# FAILURE MODES





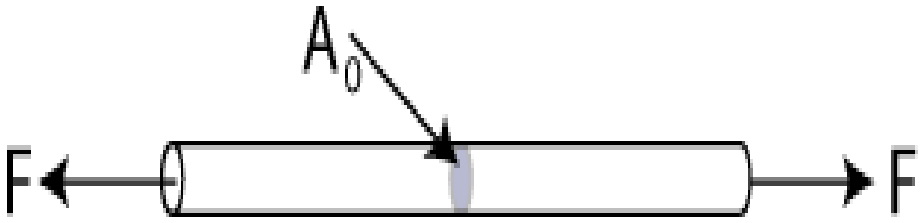


# STRESS

- When a material is loaded with a force, it produces a stress, which then causes a material to deform

  "Defined as the internal force per unit area"

  Stress = *Load* / x-*sectional area* of the specimen



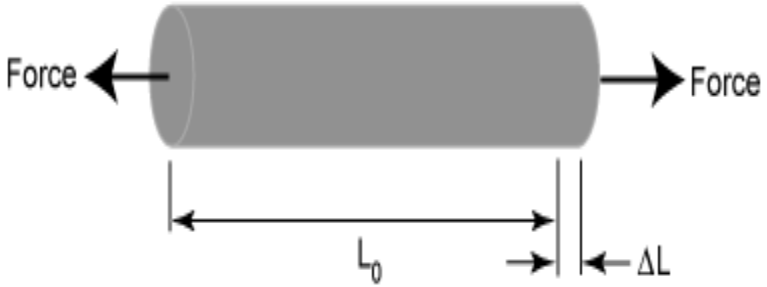

$$\text{Stress, } \sigma = \frac{\text{Force}}{\text{Cross-Sectional Area}} = \frac{F}{A_0}$$

# STRAIN

- Relative change in size & shape of the material due to externally applied forces

  “Defined as the amount of deformation in the direction of the applied force divided by the original length of the material”

  Strain = *Increase in length /Original length*

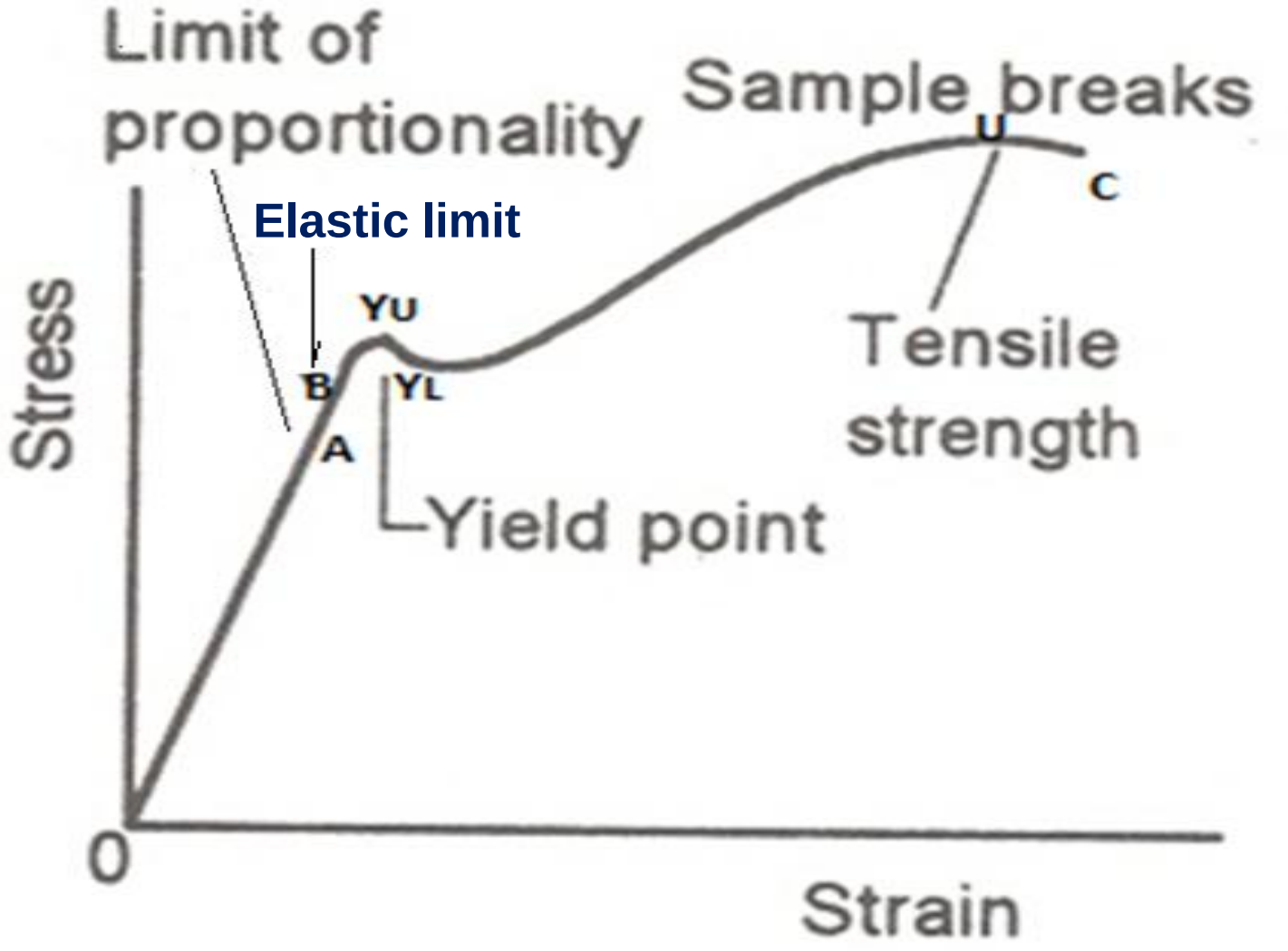



$$\text{Strain} = \frac{\text{Elongation}}{\text{Orininal Length}} = \frac{\Delta L}{L_0}$$

# STRESS-STRAIN DIAGRAM FOR MS

- A stress –strain diagram is shown for mild steel
- When the load applied over the test specimen is slowly increased, it is seen that stress is proportional to strain up to A. A is the limit up to which stress & strain bear a constant ratio & obeys Hook's law. Point 'A' denotes the limit of proportionality.

# STRESS-STRAIN DIAGRAM FOR MS



# STRESS-STRAIN DIAGRAM FOR MS

- The stress at which the material starts to behave in a non-elastic manner is called the elastic limit.
- Between A & B, the material behaves elastically & regains the original position after removal of load.
- Point ‘B’ denotes the elastic limit
- As the load is increased beyond point B, there comes a point at which there is a sudden extension & continued extension with a lower load

# STRESS-STRAIN DIAGRAM FOR MS

- If the load is removed, the specimen does not recover its original dimension & it is said to have undergone plastic deformation or plastic flow
- The upper is yield point & denoted by $Y_U$, the highest stress before sudden extension occurs.
- The lower YP ($Y_L$) is the lowest stress producing the large elongation
- Two yield points are noticed in mild steel

# STRESS-STRAIN DIAGRAM FOR MS

- In general, ductile materials show only one yield pt.
- As the load is increased beyond YP, the test specimen stretches rapidly- first uniformly along the entire length & then locally to form a ‘Neck’
- This necking occurs just after the max force value is reached at U & since the x-section decreases rapidly at the neck, the force at C required to break the test piece is less than the max force applied at U.

# STRESS-STRAIN DIAGRAM FOR MS

- Ultimate tensile stress is the stress corresponding to point U. it is the max stress that a material can bear.
- After point U, there is a rapid increase in permanent deformation & stress value decreases. Finally rupture of material takes place at point C.

# PROPORTIONAL LIMIT & ELASTIC LIMIT

Definition: (Proportional limit )

"The highest stress at which stress is directly proportional to strain".

- obtained by observing the deviation from the straight-line portion of the stress-strain curve.

Definition: (Elastic limit )

"The greatest stress the material can withstand without any measurable permanent strain"

*In most metallic materials the elastic limit and proportional limit are essentially the same.

# TENSILE STRENGTH

Definition:

"The maximum load applied in breaking a tensile test piece divided by the original cross-sectional area of the test specimen"

Tensile Strength=Max Load/Original x-sectional area

- Expressed in tsi & now measured as $N/mm^2$

# ELONGATION

Definition:

"The percentage increase in length of a tensile test piece caused by wasting or necking of the specimen"

%E=Increase in GL/Original GL X100

- A measure of ductility
- Higher elongation indicates high ductility (material  more deformable)
- The two pieces are placed together and the amount of extension is measured against marks made before starting the test
- Expressed as a %age of the original GL

# REDUCTION OF AREA

Definition:

"The percentage decrease in the cross- sectional area of a tensile test piece caused by wasting or necking of the specimen"

%RA=Difference in x-sectional area/Original area x100

- A measure of ductility
- The change in cross-sectional area divided by the original cross-sectional area
- This change is measured in the necked down region of the specimen
- Expressed as a percentage of the original area of the test piece
- It decreases, if defects are present in the test piece

# YIELD STRENGTH

Definition:

"Stress applied to the material at which plastic deformation starts while the material is loaded".

YS=Yield force/Original x-sectional area

- more important than tensile strength in mechanical design

# MODULUS OF ELASTICITY

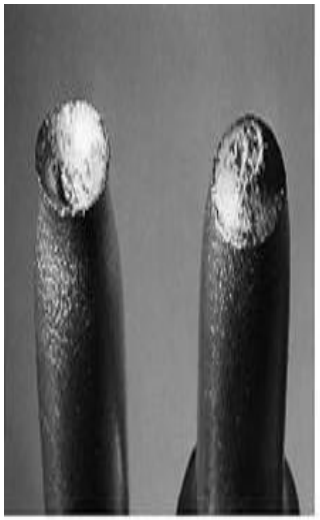
- The elastic behaviour is characterised as the ratio of stress to strain & is referred to as Young's modulus.

  YM= Stress / Strain

- Real indicator of stiffness (high YM material is stiff)
- Can be measured from the slope of stress – strain curve
- More appropriate guide to the required properties

# FRACTURE

- Fracture: Fractus(Latin) means fracture
- Physical separation or tearing of a component into two or more pieces through an internal or external crack under the action of load.
- Occurs when a piece of metal is stressed beyond its UTS
- Can occur at stresses even below its elastic limit



Ductile fracture



Brittle fracture

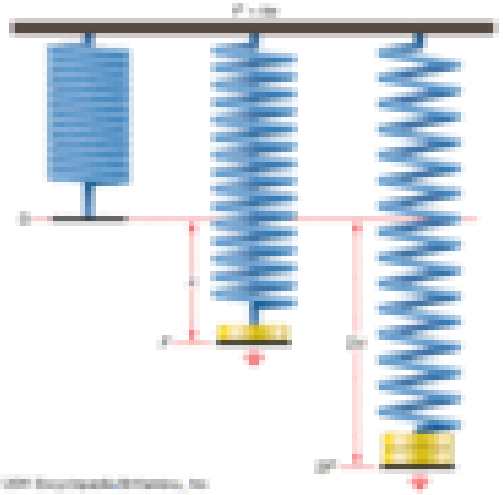


Fatigue fracture

# DEFORMATION & ITS TYPES

Definition:

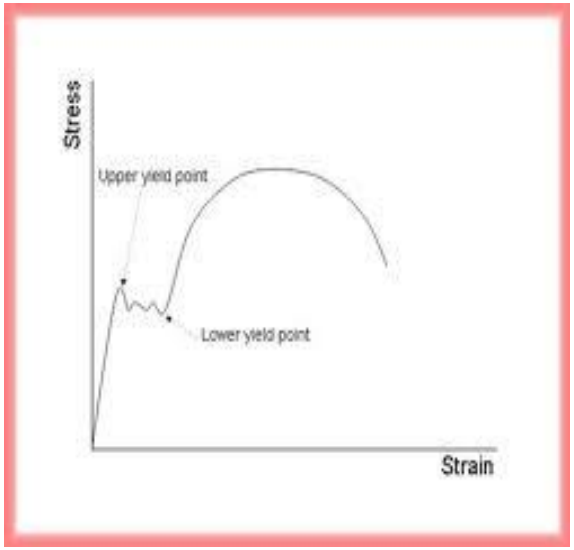
Changes in dimension of a material under the action of sufficient load.



Types of deformation:-

- Elastic deformation:
  - Takes place when a small load is applied.
  - Temporary shape change
  - Returns back to its original shape after load removal.
  - Occurs when stress □ YS

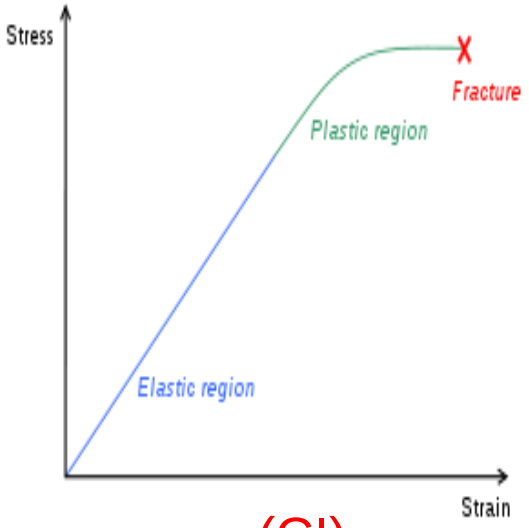
  Examples: Elastomers (natural rubber, PVC), soft thermo- plastic (polythene), some metals, etc.



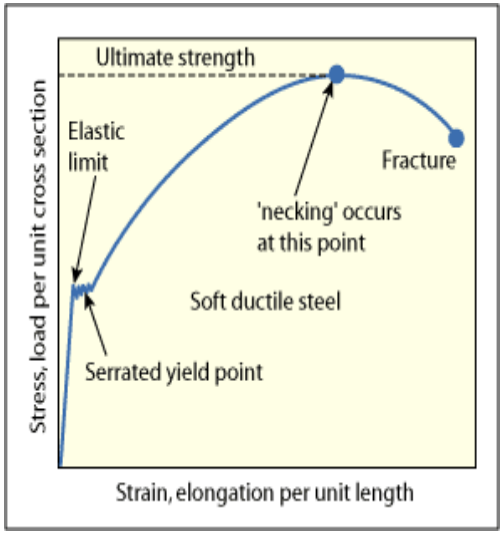
# CONTD----

- Plastic deformation:
  - Takes place when loaded beyond its elastic limit
  - continues with increasing load until fracture takes place
  - permanent shape change
  - fails to return its original shape after removal of load.

  Example: ceramics (glasses, porcelain, rocks, etc), hard thermosetting plastics (Bakelite), etc




(CI)




(MS)

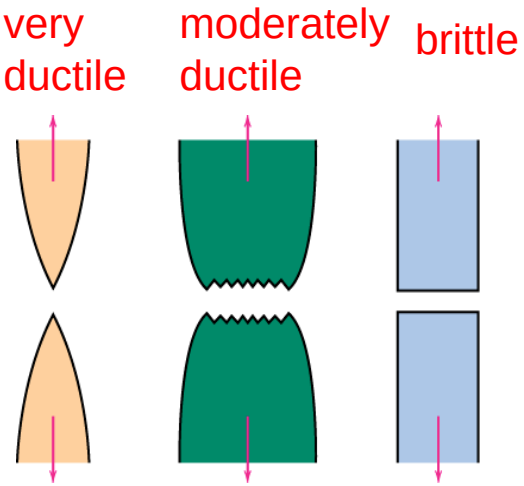
# FAILURE MODE & ITS TYPE

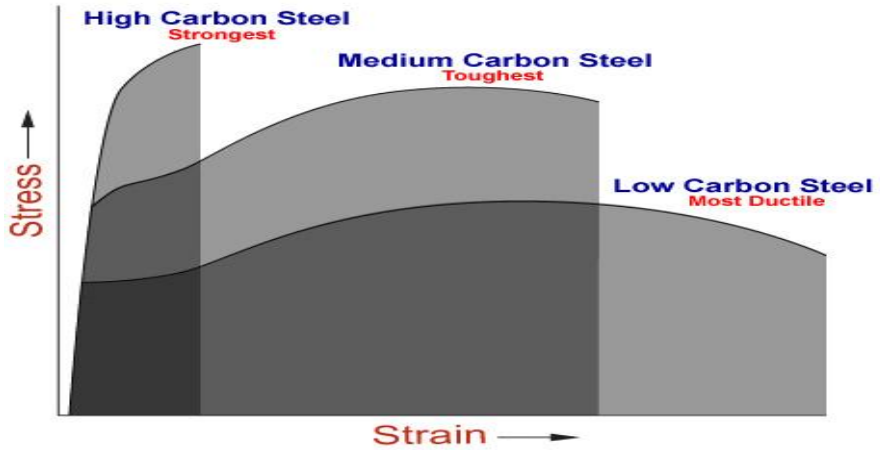
"The way in which a system fails”

Types of failure mode:

A component fails in either of the modes:-

- Ductile mode
- Brittle mode
- Mixed mode



# SUDDEN FRACTURE

- Bright & crystalline appearance.
- Entire f/f: Sudden and crystalline without origin.
- No apparent smooth zone.
- No apparent sign of plastic deformation.
- Occurs suddenly without any warning
- Very little or no plastic deformation
- Shiny appearance with no RA & necking at the fracture point.

# SUDDEN FRACTURE

- Sudden shock or impact loading: main cause.
- Mostly results in catastrophic failure [sudden failure leading sometimes to mishaps (including destruction of property & life)]
- Usually contains a pattern on f/f like “chevron pattern“ (V-shaped markings) is formed which indicate the origin of fracture.



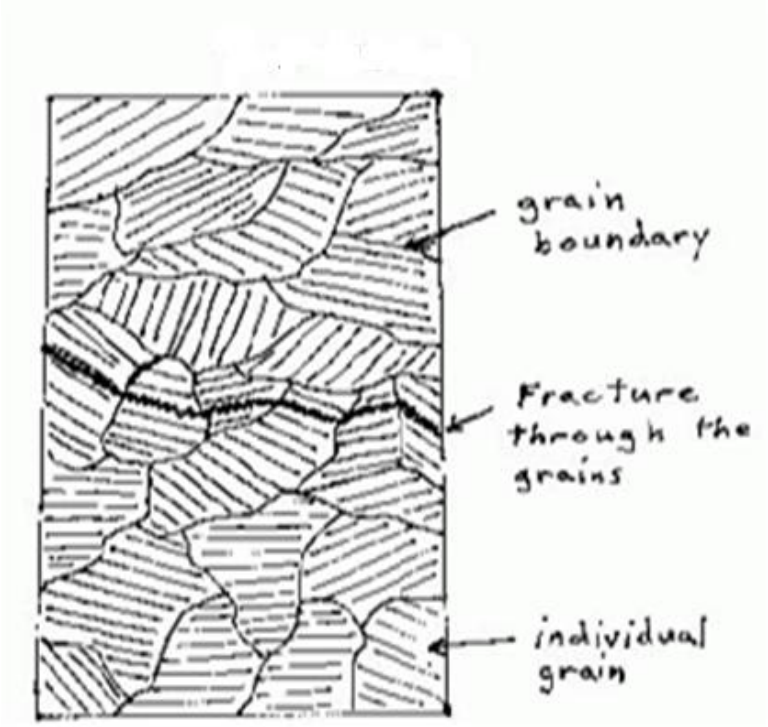


V-shaped markings (chevron type) pointing to the origin of the crack.

# TYPES OF SUDDEN FRACTURE

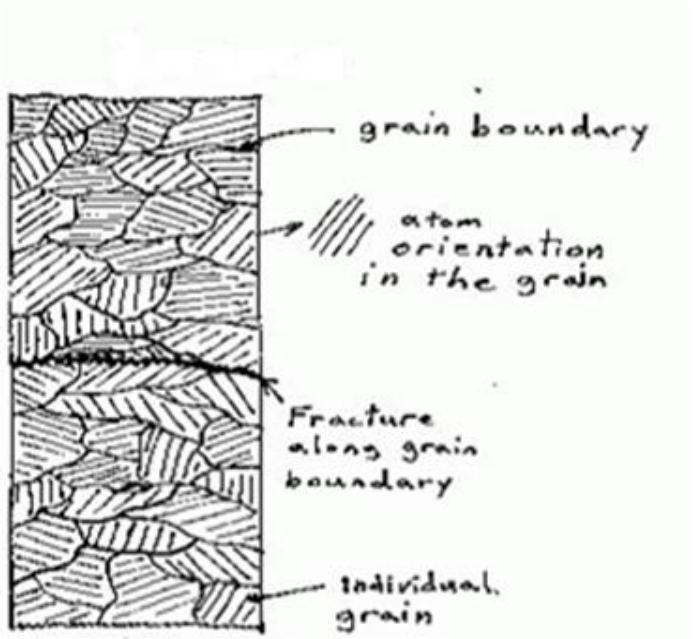
**Transgranular**

- Crack travelling through grain of the material.




**Intergranular**

- crack travelling along the grain boundaries, and not through the actual grains.



# SUDDEN FRACTURE

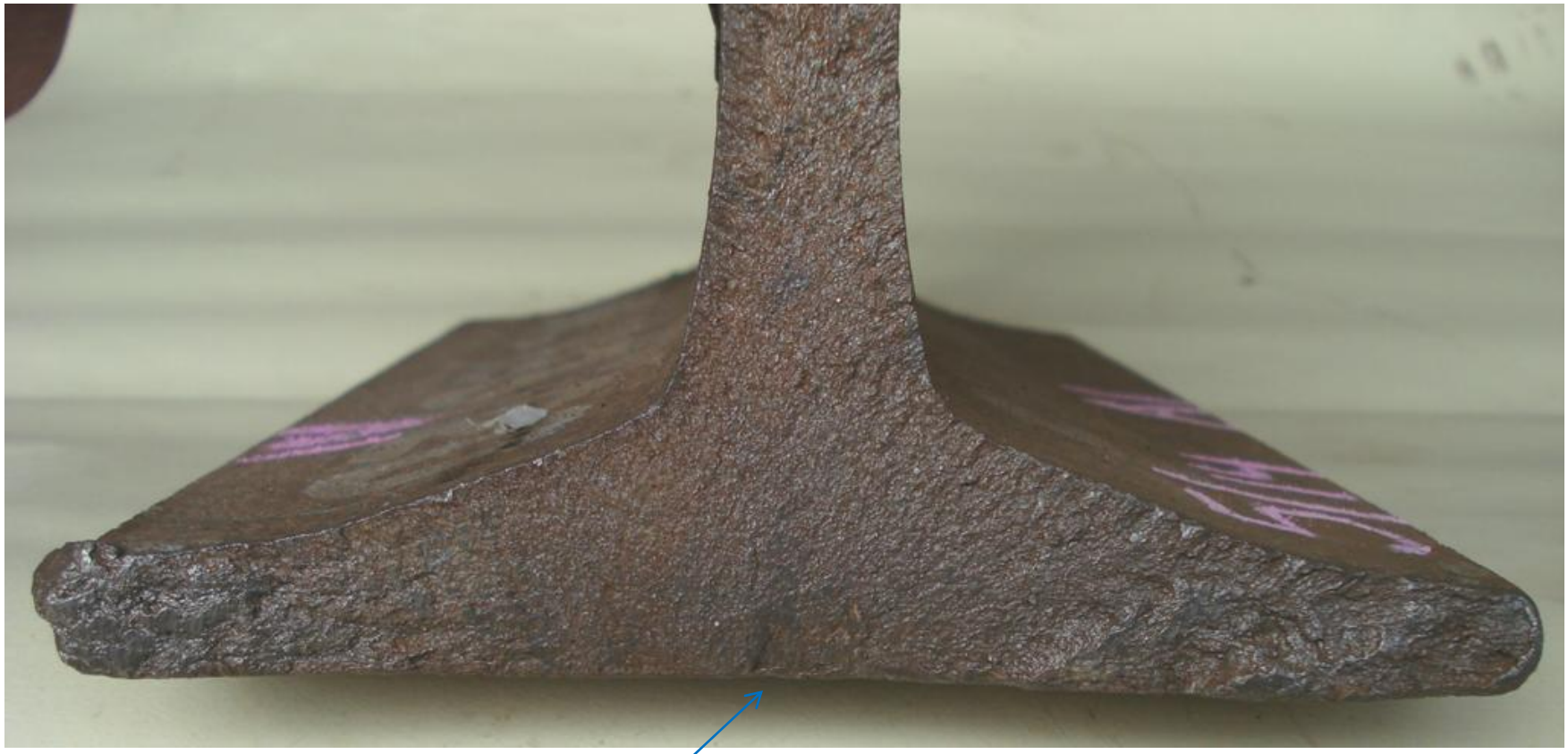
Brittle fracture of a rail



Brittle fracture of a Knuckle



# SUDDEN FRACTURE



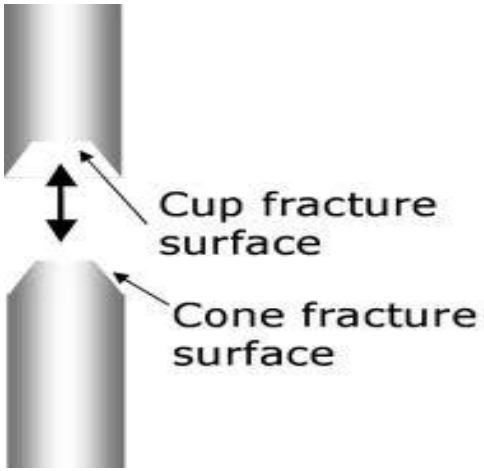
Chevron patterns

# DUCTILE FRACTURE

- Dull grey and fibrous appearance
- Cup and cone shape
- Large amounts of plastic deformation occurs
- Associated with “RA & Neck formation” at the pt. of fracture i.e. cup & cone type fracture
- net cross section is insufficient to bear the gross load.
- Overloading is its main reason.
- Ductile fracture is usually more desirable than brittle fracture.



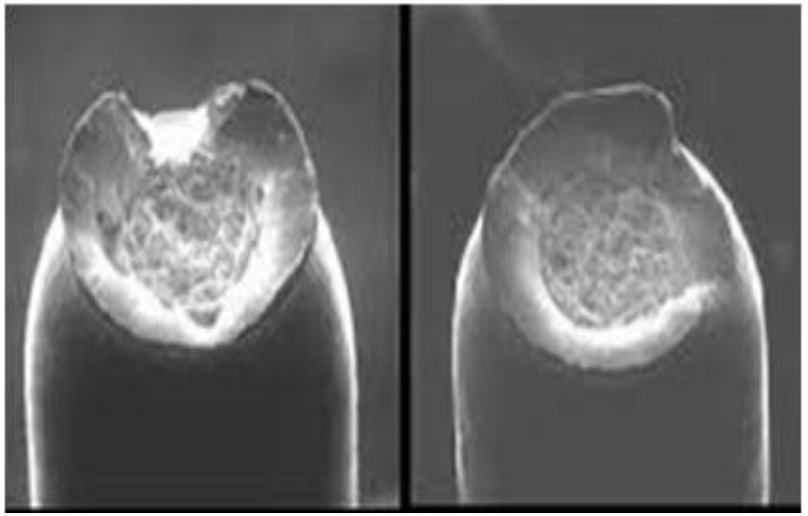




# DUCTILE FRACTURE

- Tough metals:usually ductile (Cu is extremely tough while CI is not)
- Ductile materials: fracture strength lower than the UTS.

fracture of ductile material








# MIXED MODE

- Crack initiates and propagates along the cross section due to:-
  - Fatigue
  - Creep
  - SCC, etc.
- Ultimately, the available cross section becomes inadequate to bear the applied load and separation takes place.

# MODES OF FAILURE IN SERVICE

| Mode | Contribution of surface | Contribution of interior |
|---|---|---|
| Wear | 100 | Nil |
| Fracture by fatigue | 90 | 10 |
| Sudden fracture | 95 | 5 |
| Corrosion | 100 | Nil |

# FATIGUE FRACTURE

Fatigue: Cracks are initiated at little defects &

propagate step wise through the component . Fatigue is a form of failure occurs in materials subjected to fluctuating stresses.

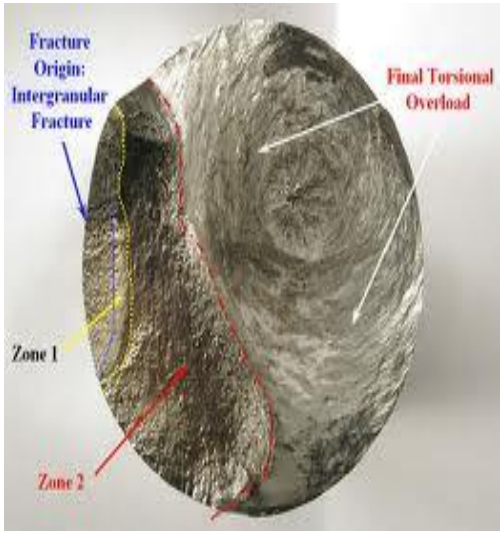
- The term fatigue is used because this type of failure normally occurs after a lengthy period of repeated stress cycling
- The single largest cause of metallic failure (approx 90%)

# FATIGUE FRACTURE

- Fatigue arises due to:
  - bad design, poor m/c, sharp fillet, notches, cracks, non- metallic inclusions, blow holes, incorrect HT, etc
- Polymers and ceramics (other than glasses): also susceptible to fatigue

# FATIGUE FRACTURE

- The appearance of fatigue fracture surface:
  - two distinct zones:-
    - One smooth zone: with concentric ripples/beach marks originating from a single nucleus or multiple nucleii on the surface
    - Other remaining portions: crystalline






multi nucleii (w/p shaft)

# FATIGUE FRACTURE

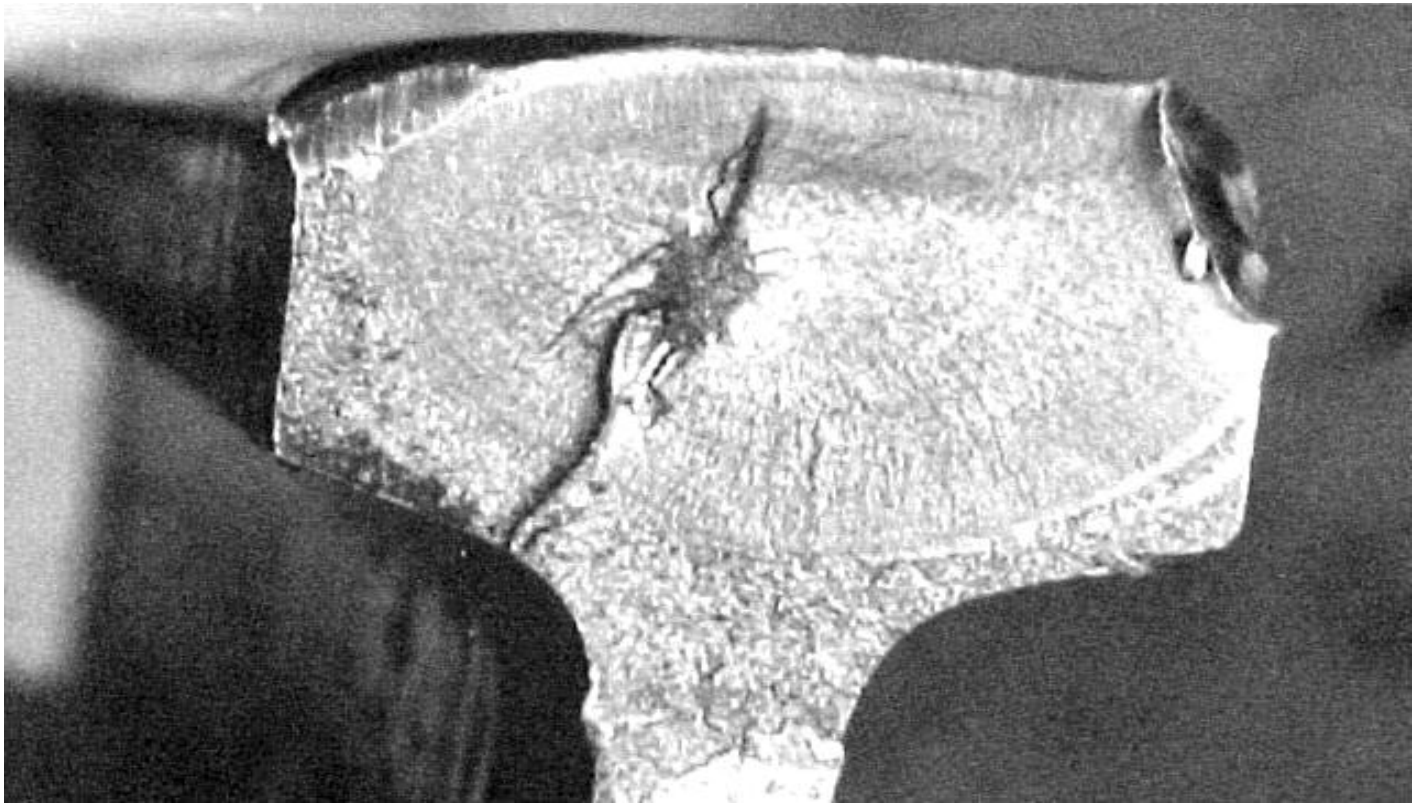


# Kidney Failure (Fatigue)

*Causes*

Presence of hydrogen flakes

Presence of abnormal inclusions



Kidney failure

# FATIGUE FRACTURE




Beach marks

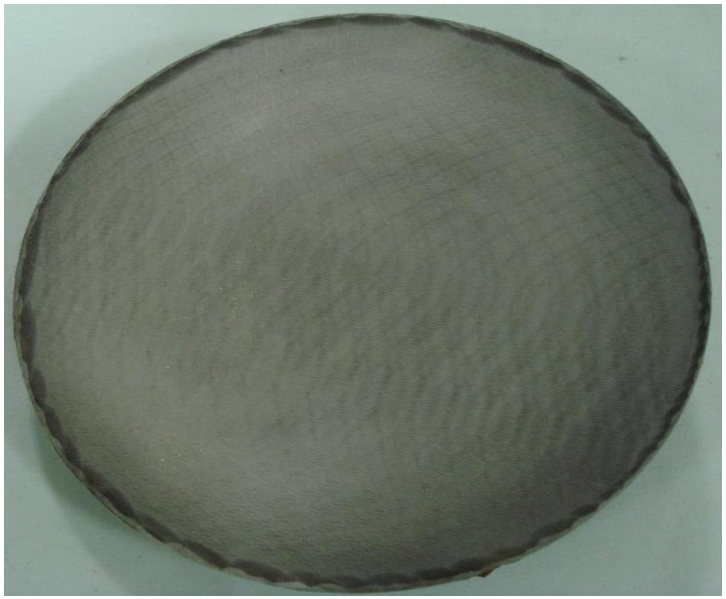
# CRACK WITHOUT FRACTURE






Reclamation of circumference of axle

# AXLE RECLAMATION BY WELDING





# WELD FRACTURE






Lack of fusion & Porosities

# RAIL FAILURE DUE TO CORROSION





# CREEP

- Materials: Gradual plastic flow of a material induced by combination of high temp & static mechanical stresses.
- Theses stresses are less than YS of the material.
- Observed in all types of material
- Creep temp for:
  - Soft metal (tin & lead)- room temp
  - Al & its alloys- $250^0$c
  - Steel-$450^0$c
  - Ni based alloys- $650^0$c

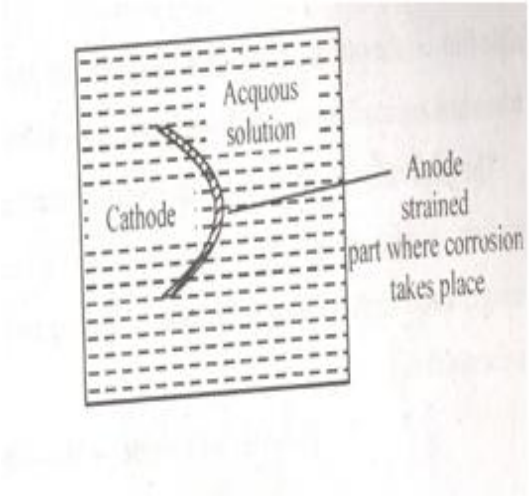


Creeping

# SCC

- Occurs due to combined effect of static tensile stresses (applied / residual) & corrosive envnt.
- The electrode potential of stressed matl: higher than the unstressed area.
- The stressed area acts as anode
- two types of stress corrosion cracking:-
  - Season cracking
  - Caustic embrittlement

stress corrosion



# SCC

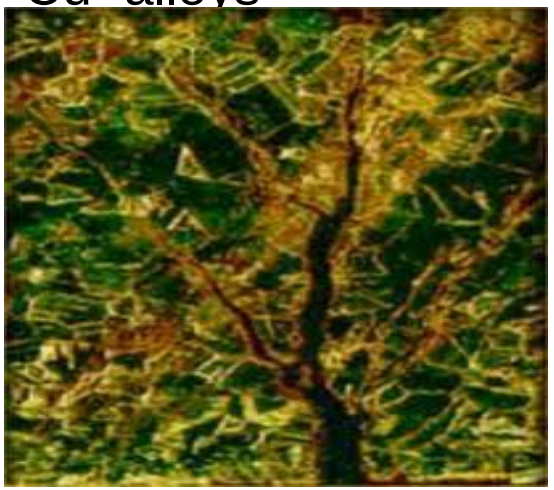
## Season cracking:-

- Occurs in Cu- alloys(mainly brasses or alloyed with P, As, Sb, Al, Si) along the grain boundaries, which become more anodic wrt the grains themselves.

Exam:- Alpha brass, when highly stressed, undergoes intergranular crack in an atmosphere, containing traces of ammonia or amines.



Season cracking in Cu- alloys



Season cracking in brass

# SCC

Caustic embritllement:-

- Occurs in MS/SS exposed to alkaline solution at high temp & stresses.
- Often associated with steam boilers & heat transfer equipments in which water of high alkalinity attacks the MS plates, particularly at the crevices near rivets.



Caustic SCC in HAZ of 316L SS


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