MODULE II

PART –I

Concept of plastic deformation of metals, critical resolve shear stress, dislocation theory, deformation by slip and twin, plastic deformation in polycrystalline metals, yield point phenomenon and related effects, concept of cold working preferred orientation. Annealing ; recovery; recrystalization and grain growth; hot working.

PART-II

Concept of alloy formation, types of alloys, solid solutions, factors governing solids solubility viz. size factor, valency factor, crystal structure factor and chemical affinity factor; order-disorder transformation.

(ALREADY DICTATED PROPERLY)

MODULE - II

Concept of Alloy Formation:

An alloy is a metallic solid (or liquid) formed by an intimate combination of a metal and one, or more than one metal and/or non-metal, but has metallic properties. The metallic atoms must dominate in it's composition and the metallic bond in it's crystal structure.

Alloys are usually made by dissolving the alloying elements in one another in the liquid state. The parent metal or solvent (base metal), in largest concentration, is melted first in a crucible & the solid pieces of the alloy additions in weighed amounts are then added in it, dissolved and stirred. At this stage the alloy should be single homogeneous liquid solution.

The metal which is present in larger proportion is known as base/parent metal/solvent, while nonmetal having smaller proportion is called solute.

A master alloy is specifically produced alloy having high conc^n of solute element in parent metal, in proportion that it solidifies as a brittle intermetallic compound, so it can be easily broken in to pieces for quick & accurate weighing.

If a liquid solution of two elements is allowed to solidify, the atoms move and arrange themselves to come to thermodynamical equilibrium among themselves.

Concept Of Plastic Deformation -

All solids get deformed i.e. show change in shape if an external load is applied on them. The basic type of deformations could be broadly divided into two categories.

1. Time independent deformation
2. Time dependent ,,

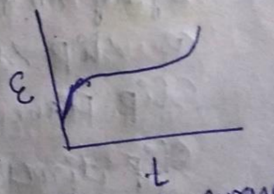
1. Time independent deformation

a) The time ,, ,, which disappears on the release of load is called <u>elastic deformation</u>. Thus it is a reversible deformation. It is true to assume that elastic deformation occurs instantaneously with application of external load.

b) The another type of deformation which occurs almost instantaneously & remains despite the removal of load is called <u>plastic deformation</u>. It is irreversible deformation.

2. Time dependent deformation

The time dependent plastic deformation could occur under a constant stress, is called creep. Here it's strain rate found out which is time dependent.



[creep curve]

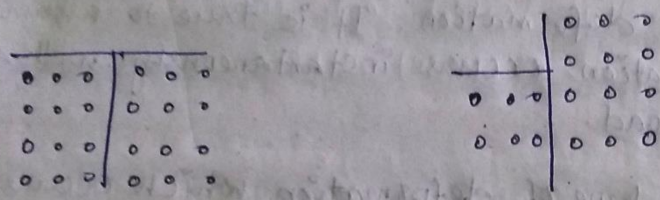
Concept of stress, strain, engineering stress, engg. strain, true stress, true strain, fracture stress, resilience, toughness.

Plastic deformation occurs by different modes such as slip, twin, kink formation etc.

Deformation by Slip

The parallel movement of two neighbouring crystal regions relative to each other across some plane or planes is called slip.

Atoms in a metal move an integral no. of atomic distances along slip plane to result in producing a step. Each step appears as a line called slip line. Slip does not occur on just one plane but over a small regions of parallel planes to result in a no. of slip line, together called slip band.



(Polished surface Before slip) (After slip)

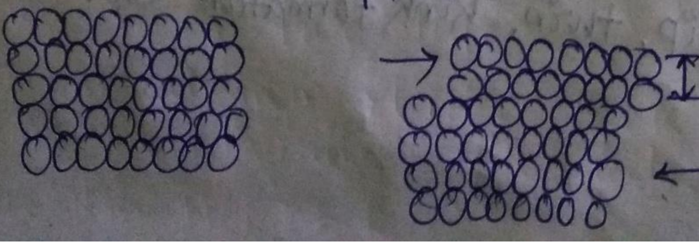
Slip occurs on well defined crystallographic planes and definite crystallographic directions. These are called slip plane and slip direction respectively.

A combination of particular slip plane and direction lying on the plane along which slip occurs is known as slip system.

Slip Plane : Plane of greatest atomic density.

Slip direction : It is the close packed direction in which atoms touch each other in a straight line.

The tendency of slip to occur in close packed dir is more strong than the tendency of slip to occur on close packed plane.

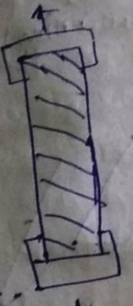


FCC have slip plane {111}, <110> slip direction produces 12 possible slip systems.

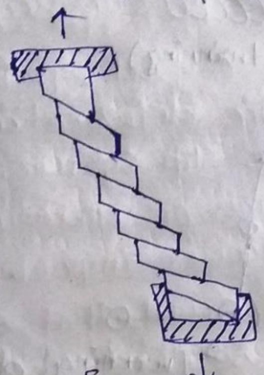
BCC have <111> slip direction and no particular slip plane as it is not a close packed system. Here 48 no.s of slip systems can be possible.

HCP have slip plane is the basal plane i.e. (0001) & dir^n <1120> in 3-axis. Few no. of slip systems (3 - 6)

Ti, Mg, Zr, Be → 3; Ti, Mg → 6



[Tensile specimen before slip]



[Multiple slip]

Rotation occurs of both slip plane and slip direction

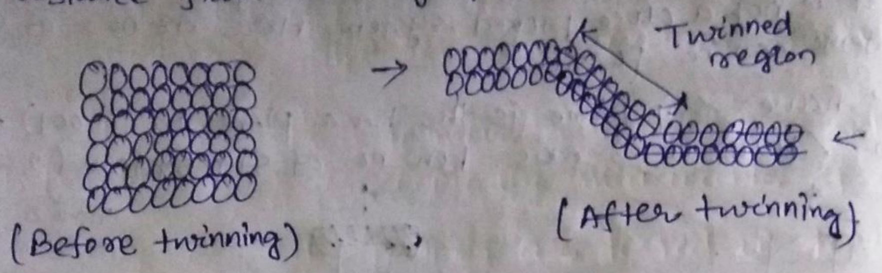
Deformation by Twin

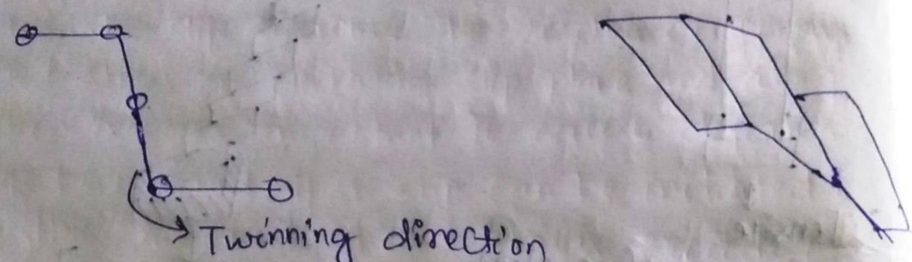
In twinning atoms slide layer by layer to take up an orientation i.e. related to the orientation of untwinned region in a definite and symmetrical way, so that twinned region of the ~~orientation~~ crystal is a mirror image of untwinned region.

The crystallographic planes of reflection or symmetry is called twin plane, which is also the boundary betn twinned and untwinned regions.

The shear movements in twinning are only a fraction of interatomic spacing & shear is uniformly distributed over a volume rather than being localised on a no. of distinct planes during slip.

Extent of total movement for an atom from it's Original position is directly proportional to it's distance from twinning plane.





For different crystal structures twin plane & twin direction are different.

For FCC, {111} plane, ⟨112⟩ dir^n

BCC, {112} plane, ⟨111⟩ dir^n

HCP, {10$\bar{1}$2} plane, ⟨10$\bar{1}\bar{1}$⟩ dir^n

During twin formation, thin lamella forms very quickly almost at a rate equal to sound, which then widens with increasing stress.

In tin (Sn) twinning it make a sound known as '<u>tin cry</u>'. Twins in iron are seen as <u>Neumann bands</u>.

Sharp audible click

Twin is of two types.

Mechanical twin → Under shock loading at low temp. mechanically deformed.

Found in HCP or BCC.

ii) Annealing twins : Obtained during annealing heat treatment after cold working.
- Found in FCC (Cu, brass γ-S.S.)

Difference in Slip & Twin

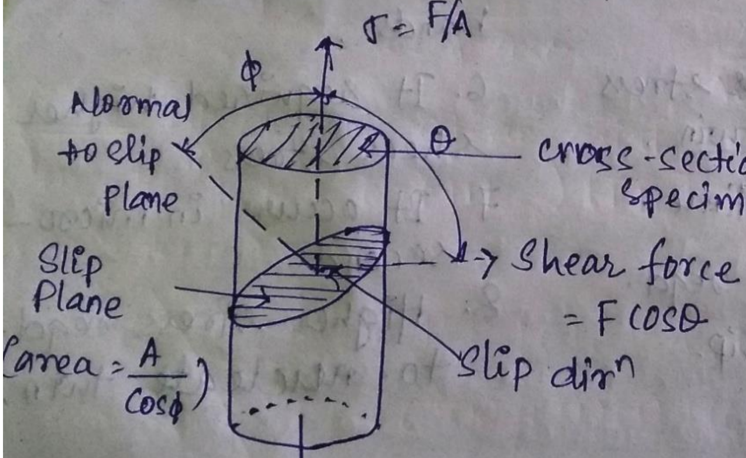
Slip	Twin
1. Orientation of atoms above & below slip plane is same after slip.	1. Twin produces orientation difference across twin plane.
2. It does not produce mirror image of original lattice.	2. It produces.
3. It is inhomogeneous deformation.	3. Uniform homogeneous deformation.
4. Direction of slip may be positive or negative.	4. Dirn of shear limited to that which produces mirror imge.
5. These are seen as slip line.	5. These are seen as bands.
6. Here less shear stress required than twin.	6. It required higher shear stress
7. It need some time.	7. It occurs in micro-seconds.
8. Higher stress reqd. to propagate slip.	8. Higher stress reqd. to nucleate twin.

Critical Resolved Shear stress (Schmid's law)

Slip in a single crystal on it's slip plane begin only after the applied stress reached a certain minimum value. That is called critical resolved shear stress τ_c.

τ_c = It is the stress to move a large no. of dislocations to produce a macroscopically measurable strain.

Generally crystal specimens are tested in tension. But plastic deformation i.e. slip occurs by shear on definite slip systems. The resolve component of applied stress on operating slip plane and along slip direction becomes important to cause deformation. It has been found that slip can be initiated only when this resolved shear stress exceeds or becomes critical i.e. attains a value called <u>Critical Resolved Shear stress</u> (CRSS).



Consider a single crystal under tensile force F.
Angle betn normal to slip plane & tensile axis = ϕ
Angle betn slip direction & tensile axis = θ
If A is cross-sectional area of specimen, then area of slip plane inclined at an angle ϕ is $A/\cos\phi$

Force acting on slip direction is $F\cos\theta$

Hence $\tau_{CRSS} = \frac{F\cos\theta}{A/\cos\phi}$

$$\tau_{CRSS} = \frac{F}{A}(\cos\theta\cos\phi)$$

$(\cos\theta\cos\phi)$ is known as <u>Schmid factor</u>.

As applied tensile stress increases from zero, the deformation will be initiated first on slip system for which resolved shear stress is maximum & thus attains a critical value.

As $\tau_{RSS} = F/A \cos\theta\cos\phi$

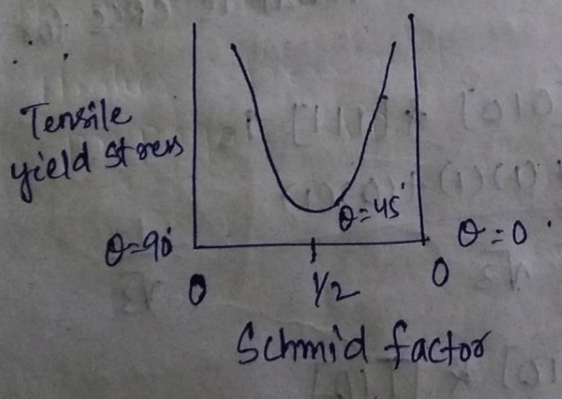
$\Rightarrow \tau_{RSS} \propto$ Schmid factor

Max^m RSS obtained when $\theta = \phi = 45'$

$\therefore \tau_{RSS} = F/A \cos 45' \cos 45'$

$\Rightarrow \tau_{RSS} = \sigma \times \frac{1}{2} = \frac{\sigma}{2}$

If tensile axis lies on slip plane i.e. $\phi = 90°$, then RSS will be zero. or if $\theta = 90°$ then also RSS will be zero.



HCP single crystal exhibit brittle behaviour in tensile test as it's basal plane ⊥r to tensile axis. So, ~~shows~~ shear stress is zero. This show ductile behavior at bend test.

Ques The τ_{CRSS} of perfect crystal of Cu is 4×10^5 N/m². Determine the amount of stress to be applied in tension along [1$\bar{1}$0] axis of Cu crystal to make it slip on (1$\bar{1}\bar{1}$) [0$\bar{1}$1] slip system.

Ans : Angle betⁿ tensile axis [1$\bar{1}$0] & normal plane (1$\bar{1}\bar{1}$)

$$\cos\phi = \frac{(1\times1)+[(-1)\times(-1)]+0}{\sqrt{1^2+(-1)^2+0^2}\sqrt{1^2+(-1)^2+(-1)^2}} = \frac{2}{\sqrt2\sqrt3} = \frac{2}{\sqrt6}$$

Angle betⁿ tensile axis & slip dirⁿ [0$\bar{1}$1]
[1$\bar{1}$0]

$$\cos\theta = \frac{(0\times1)+(-1\times-1)+(1\times0)}{\sqrt{0^2+(-1)^2+1^2}\sqrt{1^2+(-1)^2+0^2}} = \frac{1}{\sqrt2\sqrt2} = \frac{1}{2}$$

$$\tau_{CRSS} = \sigma\cos\phi\cos\theta$$

$$\Rightarrow \sigma = \frac{\tau_{CRSS}}{\cos\phi\cos\theta} = \frac{4\times10^5 \text{ N/m}^2}{\frac{2}{\sqrt6}\times\frac{1}{2}} = 9.796\times10^5 \text{ N/m}^2$$

Ques Al deforms at an axial tension of 6.9×10^5 N/m² in dirⁿ [010] on (111) [$\bar{1}$10]. What is CRSS for this system.

cosϕ, angle betⁿ [010] & [111] is

$$\cos\phi = \frac{(0)(1)+(1)(1)+(0)(1)}{\sqrt1\sqrt3} = \frac{1}{\sqrt3}$$

cosθ angle betⁿ [010] & [$\bar{1}$10]

$$\cos\theta = \frac{0(-1)+(1\times1)+0}{\sqrt1\sqrt2} = \frac{1}{\sqrt2}$$

$$CRSS = \frac{6.9\times10^5}{\sqrt2\sqrt3} = 2.82\times10^5 \text{ N/m}^2$$

Ques A slip system has $\theta = 70$, $\phi = 30^\circ$, slip starts at a stress of 35 MPa. What is CRSS?

$$\tau_{CRSS} = \sigma \cos\theta \cos\phi = 35 \cos 70 \cos 30$$
$$= 10.37 \text{ MPa}$$

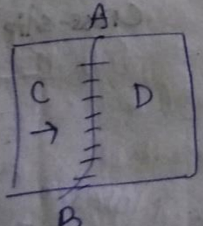
Dislocation Theory

A dislocation is a one dimensional (it has only one dimension length), or a line defect (just like a line). As the name suggests the distortion around a dislocation is centered along a line. Dislocations can be of 3 groups.

i) Edge dislocation
ii) Screw dislocation
iii) Mixed dislocation (partly screw and partly edge)

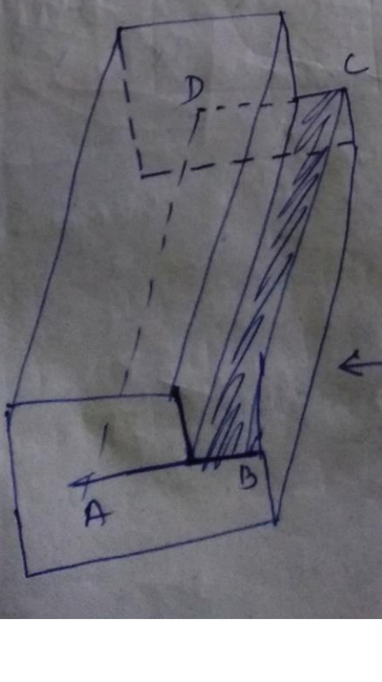
Edge dislocation

Dislocation is to consider that it is the region of localized lattice disturbance separating the slipped and unslipped regions of a crystal.



All atoms above C has been displaced one atomic distance in slip direction. D is not yet slipped.

AD ⊥r slip dirn

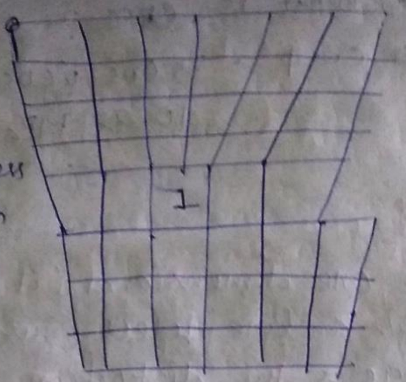


Slip has occurred in the dirn of slip vector over the area ABCD.

The amount of dislocation is equal to Burger vector 'b' of dislocation.

b ⊥r dislocation line.

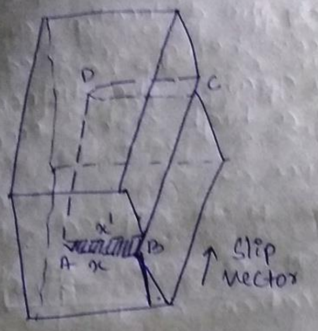
Movement by Climb is ~~a much~~ diffusion controlled, motion is much slower in glide & less likely except at high temp.



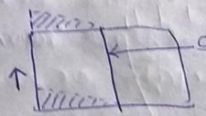
A pure edge disl… can glide or slip … dirⁿ ⊥ʳ to it's len… However, it ma… move vertically … a process known … Climb, if diffus… of atoms or vacan… can take place … appreciable rat…

Dislocation property	Edge	Screw
Relⁿ betⁿ dislocation line & b	⊥ʳ	∥
Slip direction	parallel to b	Parallel to b.
Dirⁿ of dislocation line movement relative to b (Slip direction)	parallel	⊥ʳ
Process by which dislocation may leave slip plane	Climb	Cross-slip

Screw dislocation



The upper part of crystal to right of AD has moved relative to the lower part in the dirn of slip vector. No slip has taken place to the left of AD, & therefore AD is a dislocation line.
Thus dislocation line is parallel to it's Burger vector or slip vector.



A screw dislocation does not have a preferred slip plane, as an edge dislocation has & therefore motion of a screw dislo--cation is less restricted.

Dislocation width is important because it determines the force reqd to move a dislocation through crystal lattice. This force is called Peierls-Nabarro force. It is the shear stress reqd. to move a dislocation through crystal lattice in particular direction.

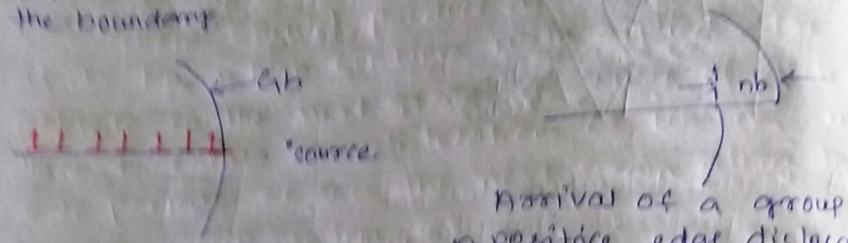
$$\tau_p \approx \frac{2G}{1-\nu} e^{-2\pi w/b}$$

w = width
b = Distance between atoms in slip direction.

Deformation Of Polycrystals:

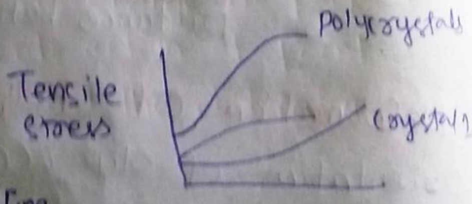
Orientation of slip occurs in adjacent grains. So dislocation moves from one grain to another. This leads to increase in strength of polycrystals.
At temp. below 0.4Tmp the gb are quite strong & crack propagates normally in transgranular manner across the grains. At high temp. gb sliding can occur resulting in entergranular fracture.

Dislocation motion in polycrystals:
The movement of dislocation in polycrystals is in ... the favourable oriented grains. These grains will exhibit ... slip plane & slip dirⁿ. Due to misorientation of slip planes ... the dislocation cannot ... across a large angle boundary; the dislocation ... restricted to the boundary. The slip process being ... the boundary of individuals grains. The dislocation ... against a boundary create a high stress ... around the boundary.



Arrival of a group of n positive edge dislocation on a boundary is analogous to ... of a stack of extra half plane of thickness, nb above slip plane at gb.

Polycrystals undergoing plastic deformation do not develop voids at gb. It is evident that individual grains deform in such a manner as to fill the space after deformation just as they did before. Stressing. If each grain is to remain coherent with its neighbours multiple slip has to occur.



The yield strength of polycrystalline materials usually exhibits the following relⁿship to grain size (Hall-Petch relⁿship)

$$\sigma_{LYP} = \sigma_i + K_y d^{-1/2} \quad ? \quad \sigma_{LYP} \propto \frac{K}{\sqrt{d}}$$

σ_{LYP} = Lower yield stress

Material const ← σ_i & K_y const , d = Avg. grain diameter

Yield point Phenomena and Related effects.

A tensile test provides the basic data about mechanical properties of metals. The initial linear portion of load-elongation or stress-strain curves is the elastic region within which Hooke's law is obeyed, with the max^m point called elastic limit.

The start of general yielding in polycrystalline material occurs at a stress at which dislocation sources (Frank-Reed sources) can create slip bands in metals.

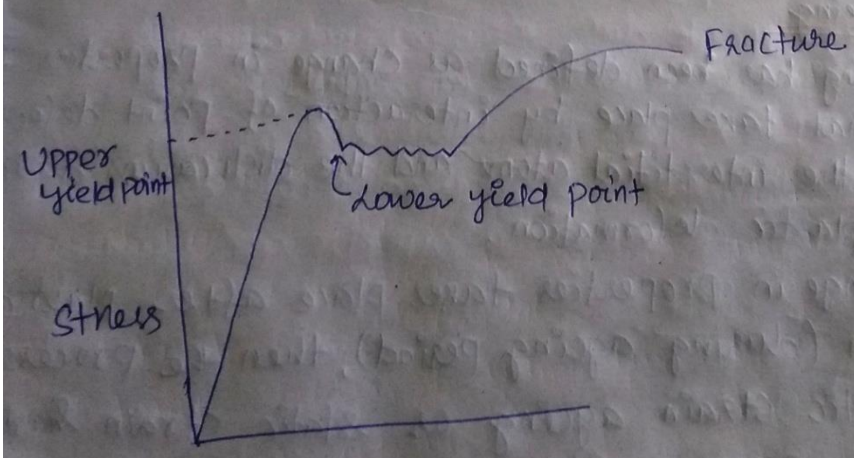
The general yield stress, σ_y is $\sigma_y = \sigma_s + \sigma_i$

σ_s = Stress needed to operate a source.

σ_i = Friction stress.

Luders band Formation:

Stress-Strain curve of low C steel shows an abrupt or sharp yield point. Here load increases steadily with elastic strain to a certain high value, drops suddenly & then fractures about some constant value of stress & then raises suddenly again as specimen work-hardens.



The stress at which sudden drop occurs is called upper yield point. The average constant load to which drop occurs is called lower yield point and the elongation associated with this load is called yield point elongation. or Luder strain, which could be over 10%.

How Luder Band Forms ??

In polycrystalline materials, the preyield microstrain takes place in a few grains i.e. slip bands traverse some of grains at stresses below upper yield point. Before a slip band can cross a grain, the pile up of dislocations should produce a stress-concentration at it's tip, which combines with applied stress to activate in the next grain, a source of dislocation "or unlock" there to create new dislocations along the & to propagate across the next grain operative slip system.

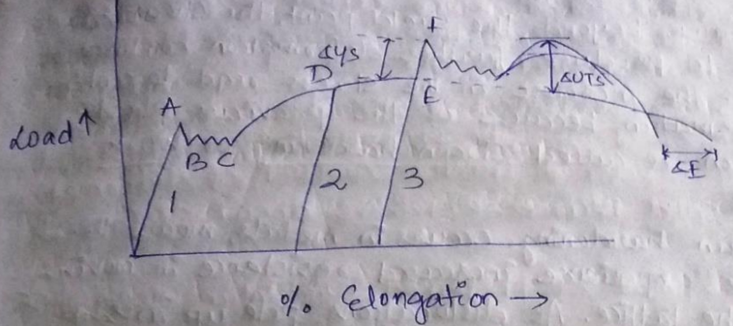
As the stress increases slip bands propagate through several grains in a group because the increased stress increases dislocation velocity rapidly as the length of pile up increases, the stress concentration at the tip increases, letting slip band to cross more grains. Once the entire cross section has been traversed a Luders band formed.

<u>Strain Ageing</u>

Strain ageing has been defined as change in properties of an alloy that takes place by interaction of point defects-Specially the interstitial atoms and the dislocations during or after plastic deformation.

If the change in properties takes place after plastic deformation (during ageing period), then the process is called Static strain ageing or static strain hardening

But if the properties takes place as plastic deformation progresses, then it is called dynamic strain ageing.



If a specimen is strained up to a point, say E & is then unloaded here. It is allowed to rest for several hours at room temp. or a few seconds at 200°C. The specimen on reloading follows the curve 3, & the yield point is raised to point F, & the sharp yield point reappears. This process in which yield point reappears. This process in which yield point reappears & is accompanied by the following effects is known as strain ageing or strain age hardening.

- Yield stress raised during ageing by ΔYS.
- Ultimate tensile strength raised by ΔUTS.
- Ductility decreases as indicated by decrease in total elongation by ΔE.

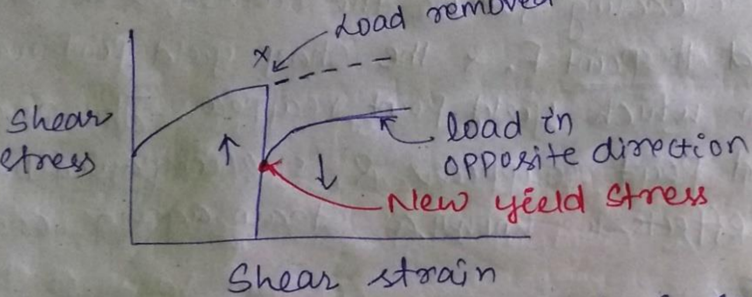
During ageing process a plastically deformed alloy reduces the energy of its strained lattice by the process of diffusion of interstitial solutes (C or N) to dislocations. The increase in its yield point & reappearance of yield point are due to this diffusion of C & N atoms to dislocations during ageing time to form new atmospheres of the interstitials & thus anchor dislocations.

Strain ageing is a time and temp. dependent process

Bauschinger Effect :

When a single crystal is continued to be deformed in the plastic range beyond the yield point, the shear stress required to produce further deformation continues to increase. The increase in the stress reqd. to continue the deformation because of the previous plastic deformation is called strain hardening or work hardening.

As strain hardening occurs in metals, means that dislocations experience increased resistance in moving through the lattice. As dislocations pile up on slip planes at the barriers in the crystal, the pile up produces a 'back-stress' which opposes the applied stress on slip plane.



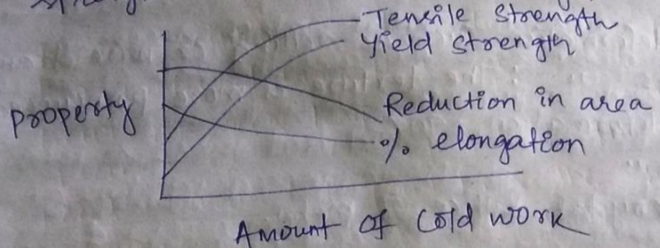
When a crystal unloaded & reloaded in opposite dirn to first slip dirn, the dislocation developed during " loading, gets added up with the applied stress when slip dirn is reversed during second loading in opposite dirn. Dislocations of opposite signs attract & annihilate each other resulting in softening of crystal. This phenomena of decreased yield strength when deformation in one dirn is followed by deformation in opposite dirn is called Bauschinger effect.

Concept of Coldworking : Preferred Orientation

↳ Cold working - when a crystalline material is plastically deformed below about 0.3Tmp (Tmp is melting point temp.) is called cold working

↳ Or working of material below recrystallization temp. is known as coldworking. It is also known as strain-hardening i.e. increase in stress read. to cause slip because of previous plastic deformation

↳ It enhances properties like tensile strength, yield strength but reduces ductility.



Cold working produces structural changes in polycrystalline metals and alloys can be classified in 3 categories

- Changes in shape & size
- Changes in Orientation of grains
- Changes in internal structure of grains.

↳ When a single crystal is plastically deformed, the slip planes tend to rotate parallel to the axis of the main stress. Even in polycrystalline metal, on deformation the individual grains tend to rotate in to a common orientation. In tension grains rotate in a way that the applied stress axis is towards operative slip dirⁿ.

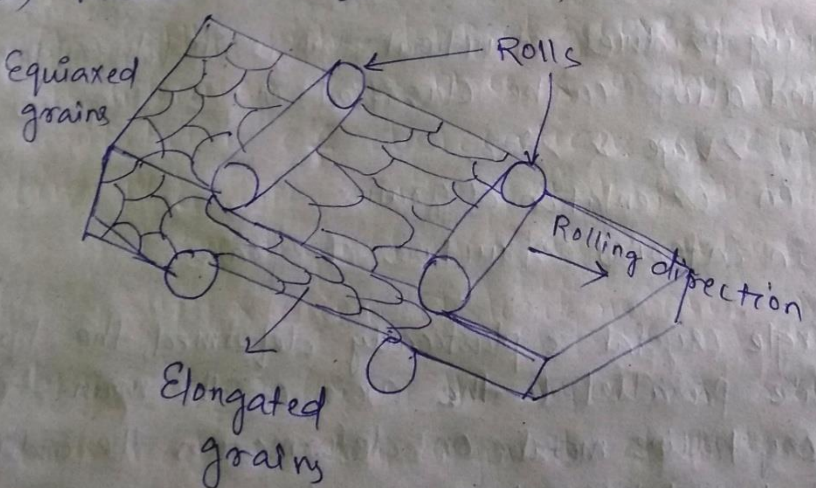
• The appearance of texture is due to the fact that slip takes place in grains in close packed directions & normally on close packed planes & that the directions regularly rotate relative to the ~~dirⁿ of stress~~ deformation axes of the object.

↳ Preferred orientation, or texture is the state of severely cold worked metal in which certain crystallographic planes of grains orient themselves in a preferred manner with respect to dirⁿ of stress.

↳ Slip planes of different grains tends to become parallel to the axis of stress. The preferred orientation is thus gradually developed as the amount of deformation increases and becomes extensive about 90% reduction in area.

↳ The development of preferred orientation depends on four factors.

i) The type of deformation such as rolling or wire drawing.
ii) The amount of " ; The texture is more pronounced with larger deformation = 90%.
iii) Temp. of "
iv) Nature of crystal lattice of metal.



The simplest deformation texture obtained by wire drawing or by rolling of wire. This also called 'fibre texture', as it resembles the arrangement in natural fibrous materials.

Annealing

The treatment to restore ductility or electrical conductivity with a simultaneous decrease in hardness and strength is called annealing.

Annealing (or recrystallization annealing) is heating the cold worked metal for a certain time at a temp higher than 0.3 - 0.5 Tmp (i.e. recrystallization temp.) where, Tmp is the melting point of metal in absolute scale & then slow cooling.

Cold worked state (having 2% to 15% of cold work energy stored in it) is thermodynamically unstable relative to the undeformed state and thus, tries to return to lower energy state by losing excess energy acquired during cold working i.e. to annealed state. This cannot occur spontaneously as the cold worked state is a complex state & can persist indefinitely at low temp. A no. of different reactions such as diffusion, climb, cross-slip etc. must occur but are thermally activated processes & can take place at elevated temp. Thermal energy allows the dislocations to move out of their slip planes.

The three thermally active and overlapping stages during annealing are:

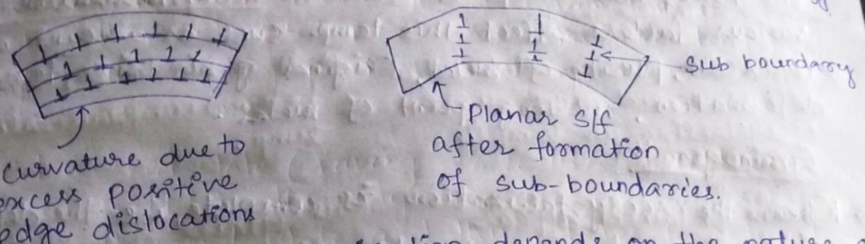
i) Recovery
ii) Recrystallization
iii) Grain growth

The first two stages of annealing are caused by stored cold worked energy. Grain growth, the third stage of annealing occurs, if annealing is continued after recrystallization has completed. In this stage the recrystallized grains grow in size at the expense of other normally smaller grains.

Recovery

- It is the initial stage of the annealing cycle of a cold worked metal before recrystallization occurs.
- Recovery is defined as the process of annihilation & rearrangement of defects within the deformed metal without the movement, or migration of high angle boundaries. So no visible change found in optical microstructure.
- The driving force for recovery and recrystallization is the stored cold worked energy. The greater the initial cold work, the more the initial rate of recovery. Decreasing the grain size increases the rate of recovery as dislocation density increases.
- Recovery is intially very rapid and more so when the annealing temp. is high. With increasing time at high const. temp. the recovery becomes slower.
- At slightly higher temp of recovery the rearrangement of dislocation takes place & in the process, mutual annihilation of dislocations of opposite signs takes place. The rearrangement of dislocations is assisted by thermal activation which causes slip, cross-slip & climb dislocations over small distances.
- Polygonisation: One of the important recovery processes, which leads to rearrangement of dislocations, with a resultant lowering of lattice strain energy, is Polygonisation. After local annihilation of opposite signed dislocations in early stages of recovery, excess dislocations of same sign are left over in the metal. Single crystal of a metal has been cold worked by bending in one direction, which produces excess edge dislocations of same sign on parallel slip planes. The stored elastic strain energies of these dislocations gets reduced further when they arrange themselves

in subboundries. The decrease in total strain energy, thus is the driving force for polagonization.
polygonisation is the process of arranging excess edge dislocations in the form of tilt boundaries, and the excess screw dislocations in the form of twist boundaries. with the resultant lowering of elastic strain energy



↳ The rate of polygonisation depends on the nature of material, the amount of cold deformation, temp. of recovery (also prehistory of heating), the amount & nature of impurities, etc.

Recrystallization

↳ Recrystallization is the process of formation of new strain free grains from deformed grains in a solid body by the movement of high angle boundaries.

↳ Mechanical properties like hardness, yield strength, tensile strength, % elongation change drastically over a very small temp range to become typical of annealed material.

↳ Physical properties like electrical resistivity, undergo appreciable decrease during recovery but also decrease sharply during recrystallization.

↳ The driving force is remaining stored cold worked energy. It's kinetics resembles a phase transformation. i.e. a nucleation & growth process. The strain free nuclei form and begin to grow in deformed metal when the temp. is high enough and gradually absorb the whole of deformed matrix.

↳ Nucleation of recrystallization in a metal occurs by the motion of pre-existing gb betⁿ neighbouring grains, by motion of sub-grain boundary, by coalescene of subgrains.

↳ When a cold worked metal gets 50% recrystallized in one hour, that temp. is known as Recrystallization temp. Various factors affect this temp. such as amount of coldwork, purity of metal, Original grain size, temp. of deformation, melting point of metal.

Grain growth

↳ When the recrystallization is complete, i.e. the deformed grains have been replaced by strain free grains, & heating is continued to higher temp. or for longer time, the gb slowly migrates & produce a uniform increase of grainsize at the cost of neighbouring recrystallized smaller grains. This process is called as grain growth.

↳ The driving force for grain growth is the energy associated with grain boundaries i.e. when the grain size increases the grain boundary area decreases, & thus the total gb energy of polycrystalline metal is lowered.

↳ The grain growth taking place with increasing time at a const. temp. is smaller than increasing temp. at const. time. (Normally one hour at a temp.)

↳ During grain growth, the average grain size uniformly increases thus the grain boundary area per unit volume decreases. The corresponding decrease in gb energy per unit volume becomes the driving force for grain growth.

↳ For a spherical grain (assumed) of radius, R, the gb energy per unit volume is inversely proportional to grain diameter.

Grain boundary energy per unit volume $= \frac{4\pi R^2 r}{\frac{4}{3}\pi R^3}$

$= \frac{3r}{R}$

$= 3r \cdot \frac{1}{R}$

$\propto \frac{1}{D}$

D - Grain diameter.

Hot Working

↳ Hot working is defined as the Plastic deformation of a material at a temp. above it's recrystallization temp.

Ex: Working of 'Pb' & 'Sn' at room temp. is called hot working as their recrystallization temp. is below room temp. Whereas 'W' when worked at 1200°c still called cold worked as it's recrystallization temp. is higher than 1200°c.

Characteristics of Hot - Worked state:

There are a no. of advantages and disadvantages of hot working a metal:

i) Lack of Strengthening: During hot working dynamic recovery and recrystallization occurs, so amount of deformation is almost unlimited. Hence it does not strengthen the metal.

ii) Removal of defects: Some defects present maybe eliminated porosity can be collapsed and welded, Segregation reduced, diffusion distance reduced.

iii) Anisotropic Properties: Properties are invariably anisotropic. Surface has finer grains than centre.

iv) Surface finish and dimensional accuracy: It almost resu in surface oxidation. Thus surface finish is poor. Dimensional accuracy is difficult during hot work as elastic strain and thermal contraction occurs.

Commonly, it is economical that ingots of metals are initially hot worked to reduce it's sizes and then cold worked to get exact dimensions & good surface finish.

Difference Between Hot working and Cold Working :-

Hot Working	Cold Working
i) It is the plastic deformation of metals and alloys above recrystallization temp. (T_r = 0.3 – 0.5 T_{mp})	i) It is plastic deformation below recrystallization temp.
ii) Grains obtained appear equiaxed and refined under microscope.	ii) Grains are elongated and distorted.
iii) It reduces chemical heterogeneity.	iii) Chemical heterogenity is retained.
iv) Properties are more or less isotropic.	iv) Properties are anisotropic particularly after heavy cold reduction.
v) There are loss of precious metal due to scale formation.	v) Here no such metal loss.
vi) Dimensional accuracy not proper.	vi) Dimensional accuracy found.
vii) Less power consumption and cheaper one.	vii) It requires more power and expensive one.