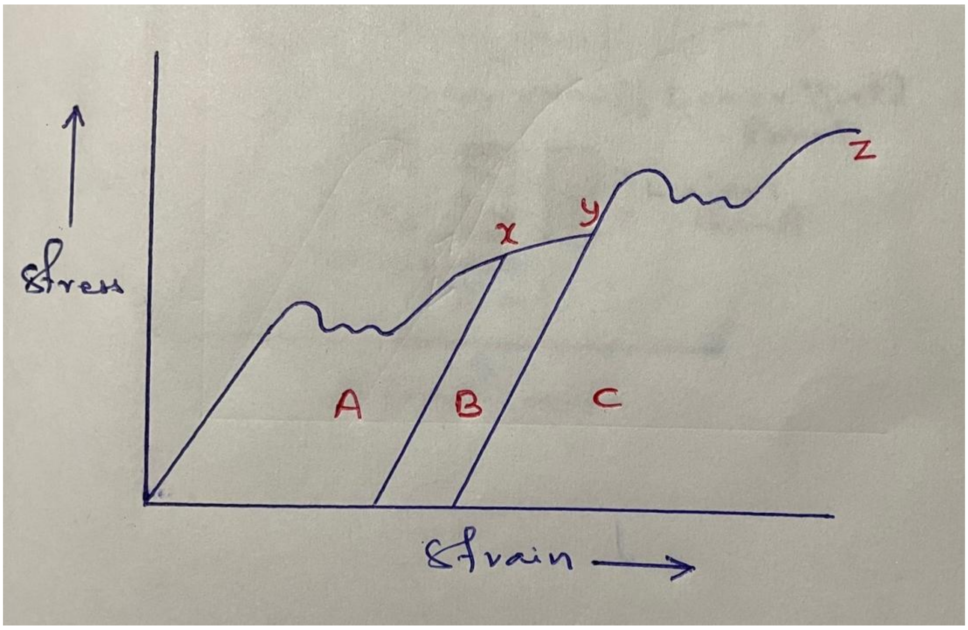
Principles of strain hardening :



When loaded, the strain increases with stress and the curve reaches the point "A" in the plastic range. If at this stage, the specimen is unloaded, the strain does not recovered along the original path "OA", but moves along "AB". If the specimen is reloaded immediately, the curve again rises from B to A, but through another path and reaches point "C", after which it will follow the curvature upto "D", if loading continued. If the specimen would not unload, after point A the curve would have followed the path "AD_1". A comparison of paths "ACD" and "AD_1" shows that the cold working has increased the yield strength and ultimate tensile strength of the metal.

Strain Ageing:

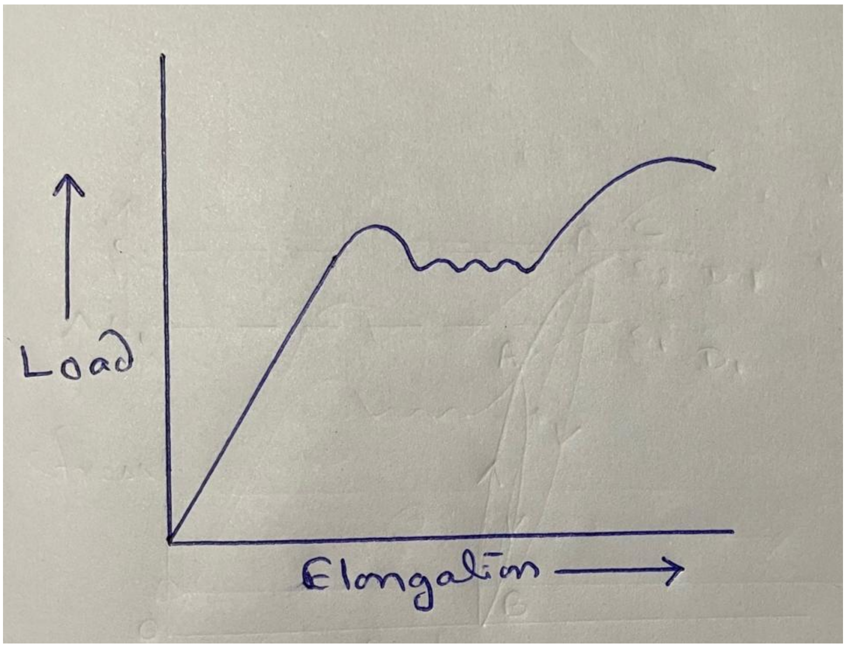
Strain ageing is a type of behaviour in which the strength of a metal is increased and the ductility is decreased on heating at a relatively low temperature after cold working. Strain ageing is associated with the yield point phenomenon. This behaviour can be illustrated by considering the diagram given below. The region "A" shows the stress-strain curve for a low carbon steel strained plastically beyond the yield point, a sharp yield point can be noticed.



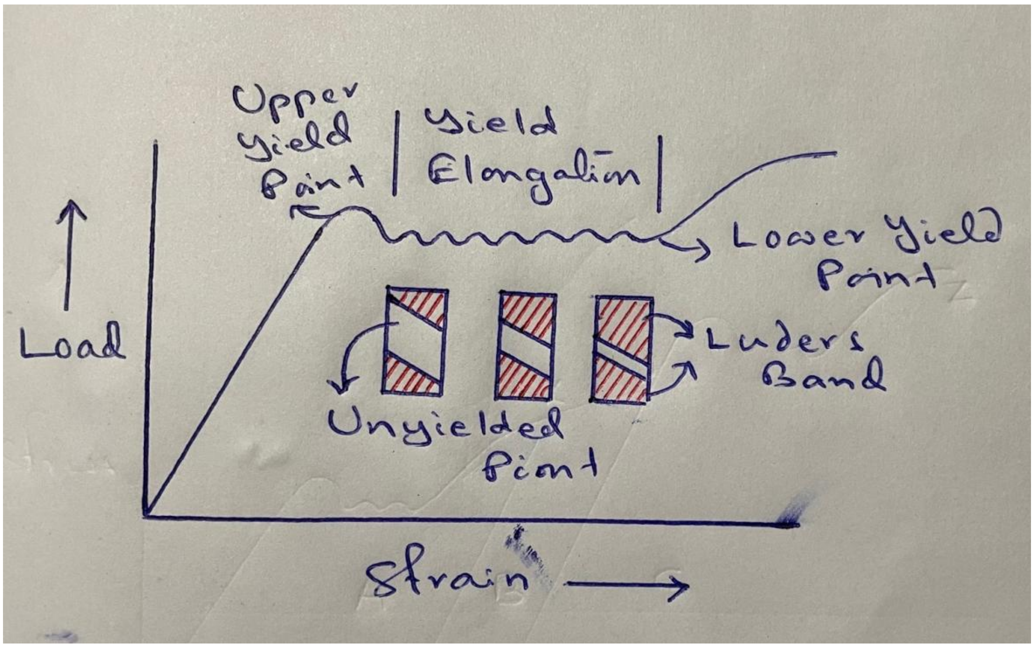
The specimen is then unloaded and reloaded without any delay or any heat treatment. On reloading the yield point does not occur, since the dislocations are away from the atmosphere of carbon and nitrogen atoms. After stage "B" (above Y), if the specimen is unloaded and then it is reloaded after ageing(400^{o}K) for several days, the yield point reappears. The yield point will be increased by the ageing treatment. This phenomenon is known as strain ageing. The appearance of yield point is due to the diffusion of carbon and nitrogen atoms to the dislocations during the ageing period to form new atmosphere for dislocation anchoring. Nitrogen plays a more important role in strain ageing of iron than carbon because it has a higher solubility and diffusion co-efficient.

Yield point phenomenon :

Many metals particularly low carbon steel shows a localized heterogeneous type of transition from elastic to plastic deformation which produces a yield point in the stress-strain curve.



The above figure shows a flow curve for a metal with a sharp yield point. In the figure load increases steadily with elastic strain, drops suddenly, fluctuated about some approximately constant value of load and then rises with further strain. The load at which the sudden drop occurs is called the upper yield point. The constant load is called as the lower yield point and the elongation which occurs at constant load is called the yield point elongation. At the upper yield point, a discrete band of deformed metal appears. As soon as the band forms, simultaneously load drops to lower yield point. The band then propagates along the length of the specimen called yield point elongation. The bands are formed at an angle of 45^o to the tensile axis. These bands are called luder band.



When several luder bands are formed, the flow curve during the yield point elongation will be irregular, each jog corresponding to the formation of a new luder band. After the luder bands have propagated to cover the entire length of the specimen, the flow stress will increase with strain in the usual manner. This marks the end of yield point elongation.

Hall-Petch relation:

A general relationship between yield stress and grain size was proposed by Hall and Petch.

$$\boldsymbol{\sigma_o = \sigma_i + KD^{-1/2}}$$

Where, σ_o = The yield stress

σ_i = The frictional stress

K = A constant, the locking parameter

D = Grain diameter

Bauschinger Effect :

During strain hardening of single crystal it was shown that, generally lower stress is required to reverse the direction of slip on a certain slip plane than to continue slip in the original direction. The directionality of strain hardening is called as Bauschinger's effect.

Consider a metal specimen subjected to a gradually increasing tensile load. If we measure the extensions of the specimen with corresponding loads and draw a graph with strain along horizontal axis and stress along vertical axis, we should obtain a curve as shown in the above figure. The point 'A' on the curve represents the yield stress of the material loaded in tension. Similarly, the point 'B' represents the yield stress of the material when it is loaded in compression. Yield stress at 'A' and 'B' will be equal in magnitude but opposite in sign. Now consider another specimen of the same material. Now if we apply gradual tensile load, which produces higher stress than the yield stress, we shall obtain the curve upto point 'C', which is higher than the yield point 'A'.

Now if the load is removed gradually, the curve will follow the path 'CD' where the specimen will develop a permanent strain 'OD'. If now a compressive stress is applied, the plastic flow will begin at the stress corresponding to point 'E', which is appreciably lower than original compressive yield stress of the material, corresponding to point 'B'. While the yield stress in tension was increased by strain hardening from 'A' to 'C', the yield stress in compression is decreased from 'B' to 'E'. This is the Bauschinger's effect. Bauschinger's effect is reversible in nature.

Chapter – 4

MECHANICAL WORKING OF METAL

Mechanical working of metal is simple plastic deformation performed to change the dimension and properties of material. In general metals are mechanically worked for three reasons.

(i) To produce a particular shape which one can not get by other means.
(ii) To break down the cast structure and improves the properties of metal.
(iii) To get the desired dimension and surface finish.

Mechanical working of metals are of two type.

(i) Hot working
(ii) Cold working

Plastic deformation of metal above the recrystalisation temperature but below the melting point is called as hot working where as working below the recrystalisation temperature is called as cold working of the material.

Hot working

It is carried out above the recrystalisation temp but below the melting point. Increasing of working temperature decreases the stress required for deformation and increases the amount of deformation. So hot working is carried out when generally large deformation is needed. In not working composition irregularities are minimized and non metallic impurities are broken into small relatively weak fragments which are uniformly distributed. Care should be taken regarding the starting and ending temp of working, as too high temperature may lead to phase change and too low temp may results in excessive work hardening. Surface finish of hot worked metal is not nearly as good as with cold working because of oxidation and scaling. Defects like blow holes, internal cracks get welded up during hot working.

Advantages of Hot working

(i) Metals can be shaped into useful objects.
(ii) It improves the properties of metal as compared to those in cast condition.

(iii) Mechanical properties like elongation and izod value are improved.
(iv) It promotes the uniformity of the material by the dissolution of alloying elements.

Disadvantages of hot working

(i) Oxidation of surface take place
(ii) Material loss takes place due to scaling of the surface.
(iii) Decarburisation of the surface reduces the percentage of carbon in steel.

Cold working

Cold working of metal is carried out below its recrystalisation temperature. But for high melting point metal like tungsten a cold working is carried out at little higher temperature. With the increase of amount of deformation stress required will increase. So the amount of deformation is limited one compared to hot working. Good surface finish is obtained by cold working. Cold working is carried out up to the temperature depending upon the strain hardening we desires. Excessive cold working leads to the formation and even propagation of cracks in the metal. The loss of ductility during cold working has a useful side effect in machining.

Advantages of cold working

(i) It is widely applied as a forming process for finished metal products.
(ii) A better surface finished is achieved.
(iii) By this we can get the dimensional accuracy.
(iv) It increases hardness of metal.

Disadvantages

(i) It increases residual stresses.
(ii) It decreases ductility of metal.
(iii) Strain hardening occurs.
(iv) Metal surface must be cleaned before cold working .
(v) Higher forces are required for deformation than those in hot working so for deformation more powerful and heavier equipments are required and the maintenance cost of equipments are large.

Chapter – 5

RECOVERY RECRYSTALLISATION AND GRAIN GROWTH

Due to repeated cold working the hardness increases, while the ductility and plasticity decreases. Also the no. of dislocation increases largely. So it induces large residual stresses in the metal. In wire drawing process while drawing the metal wire through a die the hardness of material increases and resistance to further deformation also increases and a stage will come when fracture will occur. From this stage if it is necessary to deform it further the metal should return to a condition approximately prior to the deformation. This can be achieved by the process known as annealing, which involves raising the temperature of the object so that the system more closely approaches the equilibrium and the properties of metal prior to deformation are gradually recovered. The effect of annealing on the properties of material is divided into three stages,

(i) Recovery or stress relief
(ii) Re-crystallization
(iii) Grain growth

Recovery :-

Recovery which is referred as a stress relief anneal is an important method for releasing the internal stresses in rolled, drawn and extruded objects without lowering the strength of cold worked products. Recovery minimises the distortion produced by residual stress as in cast and welded objects. Recovery involves heating the object to about 0.1 T_m where T_m is the melting point of the metal. Recovery proceeds by the movement of dislocation due to vacancy diffusion. This constitutes a boundary at which the atomic plane meets.

Recrystallisation:-

Recrystallisation proceeds at a higher temperature than recovery. Entirely new strain free crystals are formed. Recrystallisation temp is one at which the first tiny new grain appears, distorted and elongated grains disappears and the new crystal generally appears at the most drastically deformed portion of the grain, usually at the boundaries and at slip areas. Recrystallisation requires diffusion of atoms in a material. So that temperature required for recrystallisation depends on the forces holding the atoms together. During the recrystalisation the energy of the whole crystal increases. When the temp is reached at which the localised areas have sufficient energy to overcome the rigidity of the distructed lattice, they form nuclei for the formation of new strain free grains.

Recrystalisation temp depends on the type of metal used. For pure metal it is about 0.3 T_m and for alloy it is 0.5 T_m. Where T_m is the melting point of metal. The greater the degree of cold working, the lower the recrystalisation temperature .

Grain Growth:-

Recrystalisation is followed by grain growth. Grain growth proceeds by the enlargement of the nuclei formed during recrystalization stage by the joining of some new grains and it proceeds by the increase of temperature or by keeping the material at a particular temp for a longer time. It also proceeds by the enlargement of some old grains. Once the new equiaxied grains have been formed during recrystalization, if now the temp is raised these new grains will grow in size at the expense of their neighbouring grains. Some grain disappears upon absorption by the large grain.

Grain growth associates with loss in strength, hardness and gain in ductility.

The extent of grain growth depends largely on

(a) As the temp of annealing increases grain size increases.
(b) Grain grows rapidly during the initial period of heating but the rate of growth slows down firstly with the proceed of time.
(c) Slow heating will form new nuclei, favours grain growth and results in coarse grains.
(d) Heavy prior deformation results in the production of large amount of small grains and light deformation results in the formation of large grains but in smaller number.
(e) Alloying elements like Ni limits the grain growth during annealing.

Chapter – 6

ROLLING

Steel is generally casted in the form ingots are processed in rolling mill for change of shape. For this purpose a pair of rollers made up of steel or cast iron are employed. Hot rolling is used to convert ingots into smaller sections. But cold rolling is used for sheet or plate to make it more thinner. The gap between the rollers is smaller than that of the cross section of ingot. The work piece is entered into the gap and as it passed through the roles its cross section being progressively decreased. The decrease is generally 10-30%. So a number of this type operation is needed. The amount of deformation that can be achieved by a pass between a pair of roles is determined by the angle of bite. But the angle of bite depends on the strength of the material and its temperature. Too small a deformation per pass results in excessive cost. Depending on the working temperature it is divided into two types.

(i) Hot rolling mills
(ii) Cold rolling mills

Hot Rolling:-

In this case rolling of ingot is done at high temperature. The first hot working operation for most steel products is done on the primary roughing mill. These are generally two-high reversing mill with 0.6m to 1.4 m diameter rolls. The objective of this operation is to breakdown of the cast ingot into blooms or slabs for consequent finishing into bars, plates or sheets. Heavy scale removal of ingot occurs while rolling on edges. But the thickness is reduced by 90^o turn and rolling on flat surface. To maintain the desired width and preserve the edges, the ingot is turn 90^o on intermediate passes. A reversing primary mill has a relatively low production rate, since the work piece may be passed back and forth and turns from 10 to 20 times. Where high production rates are of prime concern, edging passes may be eliminated by using a universal mill. This type of mill is essentially like two rolling mills, one with two large diameter rolls and the other with vertical roles, which control the width at the same time thickness is also reduced. The production of slab from cast ingot by hot rolling can be eliminated by using continuous casting to produce slab directly from the molten metal.

In general strips and sheets are produced by a continuous hot strip mill. If the sheet to be produced is wider than the width of the slab then the first stand in a roughing train is a broad side mill, in which the width of the slab is increased by cross rolling. The roughing mills usually are equipped with vertical edging roll to control the width of strip. High pressure water jets are sprayed on the strip to remove scale. In hot rolling, steel slabs are initially heated to around 1100^{o}C and in last finishing stand it decreases upto 700^{o}C.

Cold Rolling:-

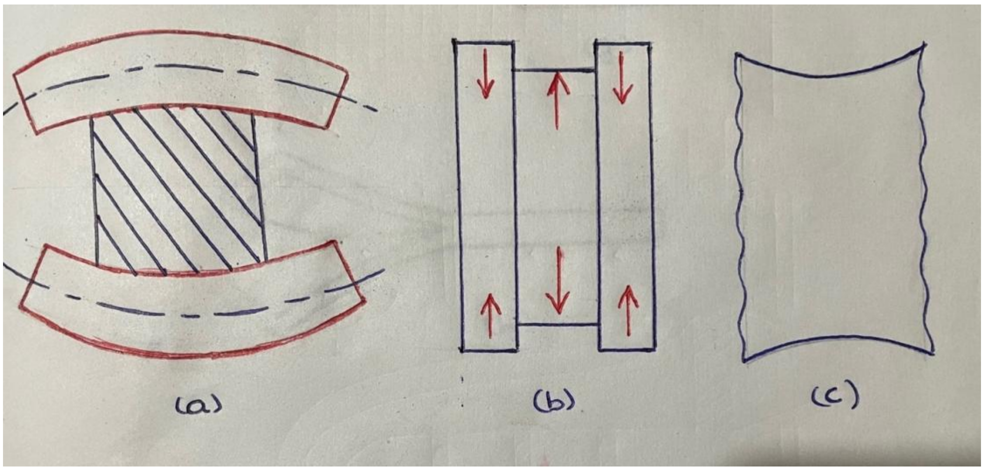
Cold rolling is used to produce sheet and strip with superior surface finish compared to hot rolled sheet. The strain hardening resulting from cold reduction may be use to give increased strength. In case of certain copper alloys, it is cold rolled directly from the cast stage. High speed four-high tandem mill with three to five stands are used for the cold rolling of steel sheet, aluminium and copper alloys. It is generally of reversing type. Continuous mill has high capacity and five stand continuous mills can run at a very high speed. However this type of equipment requires a large capital investment. Four high single stand reversing mill with front and back tension are a more versatile installation.

The total reduction achieved by cold rolling generally varies from 50-90 %. For this reduction it is desirable to distribute the work as uniformly as possible over the various passes without falling very much below the maximum reduction for each pass. In order to get better surface finish generally lowest percentage of reduction is taken in last pass. One rotational procedure for developing cold rolling schedule is to adjust the reduction in each pass, so as to produce a constant rolling load.

Rolling Defects:

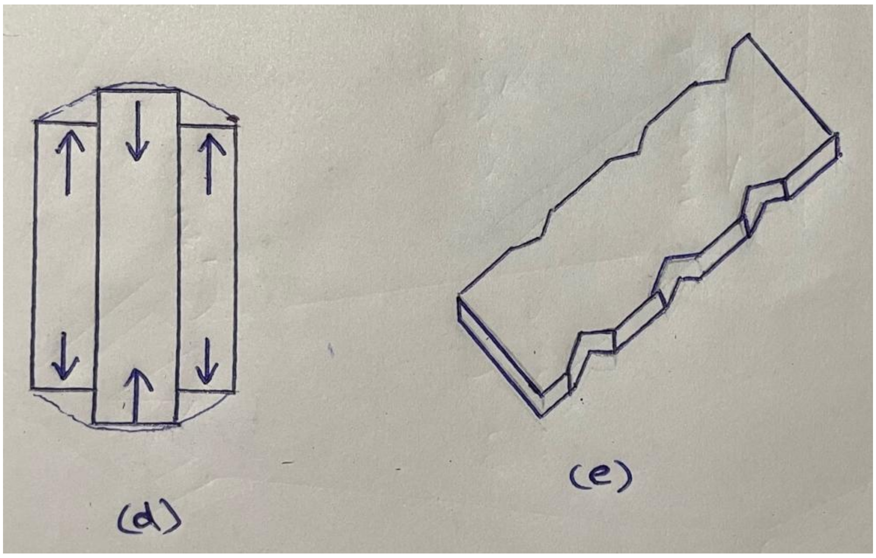
1) A number of defects during rolling can arise depending on the interaction of the plastically deformed work piece with the elastically deforming roles of rolling mill. Under the influence of the high rolling forces the roles flattens and bends. Because of mills spring the thickness of the sheet exiting from the rolling mill is greater than the original role gap set. Thus for a given material and set of rolling condition, there will be a minimum thickness below which the sheet can not be reduced further.

2)



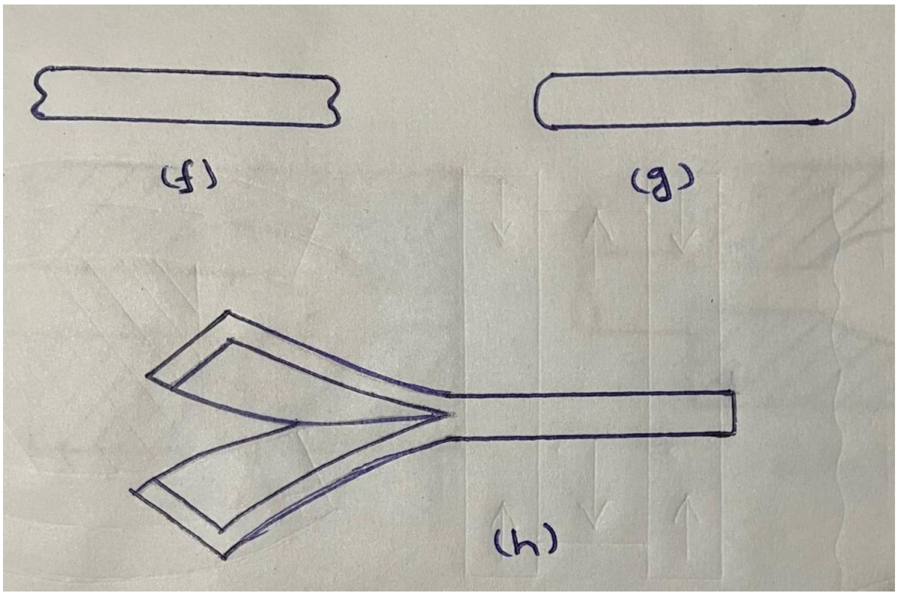
The role gap must be perfectly parallel during rolling otherwise the edges of the sheet will decrease more in thickness than the centre and since the volume and width remains constant, the edges of the sheet elongates more than the centre and the sheet bows. If the roles deflects as in fig(a) the edges of the sheet will be elongated to a greater extent in longitudinal direction than the centre i.e., it has long edges . If the edges are free to move relative to the centre, the situation would be as in fig(b). The result is that the central portion of the sheet is straight in tension and the edges are compressed in the rolling direction. The usual result is a wavy edge or edge buckle as in fig(c).To avoid this, when the roles deflects they should provide a parallel gap to the work piece.

3)



As the work piece passes through the role, all element across the width experiences some tendency to expand laterally. Because the thickness decreases in the centre of sheet all goes into increasing the length while part of the thickness decreases at the edges goes into lateral spread, the sheet may developed a slight rounding at its ends as in fig(d). Because there is continuity between the edges and centre, the edges of the sheet are strained in tension, a condition which leads to edge cracking as in fig(e).

4)



Edge cracking can also be caused by inhomogeneous deformation in the thickness direction. When the rolling condition are such that only the surface of work piece is deformed into the shape as in fig(f). This type of cracking is experienced in initial ingot break down in hot rolling where it was observed that edge deforms like that in fig(f) . This occurs with heavy reduction, so that the deformation extends through the thickness of the sheet, the centre tend to expand laterally more than the surfaces to produce a barrelled edges similar to those found in upsetting a cylinder as in fig(g). The secondary tensile stresses created by the barrelling are the ready cause of edge cracking. Edge cracking is minimised in commercial rolling practice by employing vertical edge roles, which keeps the edges straight. Since most laboratory mill do not have edge roles, as simple but time consuming procedure to prevent edge cracking is to machine the edges square after each pass. But the better procedure is to equip the mill with edge restraining bars.

Roll Passes:-

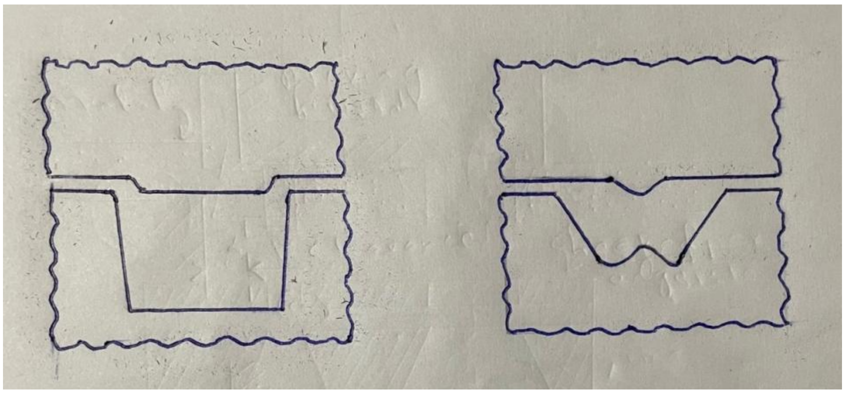
The final rolled products such as plates, sheets, rounds and sections are obtained in a number of passes starting from billets or slabs. For rolling the flat products, plain cylindrical rolls are used but for sections, grooved rolls are used. The type of grooving done is decided by the final section desired.

The roll pass sequence can be broadly categorised into three types.

1. Break down passes:- These are used for reducing the cross sectional area, nearer to what is desired . These would be the first to be present in the sequence.
2. Roughing passes: - In these passes also the cross section gets reduced, but along with it the shape of the rolled materials comes nearer to the final shape.
3. Finishing passes:- These are the final passes which gives the required shape of the rolled section.

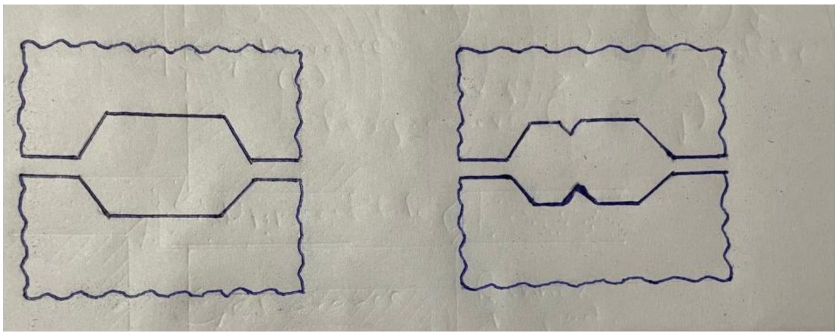
Closed Pass:-

A closed pass is one where the complete shape of the pass is on one roll.



Open Pass:-

The open pass is one where the part of the pass is present in each of the two rolls.



Both in closed and open pass the deformation is not uniform and the roll wear poses a serious problem.

Box Pass:-

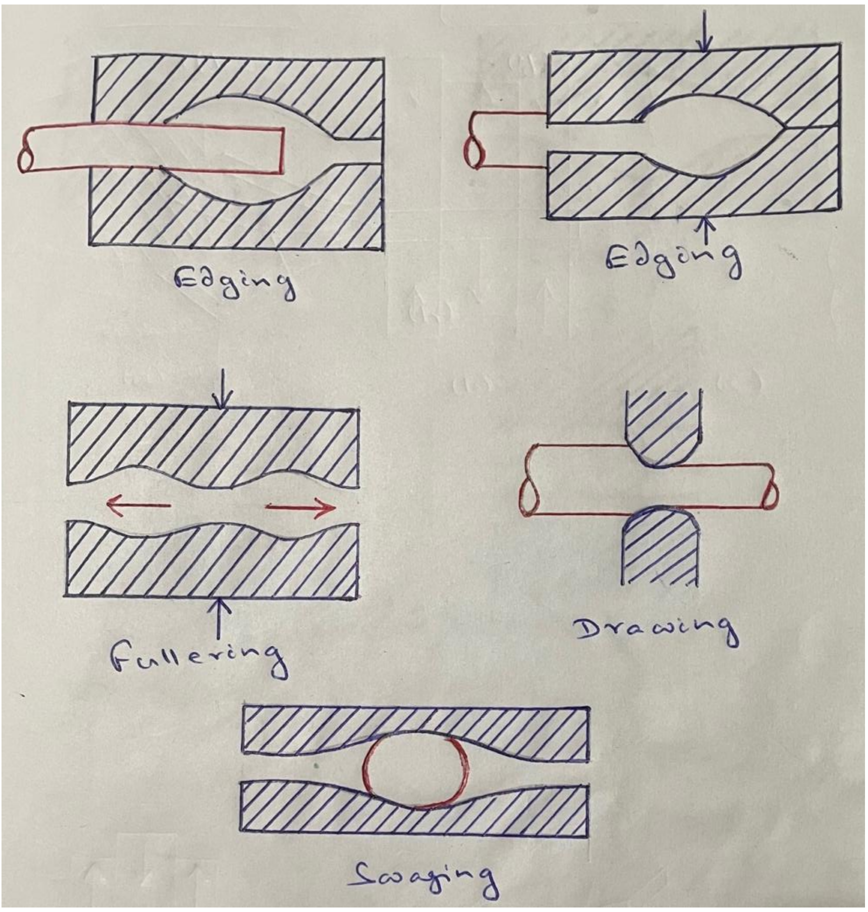
Box passes are generally used for initial, medium and large sections of blooming and billet mills. The rolls of box pass series are stronger. They can be used for different sizes by screwing down the top roll. They provide for effective descaling. However the main problems with these are smaller elongation upto 1.05 to1.15 and inaccurate square produced because the side spread is not controlled. They are generally used for larger products.

Chapter - 7

Forging

Forging is the working of metal into a useful shape by hammering or pressing. It is the oldest method of metal working process executed by blacksmith. Now a days there is a wide verity of forging machinery which is capable of making parts ranging in size from a bolt to a turbine rotter or an entire aeroplane wing.

Different forging process-

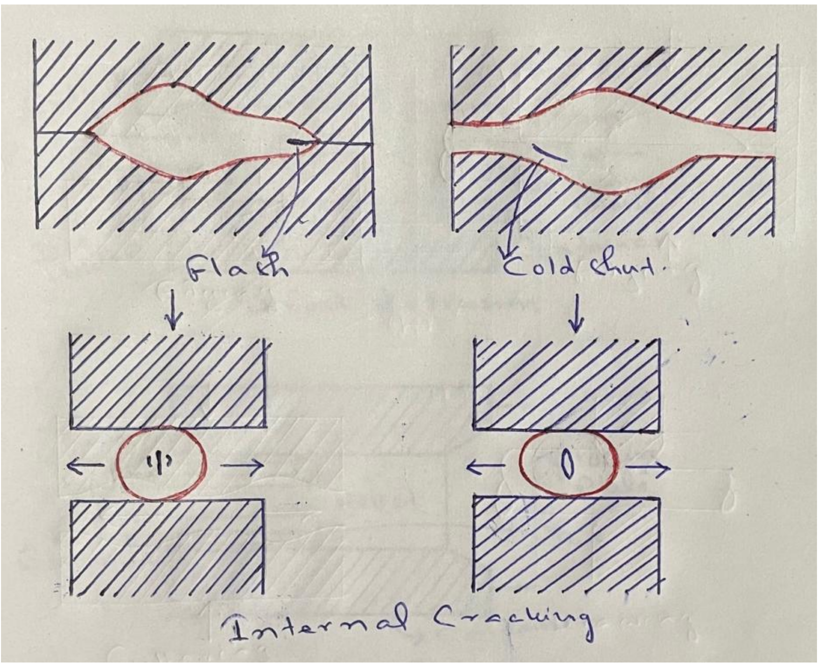


Most forging operations are carried out in hot, although certain metals may be cooled forged. Two major classes of equipment are used for forging operation. The forging hammer or drop hammer, delivers rapid impact blows to the surface of metal, while the forging press subjects the metal to a slow speed compressive force.

The two broad categories of forging processes are open dies forging & closed dies forging. Open dies forging is carried out between flat dies or dies of very simple shape. The process is used mostly for large objects. In closed die forging the work piece is deform between the two die halves, which carries the impression of desired final shape. The work piece is deformed under high pressure in a closed cavity and thus precision forging with closed dimensional tolerances can be produced.

The simplest open die forging is the upsetting of cylindrical billet between two flat dies. The metal flows laterally between the advancing die surfaces. Edging dies are used to shape the ends of the bar and to gather the metal as in fig (a) & (b), the metal is confined by the die from flowing in the horizontal direction but it is free to flow laterally to fill the die. Fullering is used to reduce the cross sectional area of a portion of the job. The metal flow is outward or away from the centre of fullering die. The reduction in cross section of the work with concurrent increase in length is called drawing down or drawing out. If the drawing down operation is carried out with concave dies so as to produce a bar of smaller diameter it is called swaging. Other operations which can be achieved by forging are bending, twisting, extrusion, punching etc.

Forging Defects :



If the deformation during forging is limited to the surface layer, the ingot structure will not be broken down at the interior of the forging. Incomplete forging penetration can readily be detected by etching a cross section of the forging.

Surface cracking can occur as a result of excessive working of the surface at a too low temp or as a result of hot shortness that is the presence of high sulphur in steel or nickel.

Cracking at the flash of closed die forging is another surface defect. This type of cracking is more common when the flash is thinner in related to the thickness of metal. Flash cracking can be avoided by increasing the flash thickness.

Another common surface defect in closed die forging is the cold shut or fold. A cold shut is a discontinuity produced when two surfaces of metal fold against each other without welding completely. This can happen when metal flows to the die cavity that has already been filled or partly filled.

Lose scale that accumulated in deep region of die forms scale pockets and cause under fill. Incomplete descaling of the work piece results in forged-in-scale on the finished part.

Secondary tensile stresses can developed during forging and cracking can thus be produced. Internal cracks can develop during the upsetting of a cylinder or round as a result of circumferential tensile stress. Proper design of the dies however can minimise this type of cracking.

The deformation produced by forging result in a certain degree of directionality to the microstructure in which second phase or inclusions are oriented parallel to the direction of greatest deformation. When viewed at low magnification this appears as flow lines or fibre structure. The existence of fibre structure is the characteristic of all forgings and is not to be considered as a forging defect.

Properties of forged products

1. Structural properties-

   The structural reliabilities achieved in a forging are better than the other production processes. There are no internal gas pockets or voids that could cause unexpected failure under stress or impact. The structural reliabilities of forging means reduced inspection requirement, uniform response to heat treatment and consistent machinabilities. This quality contributes to faster production rates and lower costs.

2. Consistency -

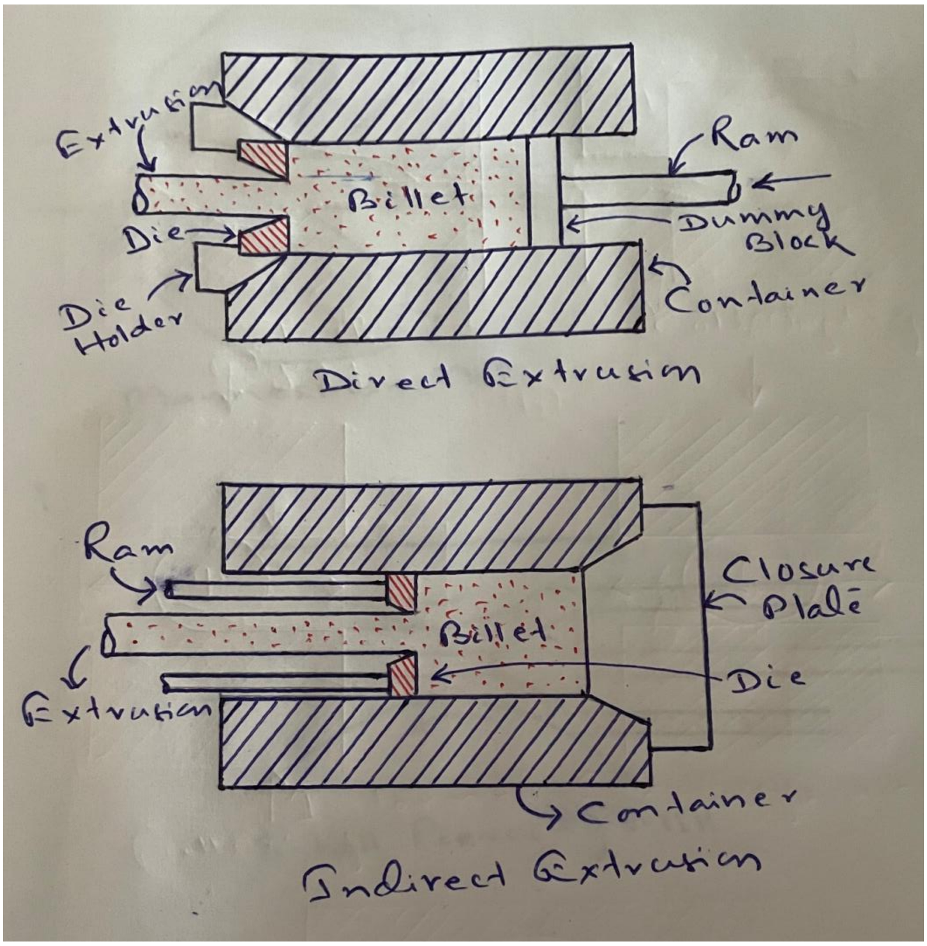
   The consistency of material from one forging to the next and between separate quantities of forgings is extremely high. Forged parts are made through a controlled sequence of production steps rather than random flow of material into the desired shape.
3. Economics -

   Economically forged products are attractive because of their inherent superior reliability, improved tolerance capabilities and the higher efficiency with which forgings can be machined and further processed by automated methods.

   The near absence of internal discontinuities or surface inclusions in forging provides a dependable machining base for metal cutting.

Chapter – 8

EXTRUSION



Extrusion is the process by which a block of metal is reduced is cross section by forcing it to flow through a die orifice under high pressure.

Extrusion processes is used for the production of cylindrical bars and hallow tubes. Due to the large forces required in extrusion most metals are extruded under hot condition. Cold extrusion may be carried out for some metals like aluminium. The reaction of the extrusion billet with the container and die results in high compressive forces which are effective in reducing the cracking of material during extrusion.

Two basic types of extrusion are

(i) Direct extrusion

(ii) Indirect extrusion

For direct extrusion as in fig (a) the metal billet is placed in a container and is driven through the die by the ram. A dummy block or pressure plate is placed at the end of the ram in contact with the billet. But in indirect extrusion as in fig(b) a hollow ram carries the die while the other end of the container is closed with a plate. Frequently for indirect extrusion the ram containing the die is kept stationary and the container with the billet is caused to move.

Because there is no relative motion between the wall of container and the billet, in indirect extrusion the frictional forces are lower and the power required for extrusion is less than that for direct extrusion. But in indirect extrusion the requirement for using a hollow ram limits the load which can be applied.

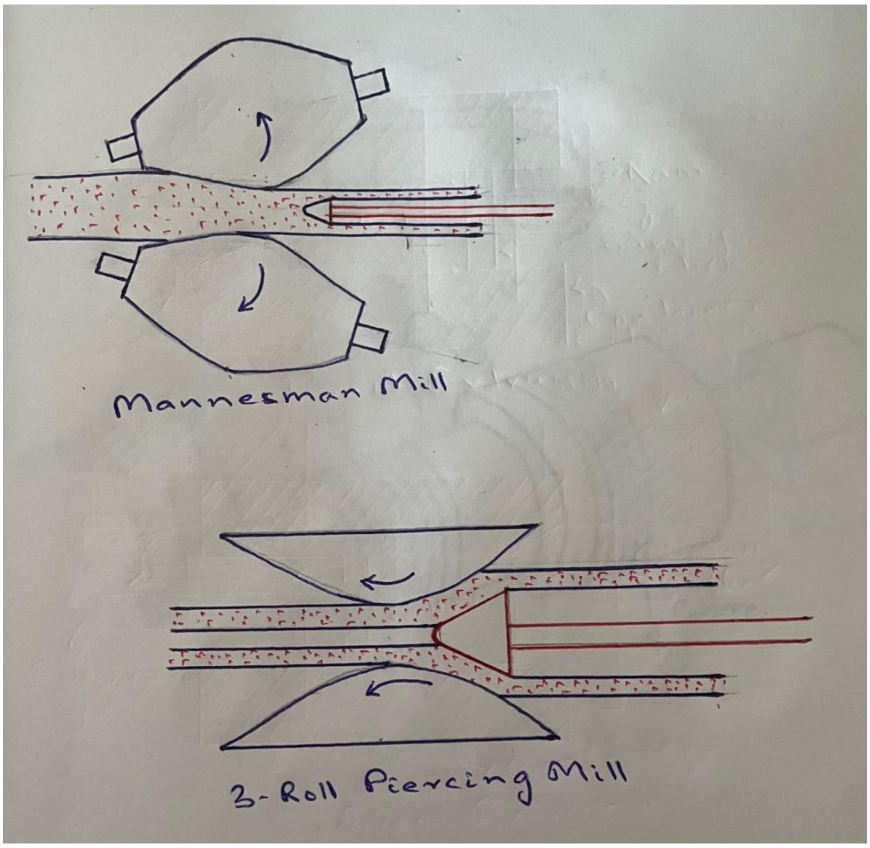
Hollow tubes can be produced by extrusion by attaching a mandrel to the end of the ram. The clearance between the mandrel and the die wall determines the wall thickness of the extruded tube. Tubes are produced either by starting with a hollow billet or by two steps extrusion operation in which a hollow billet is produced by extrusion technique from a solid billet and is used for production of hollow tube .

Extrusion Defects:-

1) Due to the inhomogeneous deformation in the direct extrusion of a billet, the centre of billet moves faster than the periphery. So the dead metal zone extends down along the outer surface of the billet. After about 2/3rd of the billet is extruded the outer surface that is dead metal zone of the billet moves towards the centre and extrudes through the die. Since the surface of billet contains oxide skin it enters into the extruded product. It is considered to be an extrusion defect. If a heated billet is placed in a cold extrusion container the outer layer of the billet will be chilled and the flow resistance of this region will increase. Therefore there will be a greater tendency for the centre part of the billet to extrude before the surface skin and the tendency for formation of extrusion defect is decreased. One way of avoiding the extrusion defect is to carry out the operation only to the point where the surface oxide begins to enter the die and then discard remainder of the billet.

2) Surface cracking is due to badly roughened surface called fir-tree cracking produced by longitudinal tensile stress generated as the extrusion passed through the die. In hot extrusion the most common cause is too high ramming speed. At lower temperature where hot shortness can not occur, transverse cracking is believed to be caused by momentary sticking in the die and the sudden building up of pressure and then break away.
3) A common problem is variation in structure and properties from front to back end of the extrusion in both the longitudinal and transverse directions. Regions of exaggerated grain growth often are found in hot extrusion. The coarseness of the grain increases from surface to centre.

Production of seamless pipes



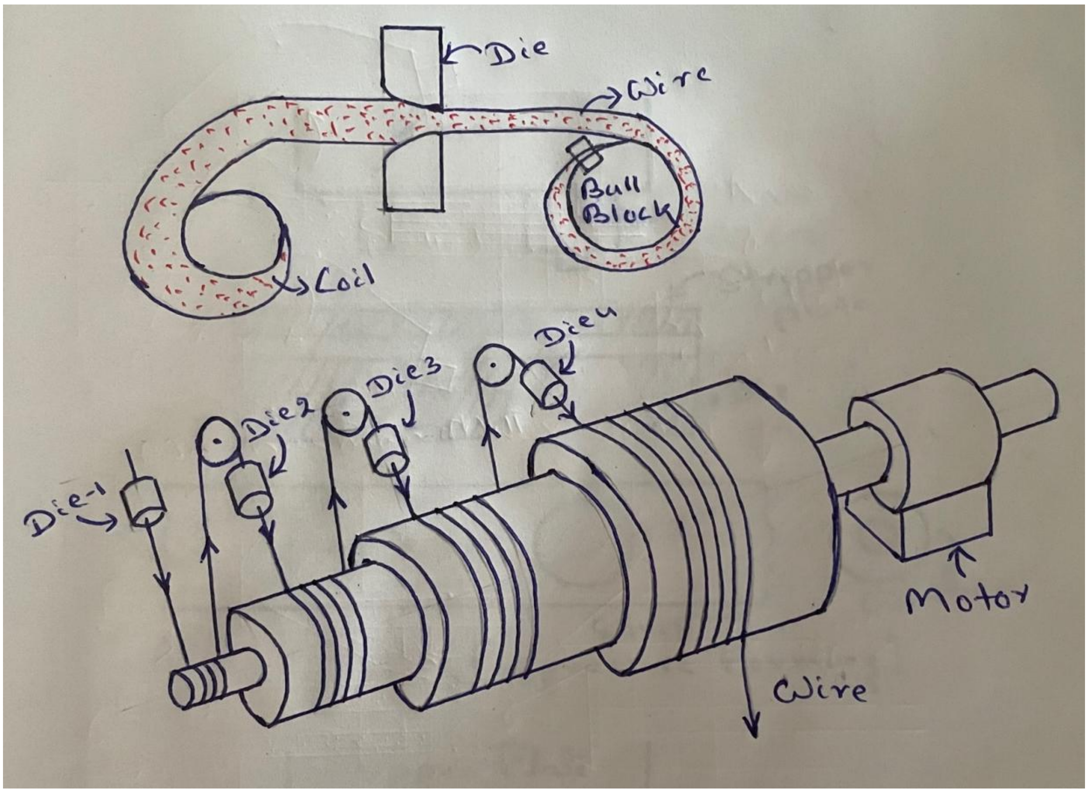
Extrusion is an excellent method of producing seamless pipes and tubes especially for metals which are difficult to work. However there are other well established processes for producing seamless pipes and tubes which generally are more economical than extrusion.

The mannesman mill (fig-a) is used extensively for the rotary piercing of steel and copper billets. The process employs two barrels shaped driven roll which are set at an angle to each other. An axial thrust is developed as well as rotation to the billet. Because of the low arc of contact with the billet, tensile stress developed along the axis of the billet. This assist in opening up the centre of the billet as it flows around the piercing point to create the tube cavity.

The mannesman mill does not provide sufficiently large wall reduction and elongation to produce finished not work tubes. Various types of plug rolling mills are there which drives the tube over a long mandrel containing a plug. The axial elongation which uses the three conical driven rolls has been adopted. This led to the development of 3 roll piercing m/c which produced more concentric tubes with smoother inside and outside surface than the older mannesman design.

Chapter – 9

WIRE DRAWING



Wire drawing usually starts with a coil of hot rolled rod. The rod is first cleaned to remove any scale which would lead to surface defect. Then it is lubricated and the lubrication is done by the use of sulphates or oxalates. These are used in conjunction with a lubricant like soap in dry drawing. In wet drawing the die and the rod are completely enter in an oil lubricant. When the rod diameter is sufficiently small, bull block drawing is usually employed because it allows the generation of long length in a much smaller floor space as in fig(a). As the cross sectional area reduction per drawing pass is rarely greater than 30-35%, many reductions are required to achieve the overall reduction, multiple blocks are used. Since the wire diameter will decrease after each pass the velocity and length of wire will increased proportionately. One way to achieved this is to equip each drawing block with its own electric motor with variable speed control.

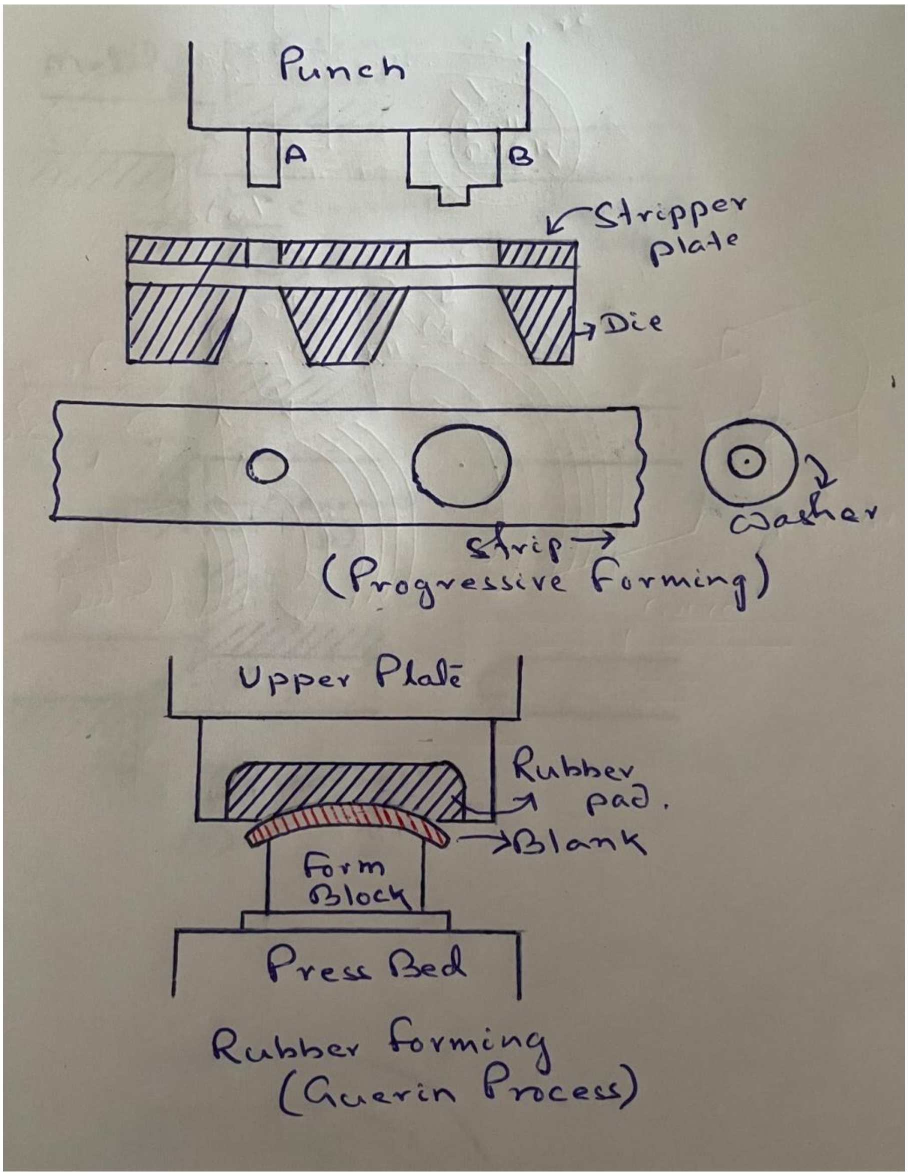
However a more economical design is to use a single electrical motor to drive a series of stepped cones as in fig(b). The diameter of each cone is designed to produce a peripheral speed equivalent to size reduction. When the wire speed and the block peripheral speed does not matches, the wire slides on the block causing friction and evolution of heat . The drawing speed in multi die machine may reach 10m/sec for ferrous drawing and for non ferrous it is 30m/sec.

Depending on the metal and reduction involve intermediate annealing may be required. Steel wire with carbon content greater than 0.25% is given a special patenting treatment. This consists of heating above the upper critical temp and then cooling at a controlled rate.

Chapter – 10

FORMING METHODS

Deep Drawing :



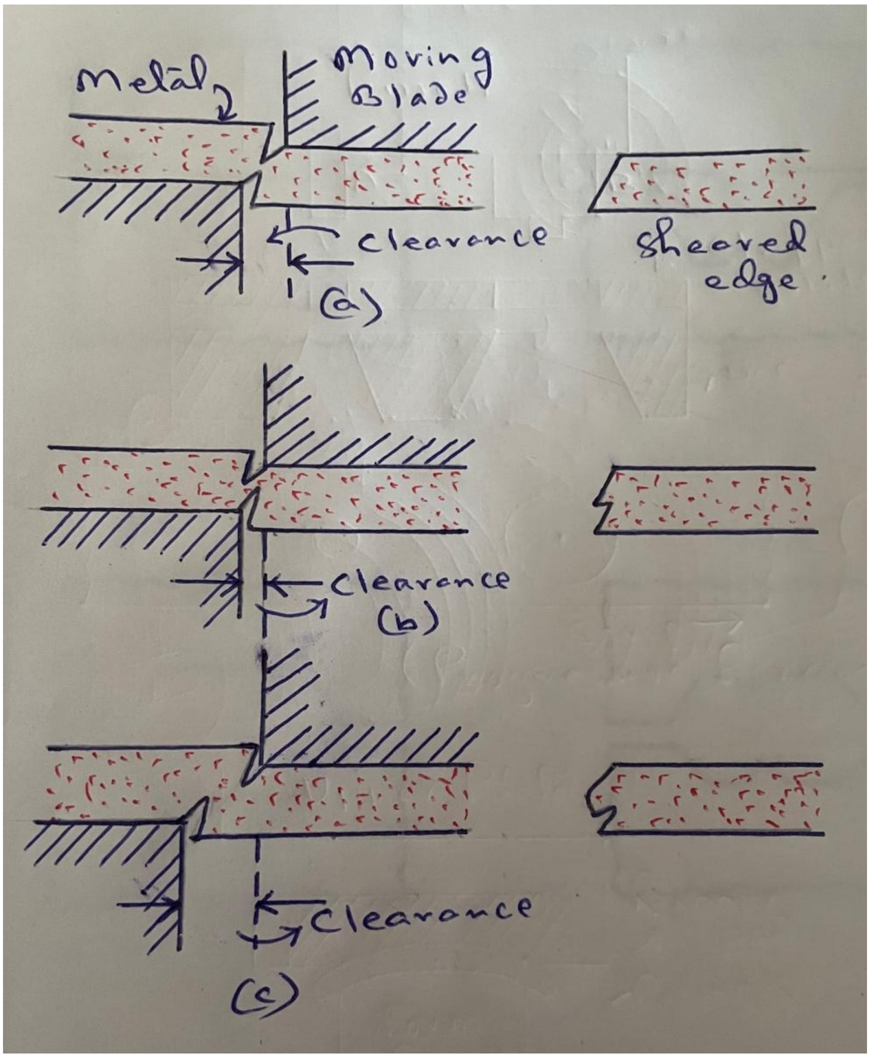
Sheet metal forming is done on a press driven by either mechanical or hydraulic action. In mechanical presses energy is stored in a flywheel and is transferred to the movable slide on the down stroke of the press. Mechanical presses are usually quick acting and have a short stroke, while hydraulic press are slower acting but can apply a longer stroke. The basic tools used with a metal working press are the punch and die.

The punch is the convex tool which meets with the concave die. Generally the punch is the moving element. As accurate alignment between the punch and die usually required it is common practice to mount them permanently in a sub press.

Frequently punches and dies are designed so that successive stages in the forming of the part are carried out in the same die on each stroke of the press, this is known as progressive forming. A simple example is a progressive blanking and piercing die to make a plane and flat washer as in fig(a). As the strip is fed from left to right, the hole for the washer is first punched and then the washer is blanked from the strip. At the same time as the washers is being blanked from the strip, punch A is piercing the hole for the next washer. The stripper plate is used to prevent the metal from separating from die, on the up stroke of the punch. Compound dies are designed to perform several operations on the same die. Because of their complexity the dies are costlier and should operate at a slower speed. The die material depends on the type of operation.

Rubber hydro forming is a modification of convectional punch and die, in which a pad of rubber serves as a die. Rubber forming on a Guerin process consists of a form block (punch) which is fastened to the bed of a single action hydraulic press and a thick blanket of rubber is placed in the upper plate of the press. When a blank is placed over the form block and the rubber forced down on the sheet, the rubber transmits a nearly uniform pressure against the sheet. The verson-wheelon process uses a soft rubber bag subjected to internal fluid pressure. The forming pressure is 4 to 5 times greater than the Guerin process to form more complicated and deeper shapes. Rubber forming is used extensively in air craft industries.

Shearing and Blanking



In shearing, a narrow strip of metal is plastically deformed to the point where it fractures. From surfaces in contact with the blade, fracture propagates inward to provide complete separation. The clearance between the blades is important variable in shearing operation. With the proper clearance the cracks that initiated at the edges of the blade will propagate through the metal and met near the centre of the thickness to provide a clear fracture surface as in fig(a). Insufficient clearance will produced a ragged fracture and also will required more energy to shear the metal than when there is proper clearance as in fig(b). With excessive clearance there is greater distortion of the edge and more energy is required because more metal must plastically deformed before it fracture. Further with too large clearance projections are likely to form on the sheared edge as in fig(c). Because the quality of the sheared edge influences the formability of the part, the control of the clearance is important. Clearances generally range between 2-10% of the thickness of the sheet. The thicker the sheet, the larger the clearance. Force required to shear a metal sheet is the product of length of cut, sheet thickness and the shearing strength of the metal. The maximum punch force to produce sharing is given by -

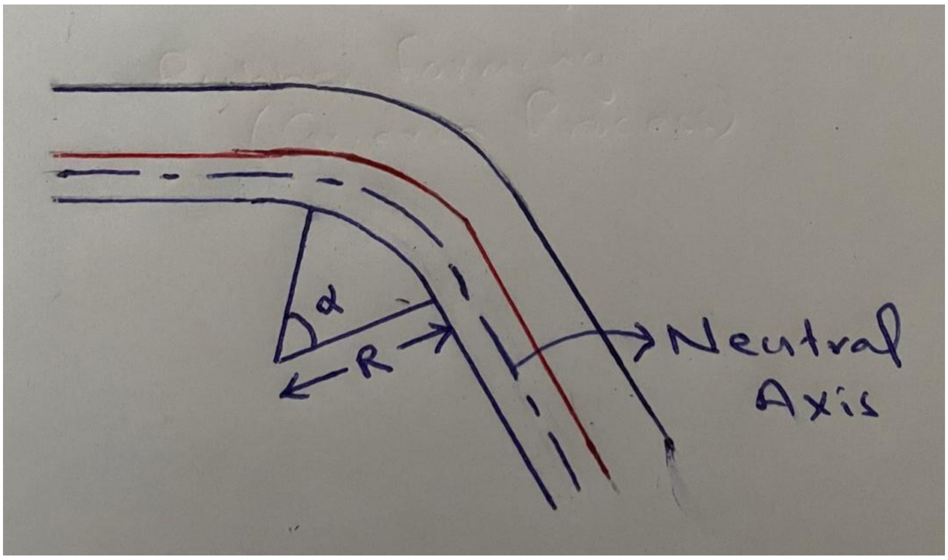
$P_{max} = 0.7\sigma_u hL$

Where, σ_u – Ultimate tensile stress.

h- Thickness of the sheet.

L- Total length of the shared edge.

Fine blanking is a process in which very smooth and square edges are produced in small parts such as gears, levers etc. To achieve this, the sheet metal is tightly locked in place to prevent distortion and is sheared with a very small clearance on the order of 1% at slow speed.



Bending is the process by which a straight length is transform into a curve length. Bending is a part of the deformation in many forming operations. The bend radius is defined as the radius of curvature on the concave or inside surface of the bend. In plastic bending the neutral axis moves closer to the inside surface of the bend as the bending proceeds. Fibres on the outer surface are strained more but the fibers in the inner surface are contracted. A fiber at the mid thickness is stressed and since this is the average fibre it follows that there must be a decrease in thickness. So the smaller the radius of the curvature, the greater the decrease in thickness on bending. If the change in thickness is neglected, the neutral axis will remain at the centre fiber. The conventional strain rate at the outer and the inner fibre is given by.

$$e = \frac{1}{\left[\left(\frac{2R}{h}\right) + 1\right]}$$

Where R= the bending radius
h= thickness of the sheet

For a given bending operation the bend radius can not made smaller than a certain value and the metal will crack on the outer tensile surface. The minimum bend radius is usually expressed in multiple of sheet thickness. Thus a 3T bend radius indicates that the metal can be bending without cracking through a radius equal to 3 times the sheet thickness. It varies considerably between different metal and always increases with cold working for a particular metal. Although some very ductile metal have a minimum bend radios of zero indicating that they can be flatten upon themselves. It is general practice to use a bend radius of not less than 1mm in order to prevent damage to the punches and the dies.