Metallurgy for Non-Metallurgists

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Syllabus

- Metallography and its applications
- Mechanical properties of metals and alloys,
- Strengthening Mechanism

Objective of Metallography

- To prepare the specimens surfaces to be examined by the microscope.

- To learn and to gain experience in the preparation of metallographic specimens.

Introduction

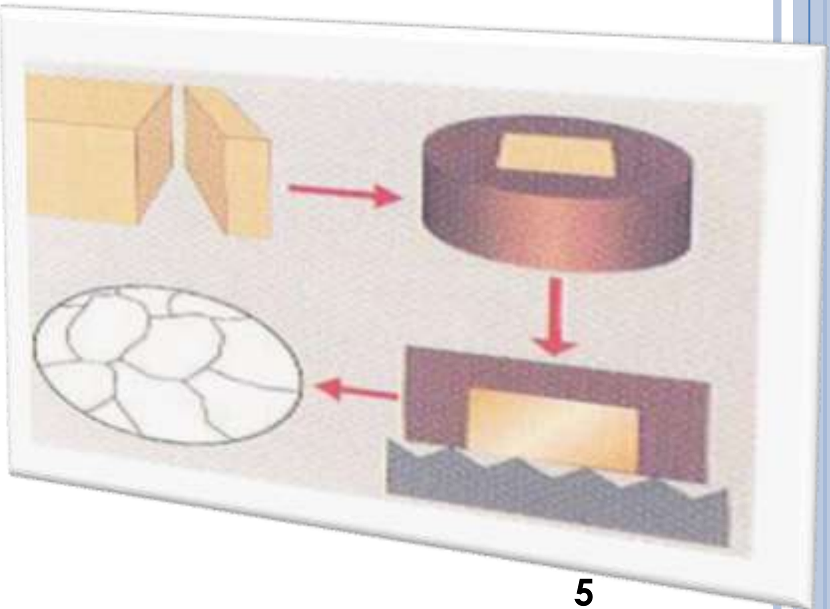
- **Metallography** is basically the study of the structures and constitution of metals and alloys, using metallurgical microscopes and magnifications, so that the physical and mechanical properties of an alloy can be related to its observed microstructure.

- Such microscopic studies can provide an abundance of constitutional information about the specimen under investigation, including the size and shape of the grains (crystallites), the presence of micro defects (such as segregation, hair cracks, and nonmetallic inclusions), and the nature and distribution of secondary phases.

- The metallographic examination can be used in quality control and to predict and/or explain the mechanical properties.

Introduction cont.

- Proper preparation of metallographic specimens to determine microstructure and content requires that a rigid step-by-step process be followed. In sequence, the steps include sectioning (cutting), ultrasonic cleaning, mounting, course grinding, fine grinding, and polishing, etching and microscopic examination. Specimens must be kept clean and preparation procedure carefully followed in order to reveal accurate microstructures



METALLOGRAPHY AND MICROSCOPY

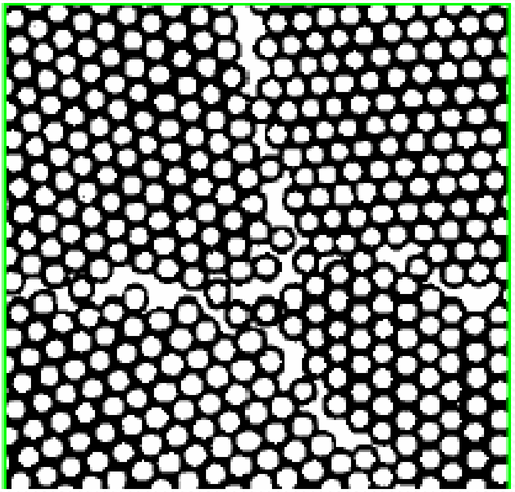
Introduction

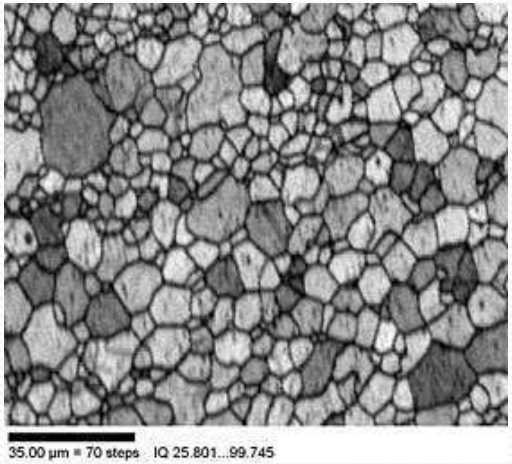
- **Microstructure:**

  It is the geometric arrangement of grains and the different phases present in a material.

- **Grain Boundaries:**

  It is the interface between two grains in a polycrystalline material where the crystal is disordered due to rapid change in crystallographic directions.





Why is Microstructural Analysis used for?

- Quality Control: Analysis is used to determine whether the structural parameters are within specifications: a criteria for ACCEPTANCE or REJECTION of products

- Failure Analysis: to determine the cause of failure. Failure occur due to several factors (incorrect material selection, improper processing treatment, poor quality control).Failure analysis provides information about the cause of failure

- Research Studies: is used to determine the microstructural changes that occur as a result of varying parameters such as composition, heat treatment or processing. The research studies develop the PROCESSING - STRUCTURE - PROPERTIES relationships.

Application

- Study and characterization of materials.
- Ensure that the associations between properties and structure are properly understood.
- Predict properties of materials.
- Design alloys with new properties.
- Check if the material has been correctly heat treated.

Safety Instructions

- Optical Metallography involves the use of etchants (standard solutions containing a variety of chemicals such as strong acids and solvents) which can be very corrosive and poisonous.

SPECIMEN PREPARATION

- Specimen preparation is an important part of metallography
- A specimen must be appropriately prepared to ensure correct observationand interpretation of the microstructure.

Specimen preparation requirements

- *Deformation-free specimen*
- *Flat specimen*
- *No thermal damage*
- *No scratches*

Specimen preparation consists of :

Sample Selection: The number, location orientation of the samples examined are important parameters in selection samples.

- SECTIONING
- MOUNTING
- GRINDING
- POLISHING
- ETCHING

SECTIONING

- Sectioning is the first step in the overall process of sample preparation.
- Sectioning of the test sample is performed carefully to avoid altering the structure of the material.
- Abrassive cutting is the most common cutting method.
- The cutting tool is made of Silicon carbide(Sic) of diamond particles.
- Use coolant fluid to avoid overheating of specimen and possible change in material structure.

- **Sawing** is perhaps the oldest met lab method of sectioning that is still used today. It can be accomplished with a hand-held hacksaw, but it can alter the microstructure

- **Abrasive Wheel Sectioning** is The most popular method of sectioning is with abrasive cut-off wheels. Wheels made of silicon carbide, aluminum oxide, and diamonds are used in the sectioning process. With this type of sectioning, the metallographer has more control over the conditions used

Machines used for sectioning:

EDM

Mounting

- **Mounting**. Small samples can be difficult to hold safely during grinding and polishing operations, and their shape may not be suitable for observation on a flat surface. They are therefore mounted inside a polymer block or mount.

Mounting

Cold mounting:

- It can be done using two components resins (epoxies) which are liquid to start with but which set solid shortly after mixing.
- It requires very simple equipment consisting of a cylindrical ring which serves as a mould and a flat piece which serves as the base of the mould. the sample is placed on the flat piece within the mould and the mixture poured in and allowed to set. Cold mounting takes few hours to complete.

Mounting

Hot-mounting

- The sample is surrounded by an organic polymeric powder which melts under the influence of heat (about 200 C).
- Pressure is also applied by a piston, ensuring a high quality mould free of porosity and with intimate contact between the sample and the polymer.

Grinding

- **Grinding** is done using rotating discscovered with silicon carbide paperand water.
- There are a number of grades of paper, with 180, 240, 400, 1200, grains of silicon carbide persquare inch. 180 grade therefore represents thecoarsest particles and this is the grade to begin the grinding operation. *Always use light pressure applied at the centre of the sample.*
- Wash the sample in water and move to the next grade, *orienting the scratches from the previous grade normal to the rotation direction*. This makes it easy to see when the coarser scratches have all been removed.
- After the final grinding operation on 1200paper, wash the sample in water followed by alcohol and dry it before moving to thepolishers.

Polishing

- The polishers consist of rotating discs covered with soft cloth impregnated with a pre-prepared slurry of hard powdery alumina particles (Al2O3, the size ranges from 0.5 to 0.03 µm).
- Begin with the coarse slurry and continue polishing until the grinding scratches have been removed. *It is of vital importance that the sample is thoroughly cleaned using soapy water, followed by alcohol, and dried before moving onto the final stage.* Any contamination of the final polishing disc will make it impossible to achieve a satisfactory polish.
- Examining the specimen in the microscope after polishing should reveal mirror like surface.

Etching

- The purpose of etching is two-fold.

1. Grinding and polishing operations produce a highly deformed, thin layer on the surface which is removed chemically during etching.
2. Attacks the surface with preference for those sites with the highest energy, leading to surface relief which allows different crystal orientations, grain boundaries, precipitates, phases and defects to be distinguished in reflected light microscopy.

Etching

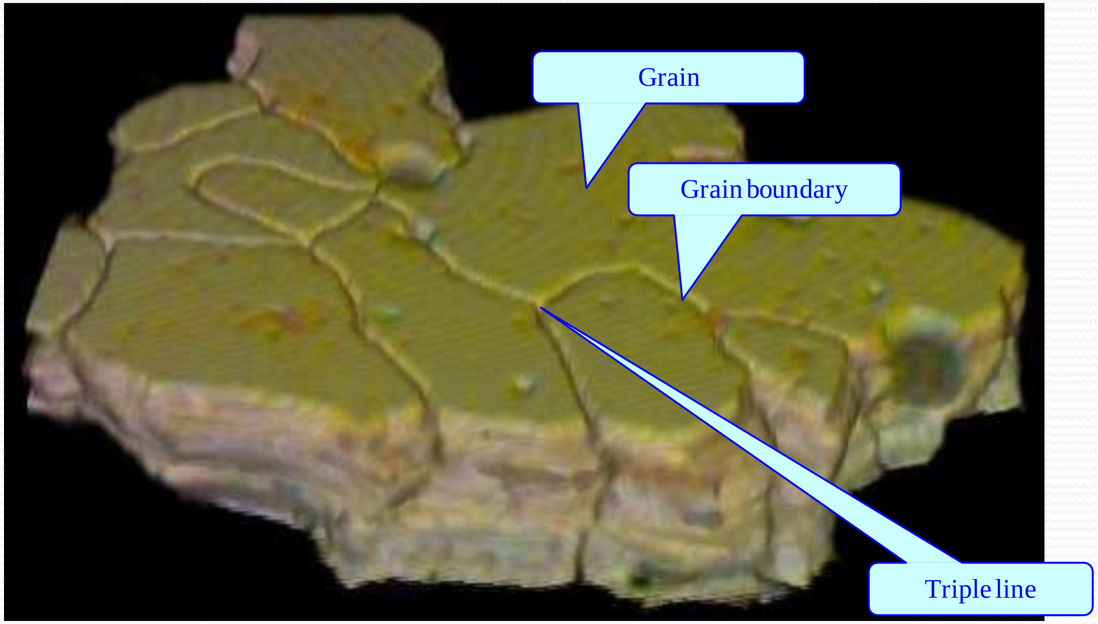
- Etching should always be done in stages, beginning with light attack, an examination in the microscope and further etching only if required.
- If you overetch a sample on the first step then the polishing procedure will have to be repeated.
- The table below gives the etchants for alloys that will be examined in this experiment.

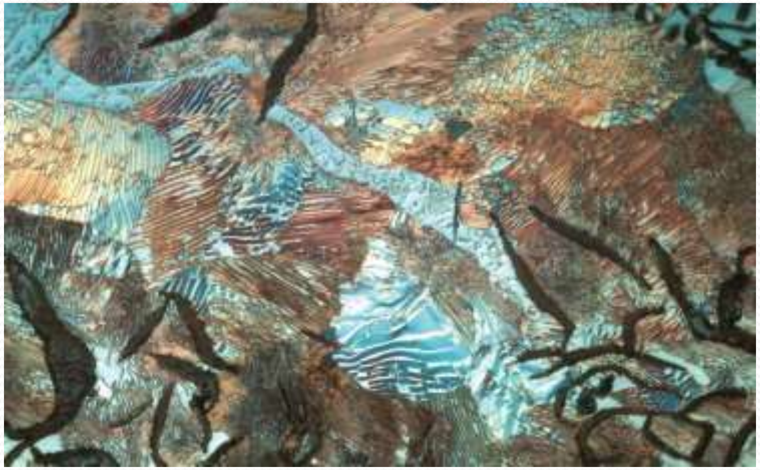
Sample	Etchant
Al alloys	Keller's (2 ml HF +3 ml HCL + 5 ml NO3+ 190 ml water)
Cu-Zn alloy (brass)	10 ml HNO3+90 ml water
Steel and cast irons	Nital (2% HNO3 + 98% ethanol)

Industrial etching

- The surface is than exposed tochemical attack or ETCHING, with grain boundaries being attacked more aggressively than reminder of the grain to reveal the microstructure.
- Light from an optical microscope is reflected or scattered from the sample surface depending how the surface is etched

- The micrograph in the figure below was created by taking optical micrographs from a specimen, after polishing (& etching) to various depths (sectioning). This gives a '3D' view of the sample.





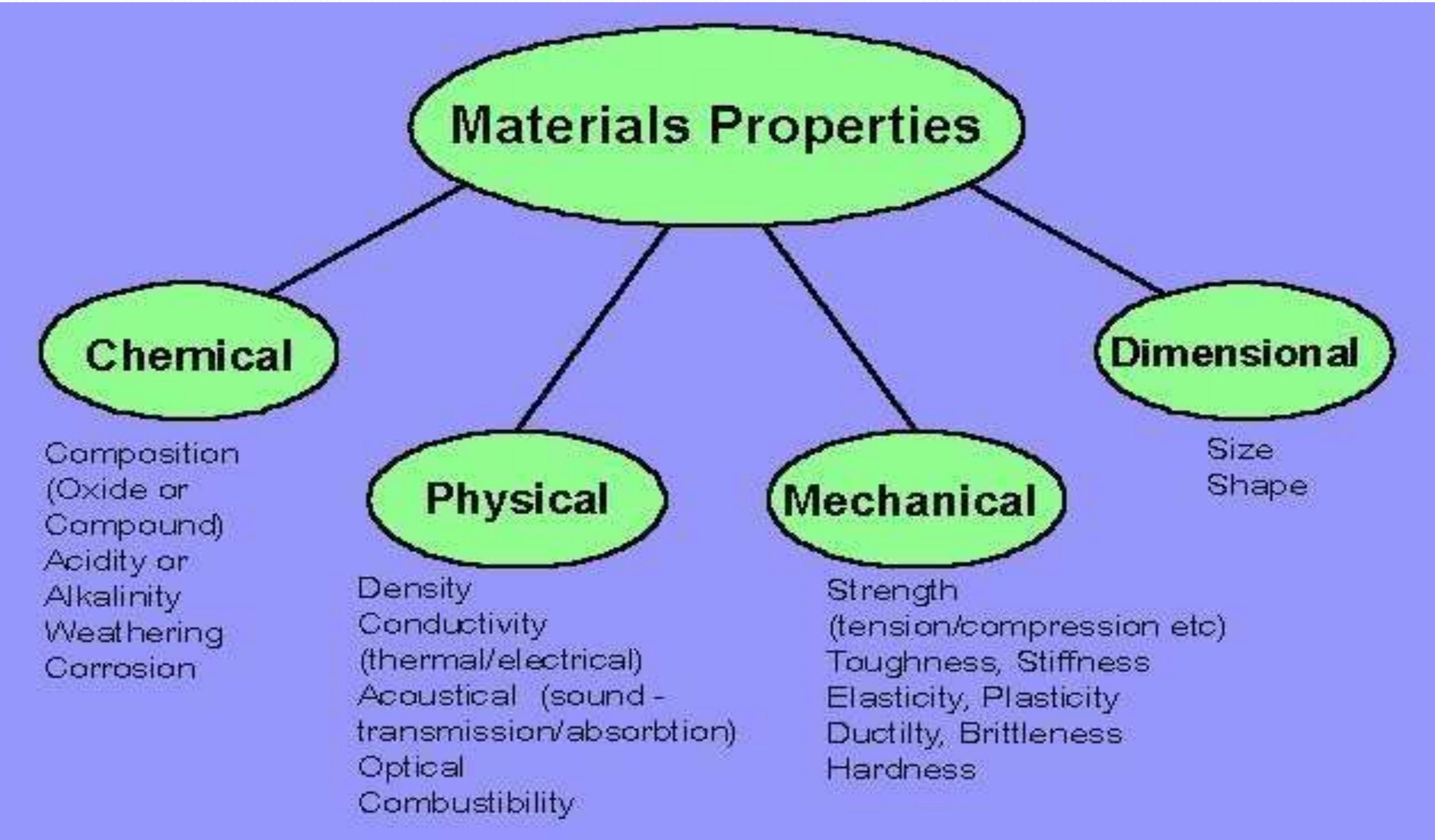
QUESTIONS

- **Describe the steps involved in the preparation of a metallographic sample:**
  - Sectioning (cutting)
  - Plastic coating of the samples
  - Mounting
  - Grinding
  - Polishing
  - Etching
- **Why should the specimen be roughly washed after each stage during either grinding or polishing?**
- **Why is fine grinding performed wet?**
- **What is the purpose of etching metallographic samples?**
- **What are the advantages of electrolytic polishing?**

INTRODUCTION:

- The practical application of engineering materials in manufacturing engineering depends upon a thorough knowledge of their particular properties under a wide range of conditions.
- The term***"property"*** is a qualitative or quantitative measure of response of materials to externally imposed conditions like forces and temperatures.
- However,the range of properties found in different classes of materials is very large.

Classification of material property:



MECHANICAL PROPERTIES:

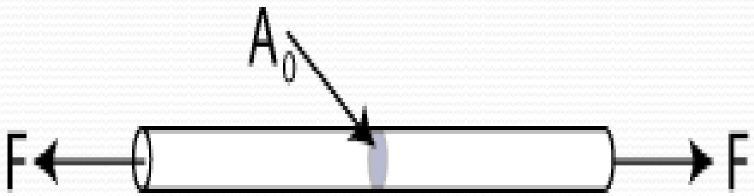
- The properties of material that determine its behaviour under applied forces are known as mechanical properties.
- They are usually related to the elastic and plastic behaviour of the material.
- These properties are expressed as functions of stress-strain,etc.
- A sound knowledge of mechanical properties of materials provides the basis for predicting behaviour of materials under different load conditions and designing the components out of them.

STRESS AND STRAIN

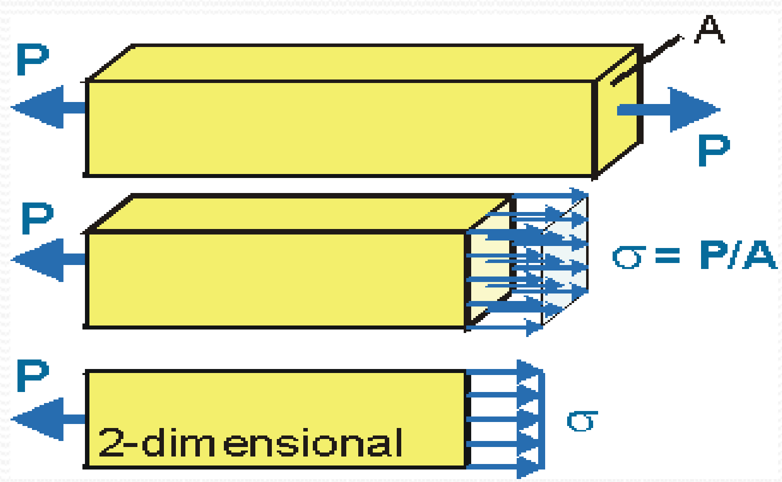
- Experience shows that any material subjected to a load may either deform, yield or break, depending upon the
  - The Magnitude of load
  - Nature of the material
  - Cross sectional dime.

CONTI..

- The sum total of all the elementary interatomic forces or internal resistances which the material is called upon to exert to counteract the applied load is called stress.
- Mathematically, the stress is expressed as force divided by cross-sectional area.

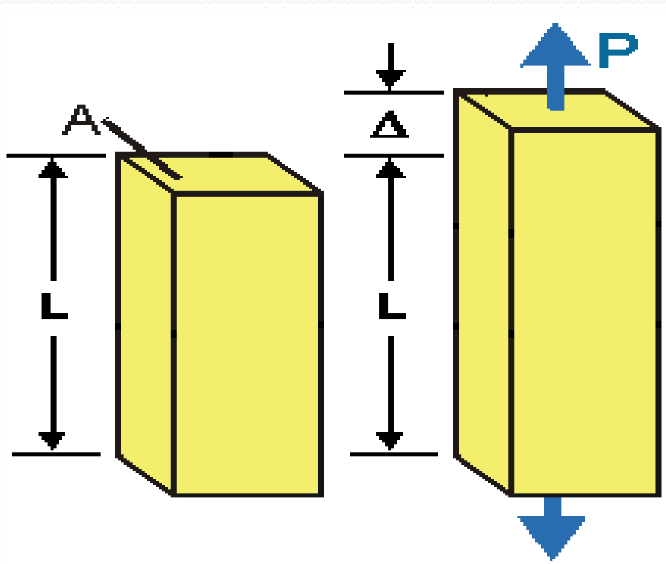


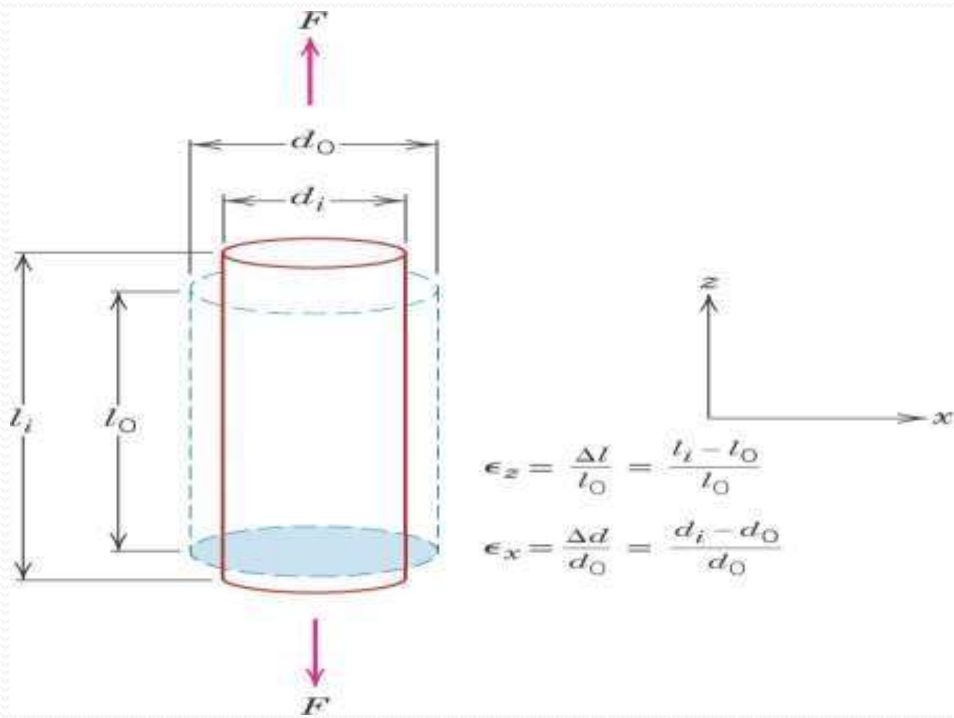
$$\text{Stress, } \sigma = \frac{\text{Force}}{\text{Cross-Sectional Area}} = \frac{F}{A_0}$$



CONTI…

- Strain is the dimensional response given by material against mechanical loading/Deformation produced per unit length.
- Mathematically Strain is change in length divided by original length.



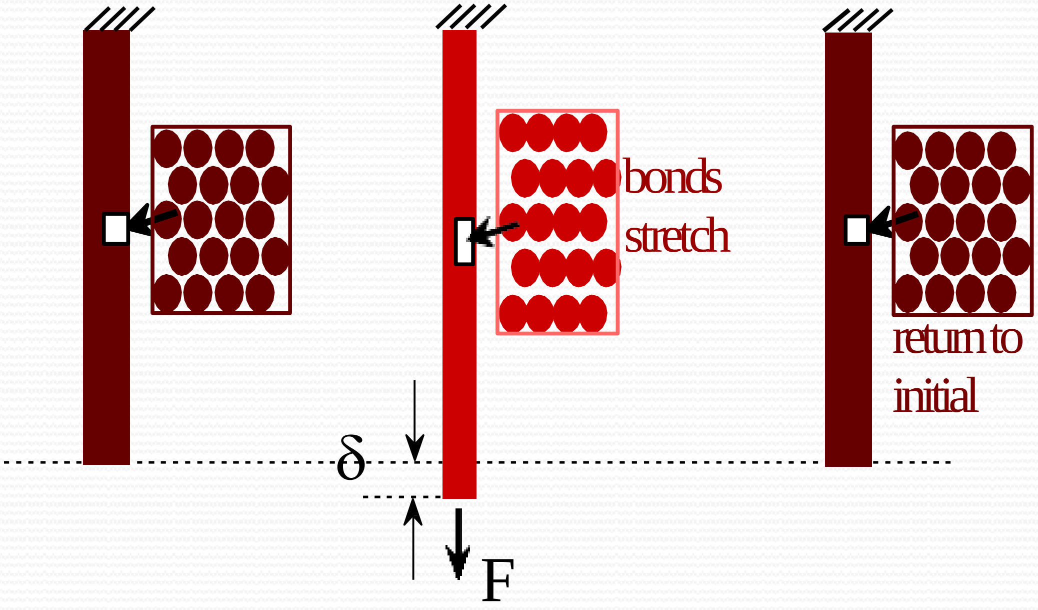


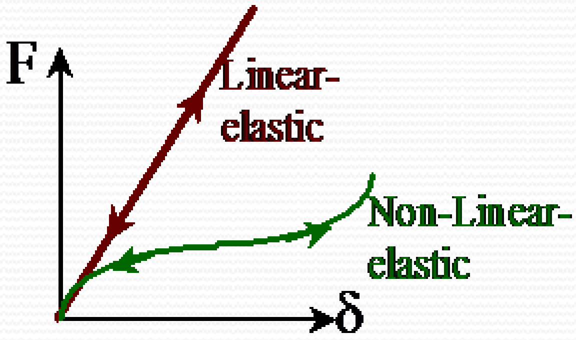
STRENGTH

- The strength of a material is its capacity to withstand destruction under the action of external loads.
- It determines the ability of a material to withstand stress without failure.
- The maximum stress that any material will withstand before destruction is called ultimatestrength.

ELASTICITY:

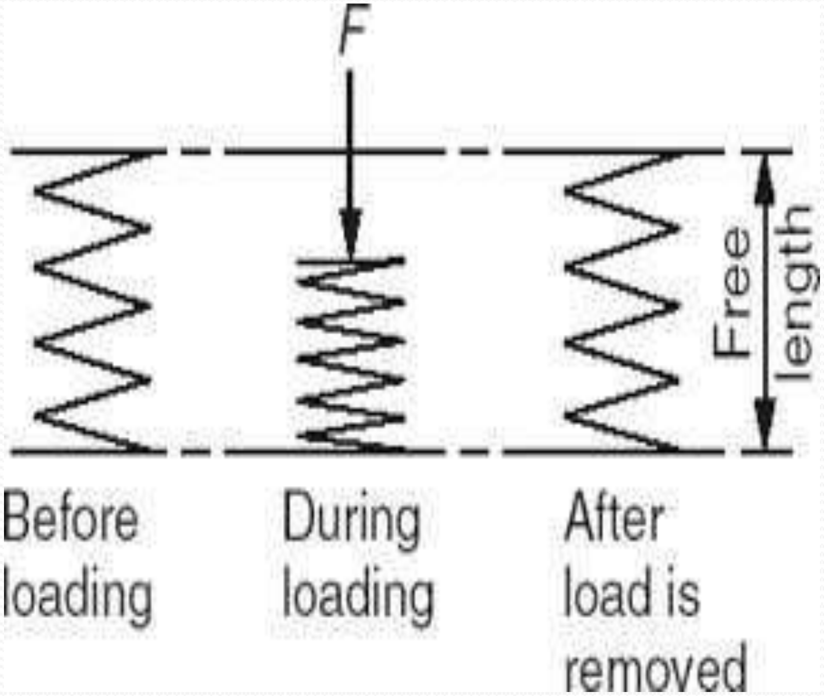
- The property of material by virtue of which deformation caused by applied load disappears upon removal of load.
- Elasticity of a material is the power of coming back to its original position after deformation when the stress or load is removed.

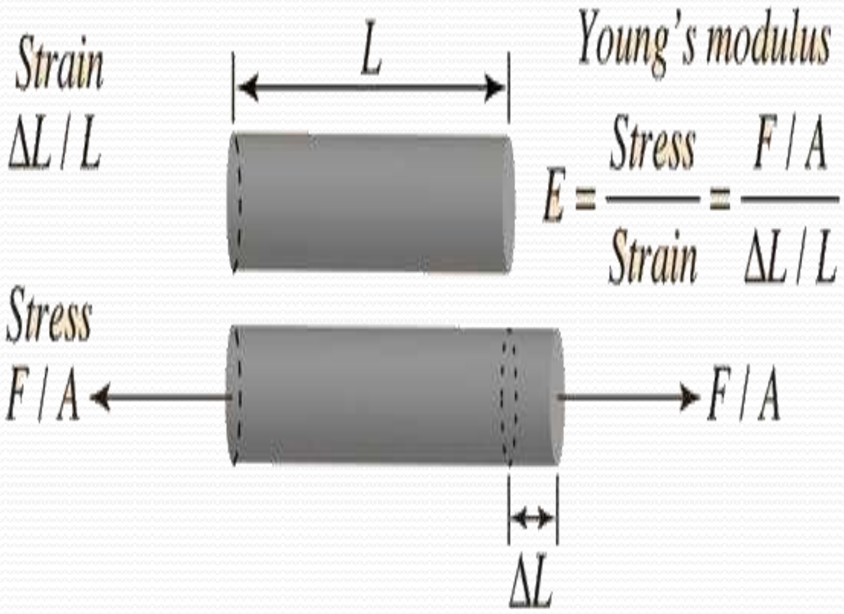




Elastic means reversible.

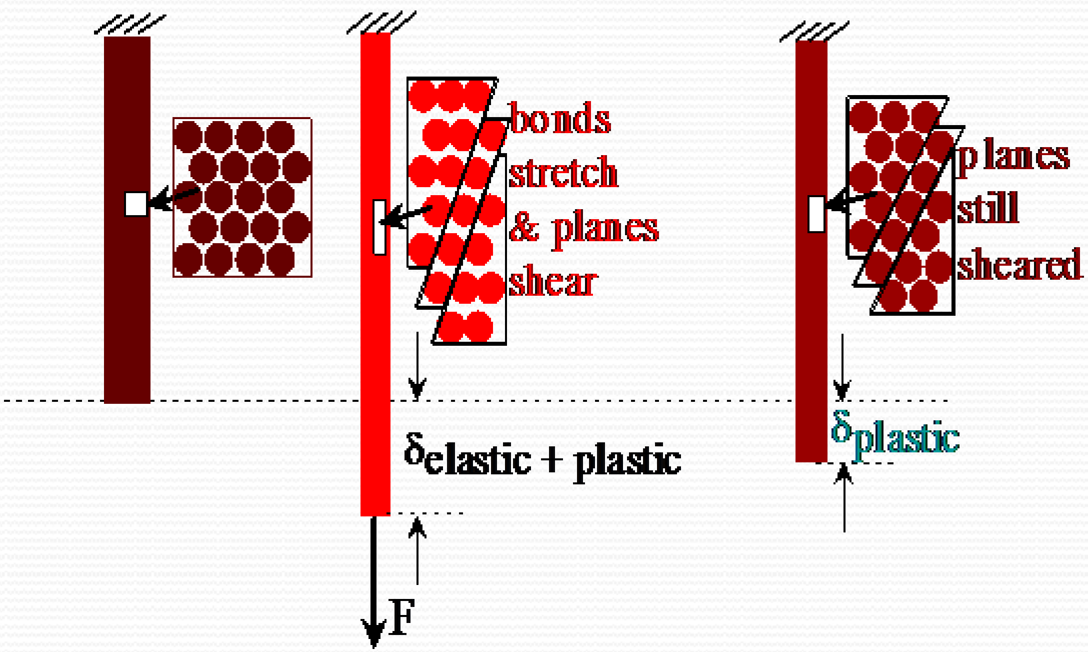
CONTI..

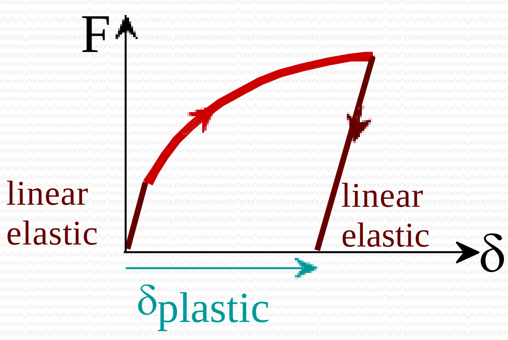

F
Free length
Before loading
During loading
After load is removed


Strain
ΔL / L
L
Young's modulus
E = Stress / Strain = F / A / ΔL / L
Stress
F / A
F / A
ΔL

PLASTICITY:

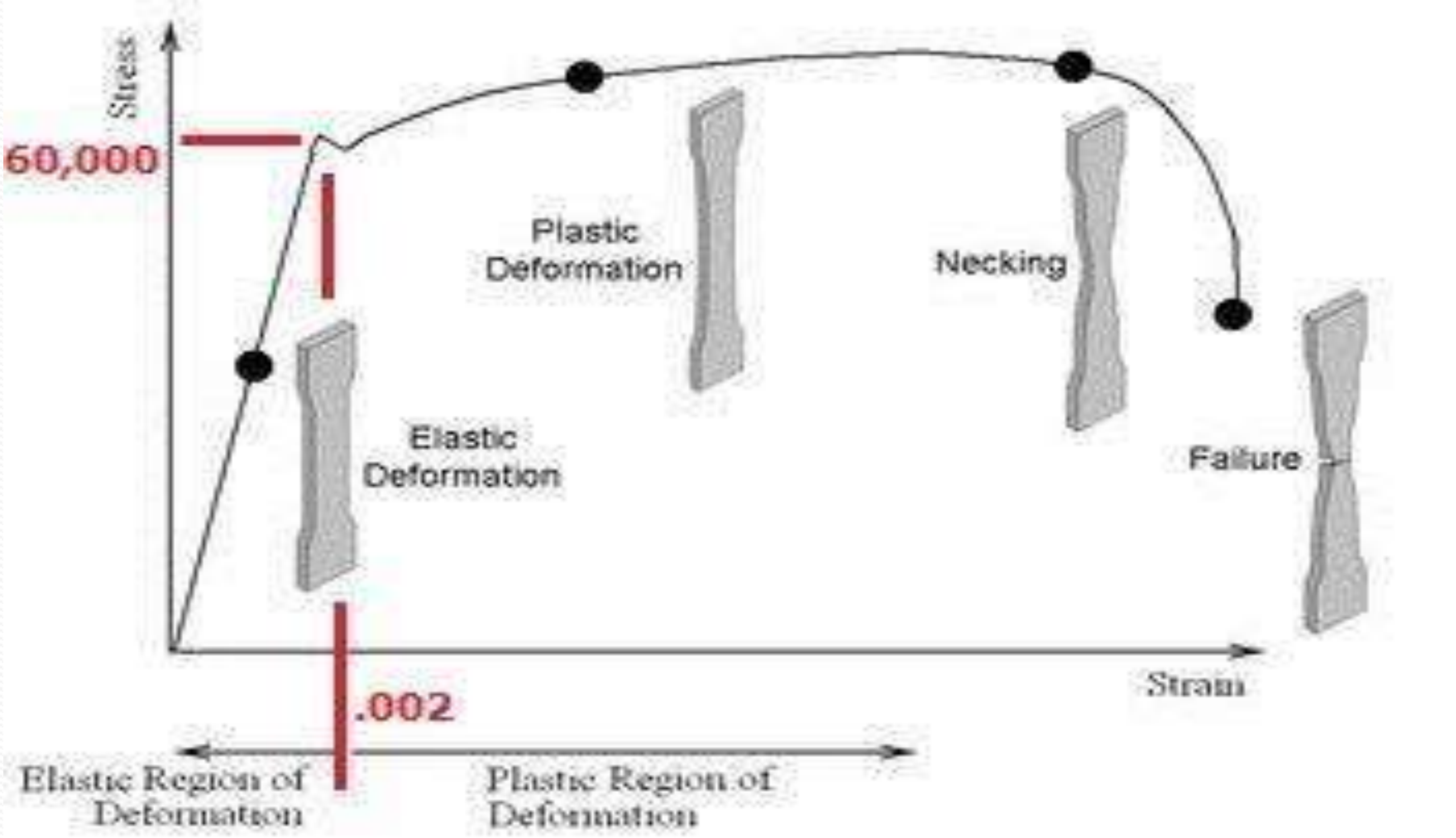
- The plasticity of a material is its ability to undergo some degree of permanent deformation without rupture or failure.
- Plastic deformation will take only after the elastic limit is exceeded.
- It increases with increase in temperature.





Plastic means permanent.

STRESS STRAIN CURVE SHOWS ELASTICITY AND PLASTICITY FOR MATERIALS:



STIFFNESS:

- The resistance of a material to elastic deformation or deflection is called stiffness or rigidity.
- A material which suffers slight deformation underload has a high degree of stiffness or rigidity.
- E.g. Steel beam is more stiffer or more rigid than aluminium beam.

DUCTILITY:

- It is the property of a material which enables it to draw out into thin wires.
- E.g., Mild steel is a ductile material.
- The percent elongation and the reduction in area in tension is often used as emperical measures of ductility.

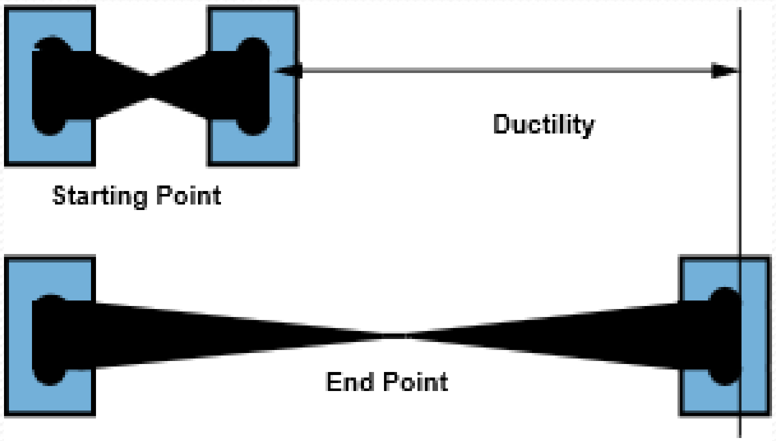
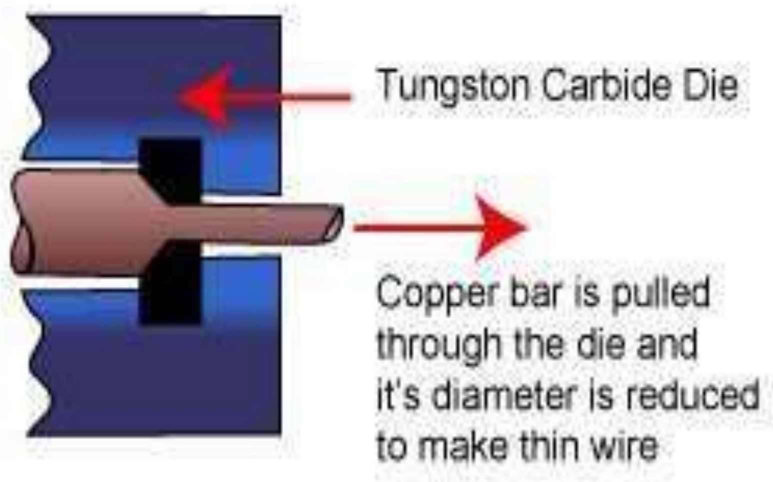
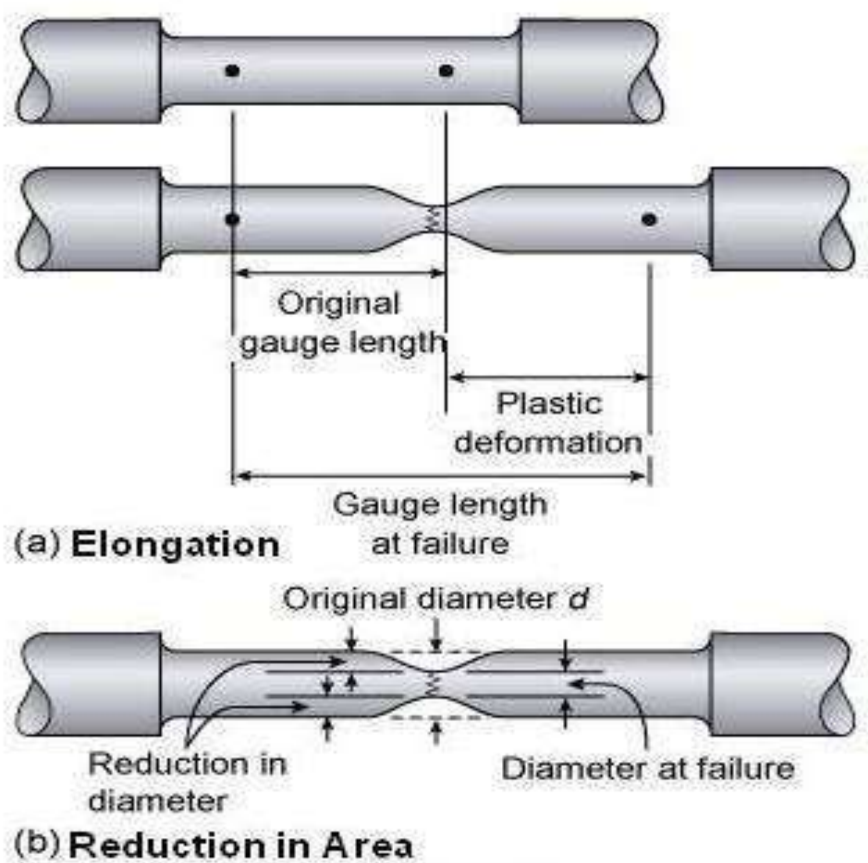
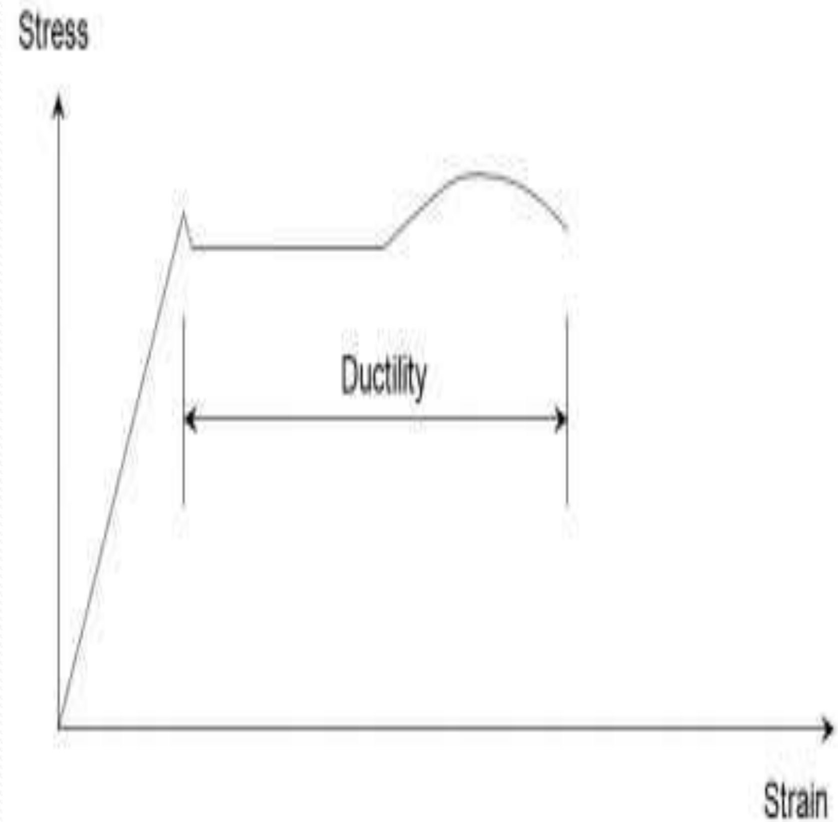


Figure 23:2: Ductility Test




Original
gauge length
Plastic
deformation
Gauge length
at failure
(a) Elongation
Original diameter d
Reduction in
diameter
Diameter at failure
(b) Reduction in Area

Ductility


Stress
Ductility
Strain

Malleability:

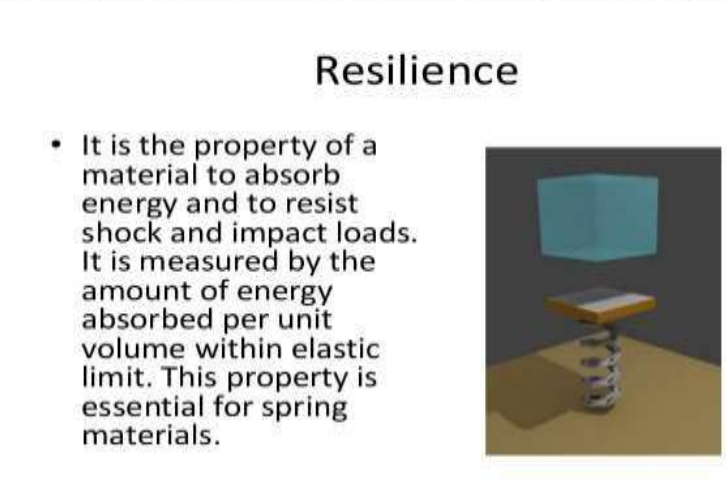
- Malleability of a material is its ability to be flattened into thin sheets without cracking by hot or cold working.
- E.g Lead can be readily rolled and hammered into thin sheets but can be drawn into wire.

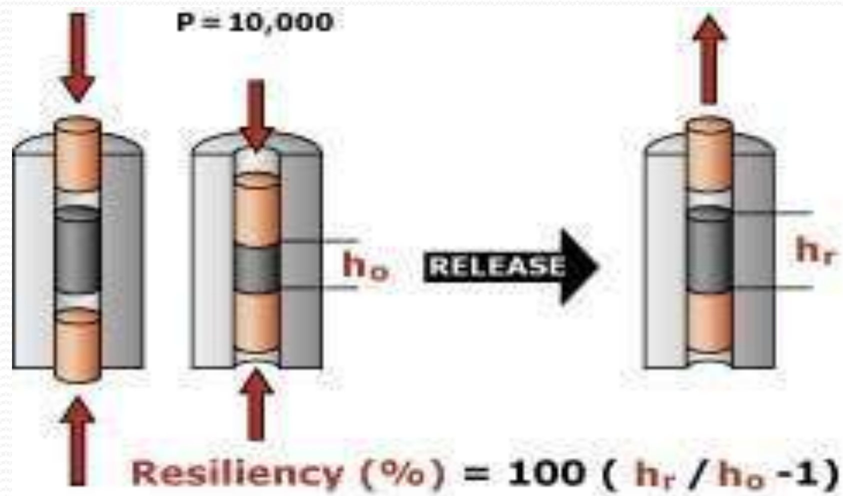
Comparision of ductility and malleability

- Ductility and Malleability are frequently used interchangeably many times.
- Ductility is ***tensile quality, while*** malleability is ***compressive quality.***

RESILIENCE:

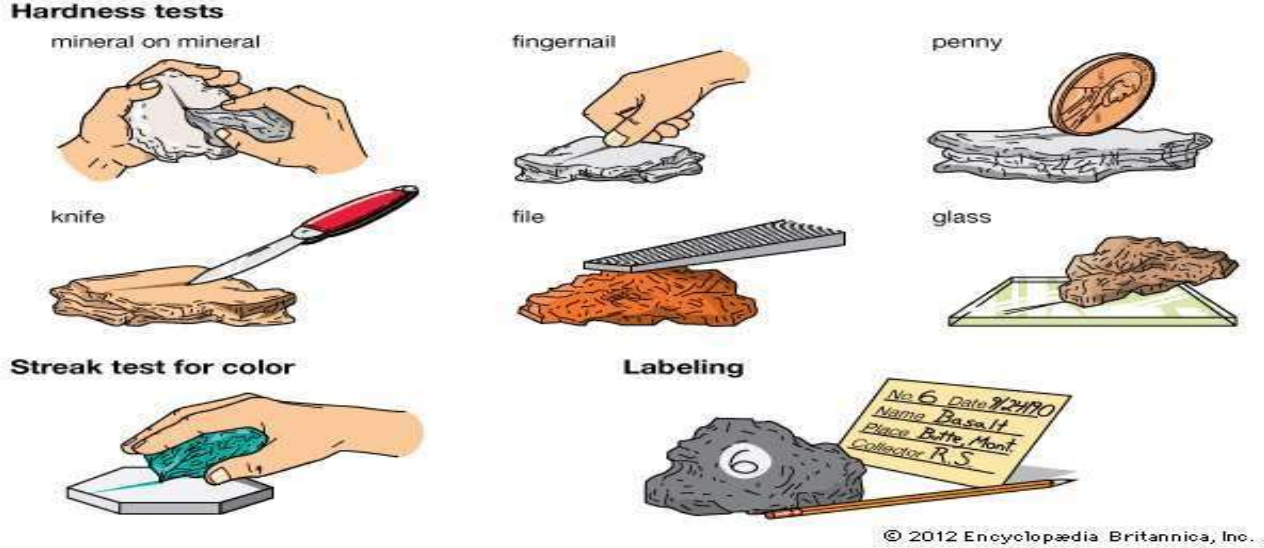
- It is the capacity of a material to absorb energy elastically.
- The maximum energy which can be stored in a body upto elastic limit is called the ***proof resilience, and*** the proof resilience per unit volume is called ***modulus of resilience***.
- The quantity gives capacity of the material to bear shocks and vibrations.





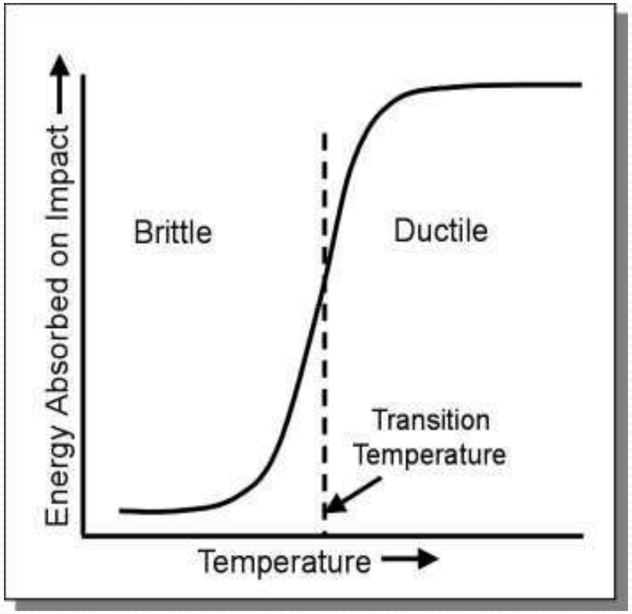
HARDNESS:

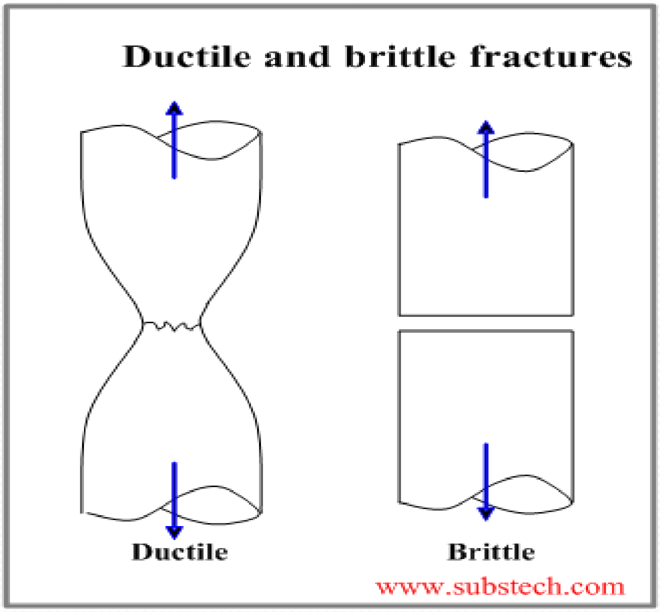
- Hardness is a fundamental property which is closely related to strength.
- Hardness is usually defined in terms of the ability of a material to resist to ***scratching, abrasion, cutting, identation,or penetration.***
- Methods used for determining hardness: Brinel, Rockwell ,Vickers.



BRITTLENESS:

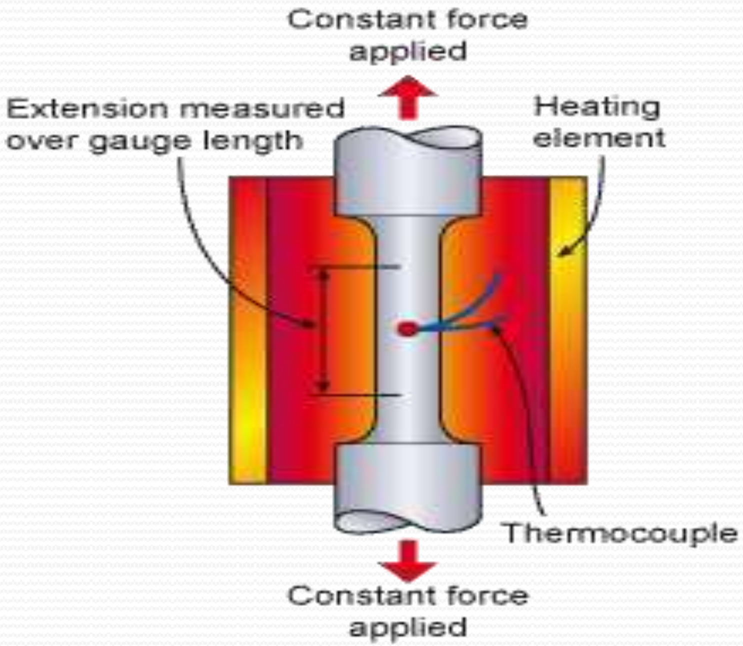
- It is the property of breaking without much permanent distortion.
- Non-Ductile material is considered to be brittle material.
- E.g, Glass, Cast iron,etc.





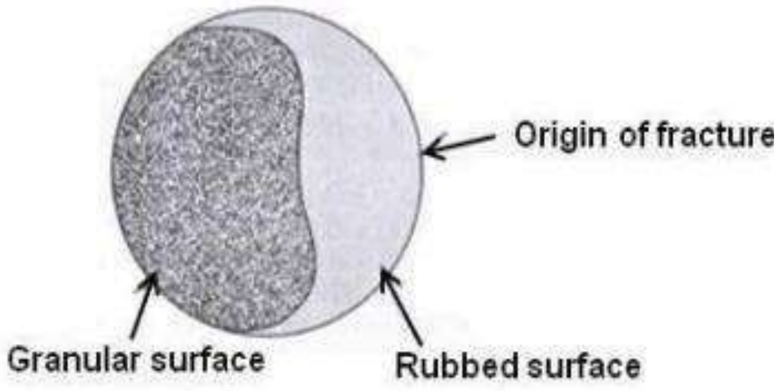
CREEP:

- The slow and progressive deformation of a material with time at constant stress is called creep.
- Depending on temperature, stresses even below the elastic limit can cause some permanent deformation.
- It is most generally defined as time-depndent strain occuring under stress.



FATIGUE:

- This phenomenon leads to fracture under repeated or fluctuating stress.
- Fatigue fractures are progressive beginning as minute cracks and grow under the action of fluctuating stress.
- Many components of high speed aero and turbine engines are of this type.



Surface of a Fatigue Fracture

Material Strengthening Mechanisms

Agenda

- Definition of strengthening
- Strengthening mechanisms
- Grain size reduction
- Solid solution alloying
- Cold Working (strain hardening)
- Three steps of Annealing: Recovery, Recrystallization & Grain Growth

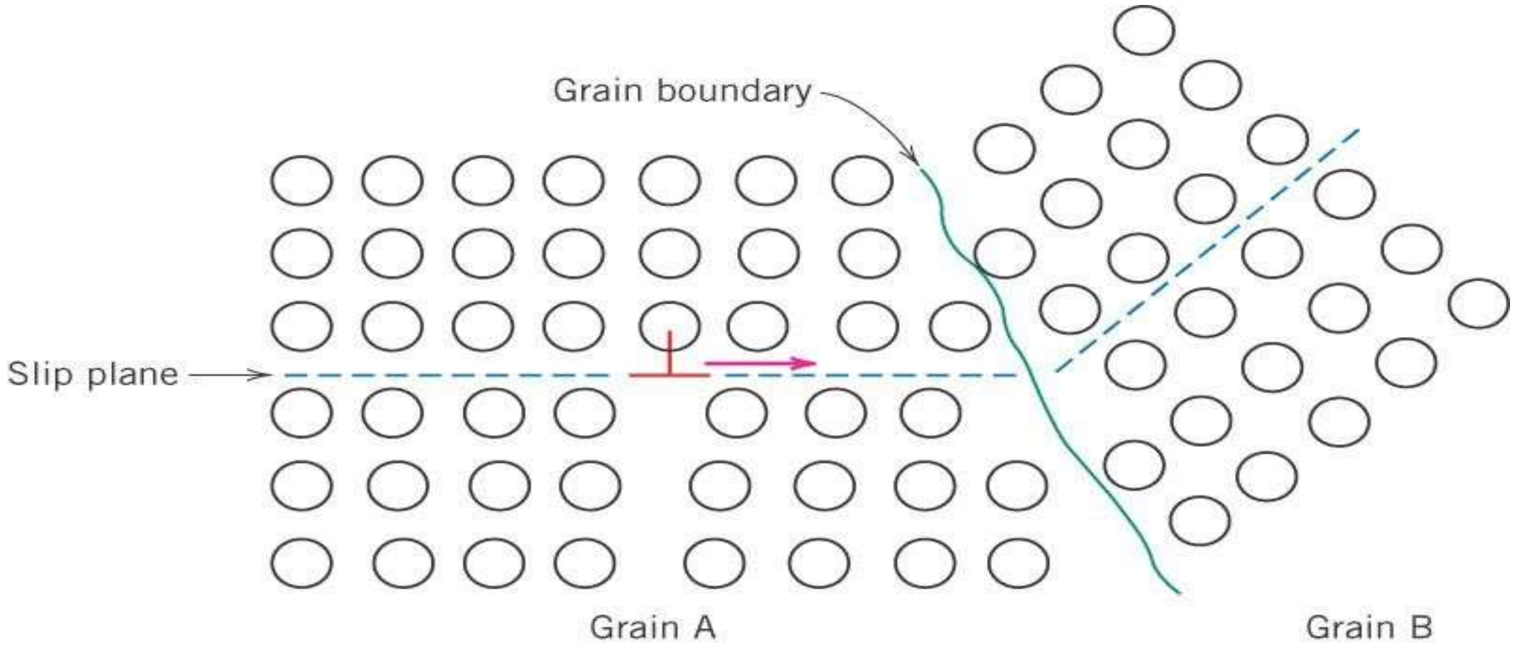
Strengthening

- The ability of a metal to deform plastically depends on the ability of dislocations to move.
- Hardness and strength are related to how easily a metal plastically deforms, so, by reducing dislocation movement, the mechanical strength can be improved.
- To the contrary, if dislocation movement is easy (unhindered), the metal will be soft, easy to deform.

Strengthening Mechanisms

1. Grain Size Reduction
2. Solid Solution Alloying
3. Strain Hardening (Cold Working)
4. Annealing

1. Grain Size Reduction



- Grain boundaries are barriers to slip.
- Barrier "strength " increases with misorientation.
- Smaller grain size: more barriers to slip.

Hall Petch Relation

- This equation indicates that the yield strength has an inverse square root relation with grain size (d).

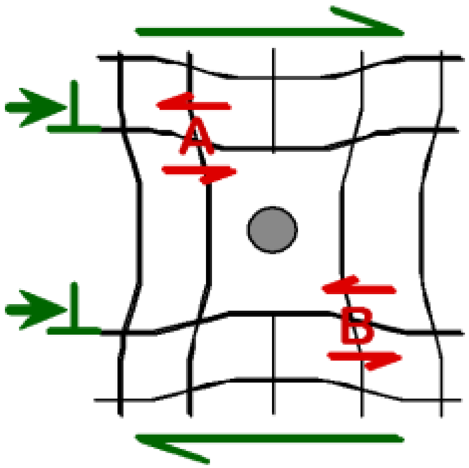
- Theoretically, a ... ong if the grains are made ...

$$\sigma_{yield} = \sigma_o + k_y d^{-1/2}$$

2. Solid Solutions

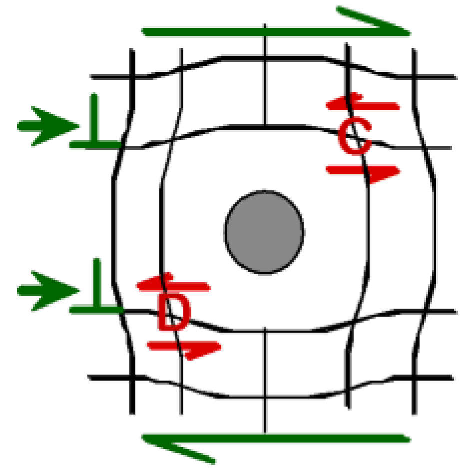
- Impurity atoms distort the lattice & generate stress.
- Stress can produce a barrier to dislocation motion.

Small substitutional impurity



Impurity generates local shear at A and B that opposes dislocation motion to the right.

Large substitutional impurity

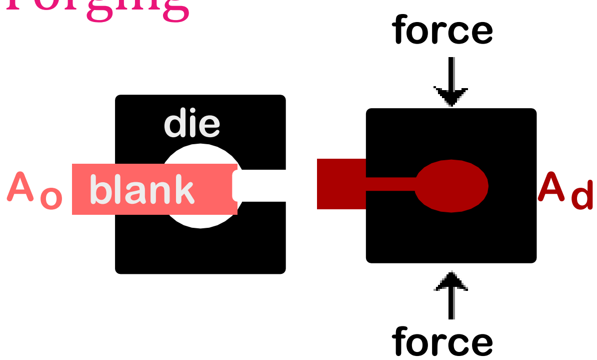


Impurity generates local shear at C and D that opposes dislocation motion to the right.

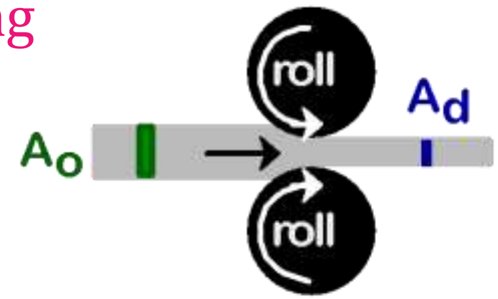
3. Strain Hardening (Cold Work)

- Room temperature deformation.
- Common forming techniques used to change the cross sectional area:

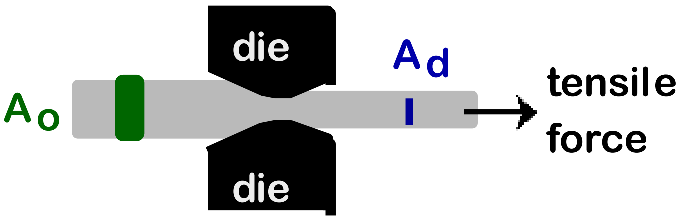
-Forging



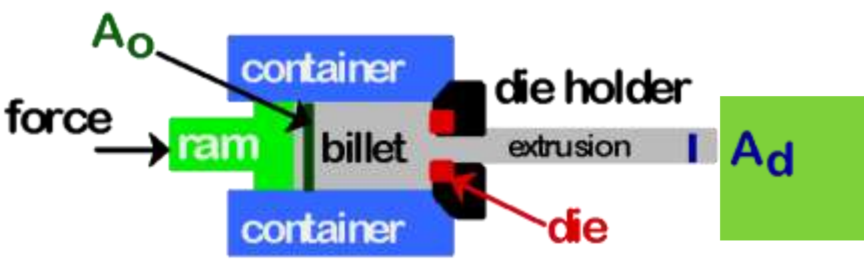
-Rolling



-Drawing



-Extrusion

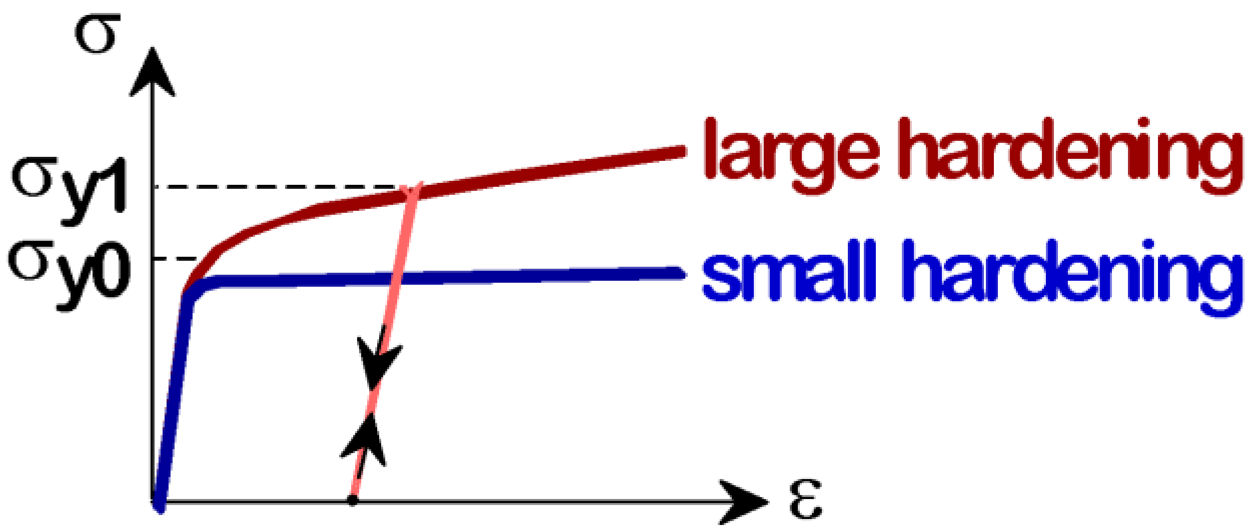


Dislocations during Cold Work

- Dislocations entangle one another during cold work.
- Dislocation motion becomes more difficult, which makes the material stronger overall.

Result of Cold Work

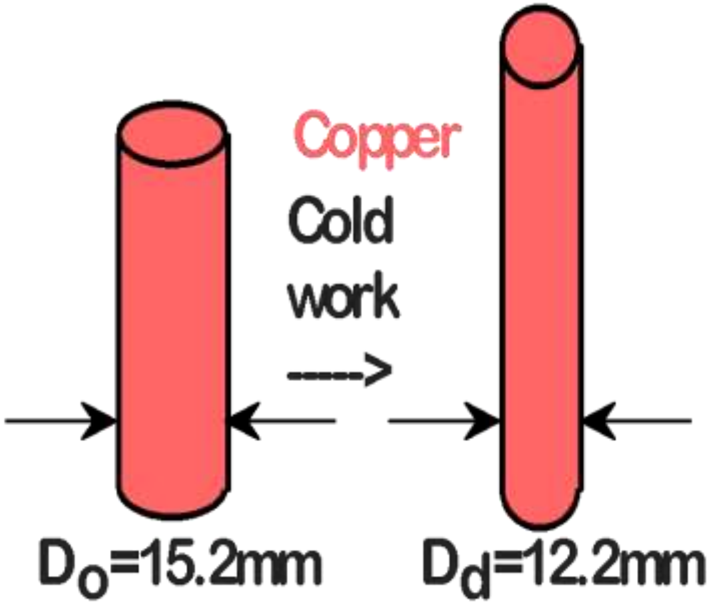
- Dislocation density increases, which leads to a increase in yield strength: Materials becomes harder.
- Ductility and tensile strength also increases.



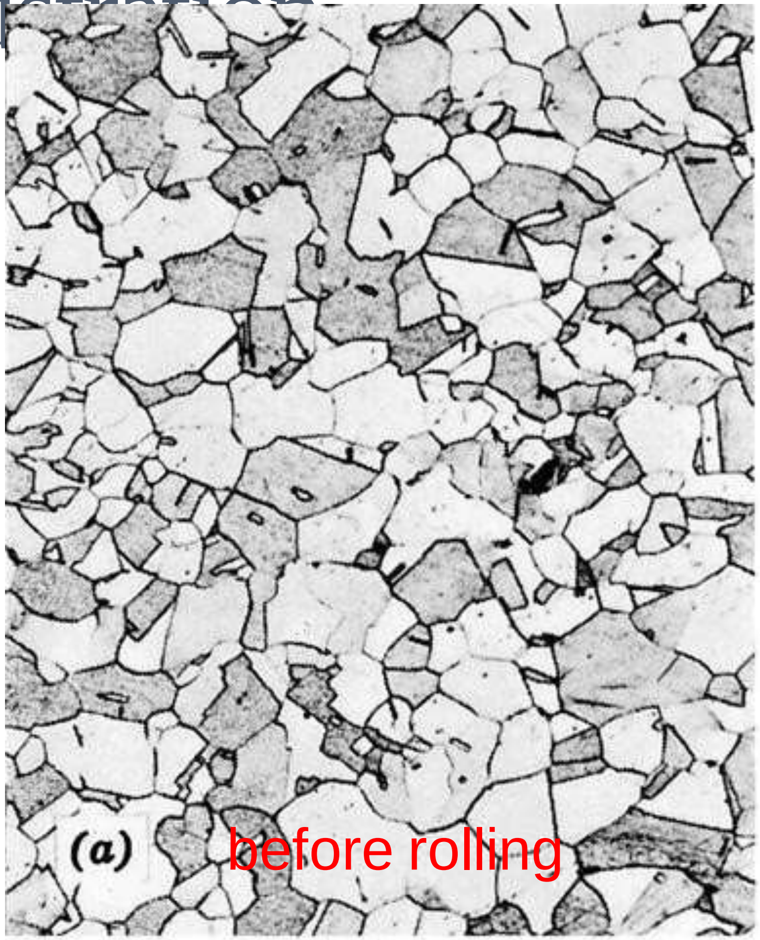
Percentage Cold Work - Definition

$$\%CW = \frac{A_o - A_d}{A_o} x100$$

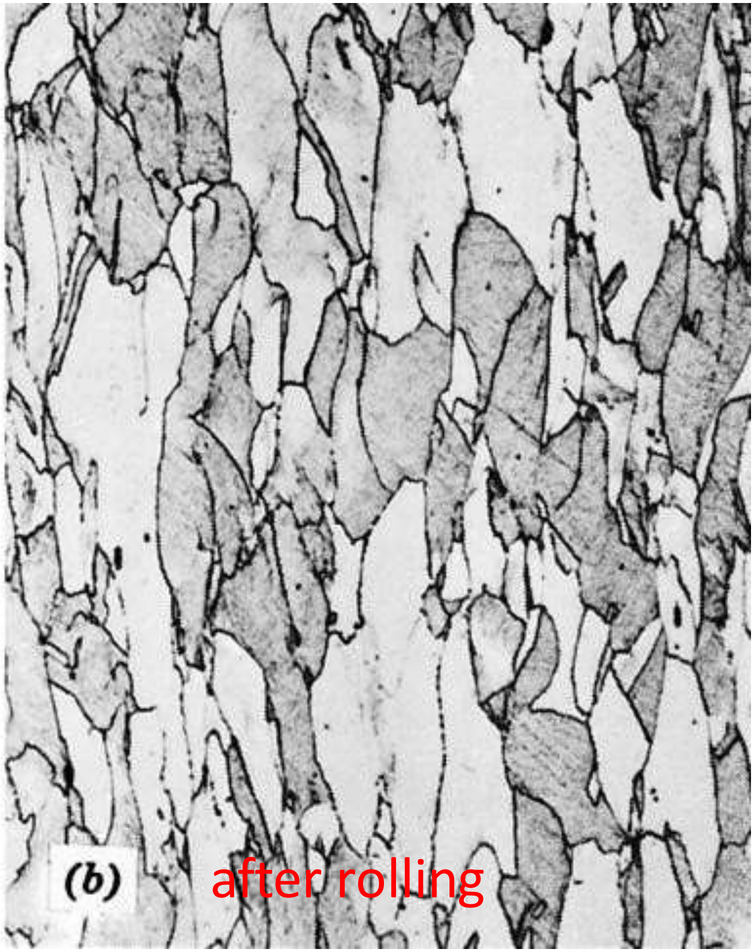
$$\%CW = \frac{\pi r_o^2 - \pi r_d^2}{\pi r_o^2} x100 = 35.6\%$$



Cold Rolling Illustration



Isotropic
grains are approx. spherical, equiaxed & randomly oriented.



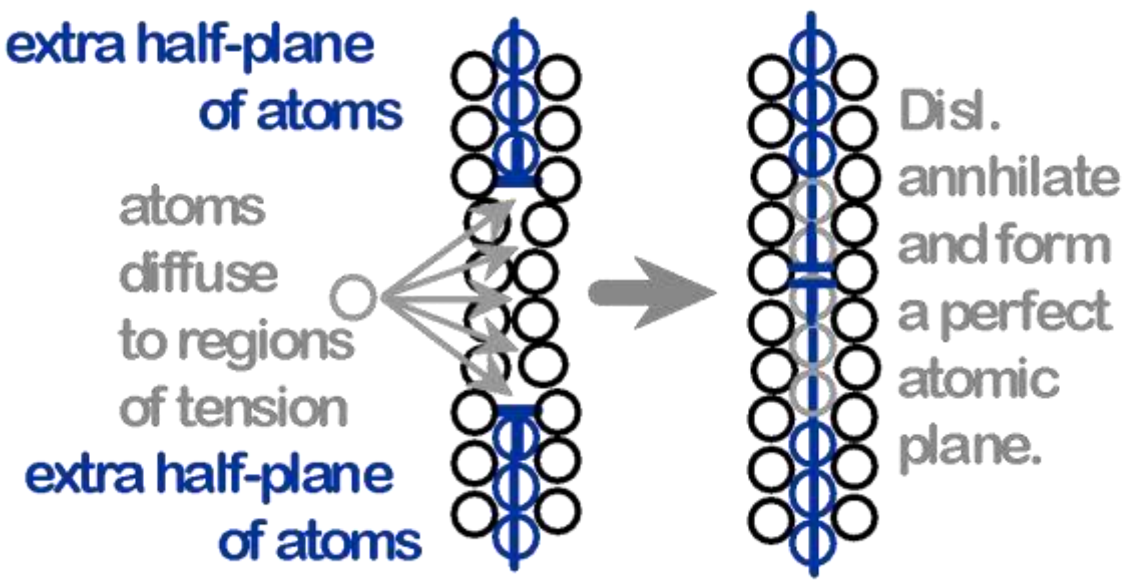
Anisotropic (directional)
since rolling affects grain orientation and shape.

Annealing

- Process where material is heated to above the recrystallization temperature of the sample and then cooled down.
- Main purpose is to improve Cold work properties by increasing ductility and retaining most of the hardness.
- There are 3 steps involved with annealing: recovery, recrystallization and grain growth.

Recovery

- During recovery, some of the stored internal strain energy is relieved through dislocation motion due to enhanced atomic diffusion at the elevated temperatures.
- Leads to reduction in the number of dislocations.



Recrystallization

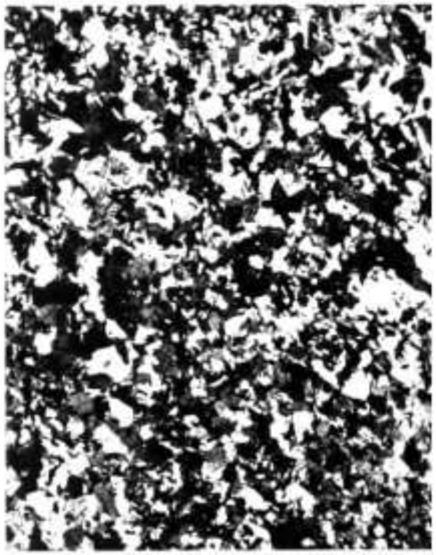
- After recovery is complete, the grains are still in a relatively high strain energy state.
- Recrystallization is the formation of a new set of strain-free and uniaxial grains that have low dislocation densities.
- The driving force to produce the new grain structure is the internal energy difference between strained and unstrained material.
- The new grains form as very small nuclei and grow until they consume the parent material.

Recrystallization Illustration

Cold Worked grains.
Not annealed.

Initial recrystallization after 3 seconds @ 580°C

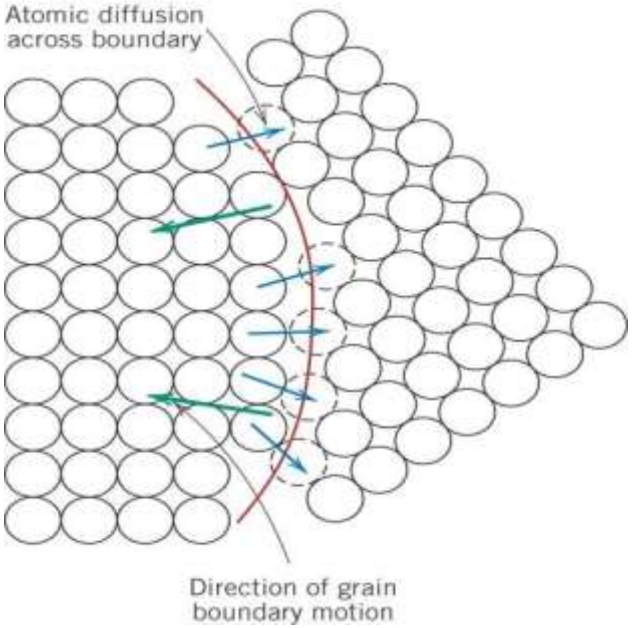
Partial replacement of grains, after 4 seconds



Complete recryst. after 8 seconds

Grain Growth

- After recrystallization, the strain-free grains will continue to grow if the metal specimen is left at elevated temperatures.
- As grains increase in size, the total boundary



area decreases, as does the total energy.

- Large grains grow at t he expense of smaller grains.