ME3392

ENGINEERING MATERIALS AND METALLURGY

UNIT - V

MECHANICAL PROPERTIES AND DEFORMATION MECHANISMS

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MECHANICAL PROPERTIES

Strength

- The ability of a material to stand up to forces being applied without it bending, breaking, shattering or deforming in any way.

Elasticity

- The ability of a material to absorb force and flex in different directions, returning to its original position.

Plasticity

- The ability of a material to be change in shape permanently.

Ductility

- The ability of a material to change shape (deform) usually by stretching along its length.

Tensile Strength

- The ability of a material to stretch without breaking or snapping.

Malleability

- The ability of a material to be reshaped in all directions without cracking.

Toughness

- A characteristic of a material that does not break or shatter when receiving a blow or under a sudden shock.

Hardness

- The ability of a material to resist scratching, wear and tear and indentation.

Conductivity

- The ability of a material to conduct electricity.

Creep

- It is the property of the material by virtue of which it deforms continuously under a steady load.

Brittleness

- It is the property of a material by virtue of which it will fracture without any deformation.

Stiffness

- It is the property of a material by virtue of which it resists deformation.

Technological Properties of Metallic Materials

- Technological properties are those properties that apply during manufacturing and forming processes using metal. Hence, the technological properties of metals are:
  - Machinability
  - Weldability
  - Castability and
  - formability

Machinability

- It is the ability of any metal to be machined or the ability of metals to be cut by machine tools. Examples of machine operations are turning, milling, and boring.

Formability

- It is the property of the material, which indicates the ease with which it can be formed in to different types.

WELDABILITY

- The weldability, also known as join ability, of a material refers to its ability to be welded. A material's weldability is used to determine the welding process and to compare the final weld quality to other materials.

CASTABILITY

- The ability of materials to set in a mould when mixed with water and a bonding agent

Factors Affecting Mechanical Properties

The mechanical properties of materials are affected by various factors

1. Grain size
2. Heat treatment
3. Atmospherics exposure
4. Low and high temperature

Effect of Grain size

- The metals are composed of crystals (or) grains. If the grain size of a metal is small, it is called a fine grained metal, on the other hand, when the grain size is comparatively large, then it is called a coarse grained metal.
- A fine grained metal has a greater tensile and fatigue strength. It can be easily work hardened.
- A coarse grain causes surface roughness.
- Coarse grain metal is difficult to polish.

Effect of Heat Treatment

- Mechanical properties like ductility hardness, tensile strength, toughness and shock resistance can be improved by heat treatment.

Heat treatment is generally done for the following purposes:

- To refine the grain and improve mechinability.
- To relieve the internal stresses induced in the metals during cold and hot working of the metals.
- To improve resistance to corrosion.
- To modify the structure, either coarse grained or fine grained.
- To improve chemical, magnetic, electrical and thermal properties.
- To improve mechanical properties like ductility, hardness, tensile strength, shock resistance etc.

Effect of Atmospheric Exposure

- Most of the metals get oxidized when exposed to the atmospheric.
- Due to oxidation, of metal surface, a film is formed.
- The presence of moisture, sulphur dioxide, hydrogen sulphide and other corrosive conditions decrease the electrical resistivity of metals.

The atmospheric effect on the metal depends on the following:

- Characteristics properties of the metal
- Value of the protective film on its surface
- Presence of certain reducing agents
- Local cells formed due to development of cracks and discontinuity on the protective film surface.

Effect of low temperature

- Decrease in temperature there is an increase in the tensile strength and yield strength of all metals.
- Alloys of nickel, copper and aluminium retain most of their ductility and toughness at low temperature.
- For mild steel, the elongation and reduction in cross – sectional area is satisfactory upto - 180°c but after that it goes down to a large extent.
- Near absolute zero temperature many metals exhibit the phenomenon of super conductivity
- Below - 100°c non-ferrous metals show better properties than ferro metals.
- Low temperature causes low thermal vibrations and lattice parameters are stabilized.

Effect of high temperature

- Field stress and ultimate tensile strength decrease with rise in temperature
- Stiffness and fracture stress of many metals also decrease with increasing temperature
- At high temperatures, the toughness of steel is reduced.
- At high temperature, creep takes place and the material fails even at a very small stress.
- Due to rise in temperature, there is a corresponding rise in thermal vibration of atoms causing changes in structural properties.

DEFORMATION MECHANISMS

Deformation of metals

- When a force is applied on a metal piece, then the size and shape will be altered.
- Any changes in metal is called deformation of metals.

Types of deformation

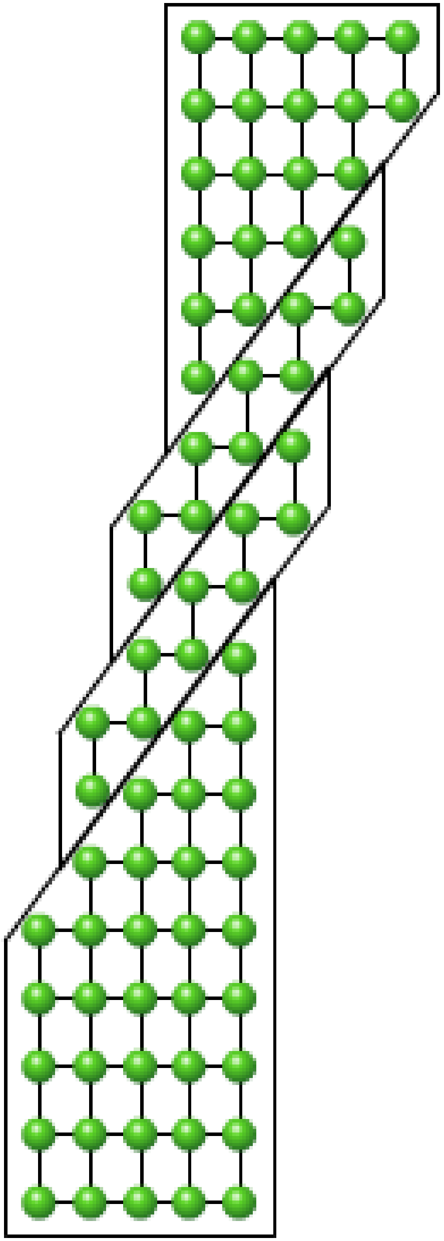
- Elastic deformation
- Plastic deformation

Mechanism of plastic deformation

- Slip
- Twinning

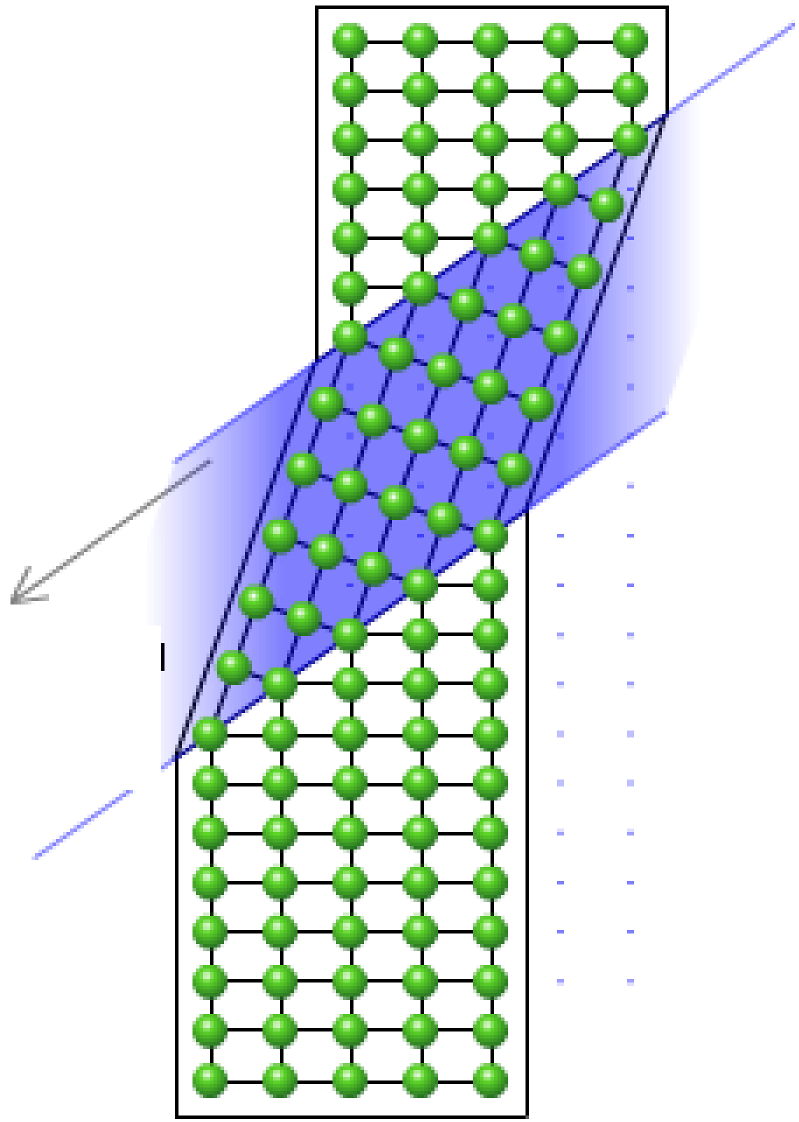
Deformation by slip

- Slip is the prominent mechanism of plastic deformation in metals.
- It involves sliding of blocks of crystal over one other along definite crystallographic planes, called slip planes.
- It is analogous to a deck of cards when it is pushed from one end. Slip occurs when shear stress applied exceeds a critical value.
- During slip each atom usually moves same integral number of atomic distances along the slip plane producing a step, but the orientation of the crystal remains the same.



Deformation by twinning

- Portion of crystal takes up an orientation that is related to the orientation of the rest of the untwined lattice in a definite, symmetrical way.
- The twinned portion of the crystal is a mirror image of the parent crystal.
- The plane of symmetry is called twinning plane.
- The important role of twinning in plastic deformation is that it causes changes in plane orientation so that further slip can occur.



FRACTURE MECHANISM

Fracture

- Fracture is the separation of a specimen info two or more parts by an applied stress.

Fracture takes place in two stages:
(i) initial formation of crack and
(ii) spreading of crack.

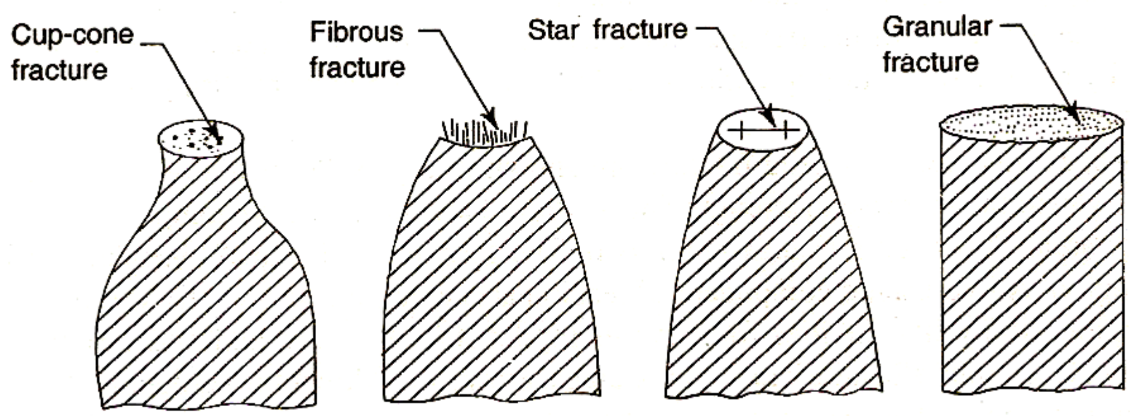
Depend upon the type of materials, the applied load, state of stress and temperature metals have different types of fracture.

Types of fracture

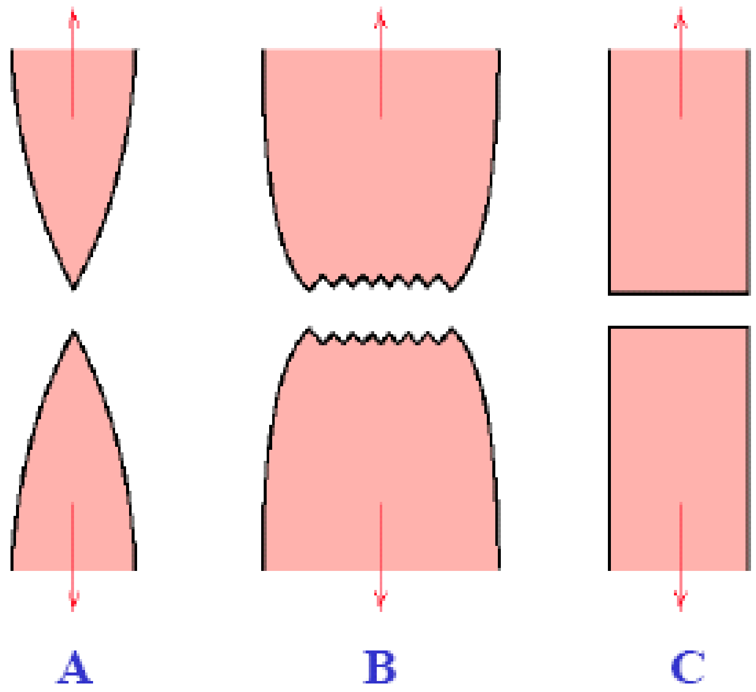
- Brittle Fracture
- Ductile Fracture
- Fatigue Fracture
- Creep Fracture

Fracture

- Fracture is usually undesirable in engineering applications.
- Flaws such as surface cracks lower the stress for brittle fracture where as line defects are responsible for initiating ductile fractures.
- Different types of fracture



Brittle vs. Ductile Fracture



A. **Very ductile**, soft metals (e.g. Pb, Au) at room temperature, other metals, polymers, glasses at high temperature.

B. **Moderately ductile fracture**, typical for ductile metals

C. **Brittle fracture,** cold metals, ceramics.

Brittle Fracture

- Brittle fracture is the failure of a material with minimum of plastic deformation. If the broken pieces of a brittle fracture are fitted together, the original shape & dimensions of the specimen are restored.
- Brittle fracture is defined as fracture which occurs at or below the elastic limit of a material.

The brittle fracture increases with

- Increasing strain rate
- Decreasing temperature
- Stress concentration conditions produced by a notch.

Salient Features of Brittle Fracture

- Brittle fracture occurs when a small crackle in materials grows. Growth continues until fracture occurs.
- The atoms at the surfaces do not have as many neighbors as those in the interior of a solid and therefore they form fever bonds. That implies, surface atoms are at a higher energy than a plane of interior atom. As a result of Brittle fracture destroying the inter atomic bonds by normal stresses.
- In metals brittle fracture is characterized by rate of crack propagation with minimum energy of absorption.
- In brittle fracture, adjacent parts of the metal are separated by stresses normal to the fracture surface.
- Brittle fracture occurs along characteristics crystallographic planes called as cleavage planes. The fracture is termed as cleavage fracture.
- Brittle fracture does not produce plastic deformation, so that it requires less energy than a ductile failure.

Mechanism of Brittle Fracture

- The mechanism of Brittle fracture is explained by Griffith theory.
- Griffith postulated that in a brittle material there are always presence of micro cracks which act to concentrated the stress at their tips.
- The crack could come from a number of source, e.g. as a collection of dislocations, as flow occurred during solidification or a surface scratch.
- In order to explain the mechanism of ideal brittle fracture, let us consider the stress distribution in a specimen under constant velocity in the vicinity of crack.

Mechanism of Brittle Fracture

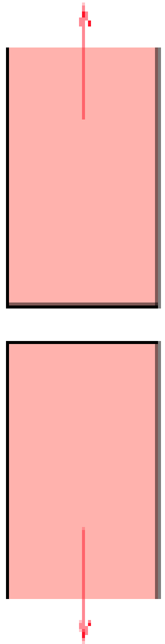
$$\sigma = \sqrt{\frac{2\gamma E}{\pi e}}$$

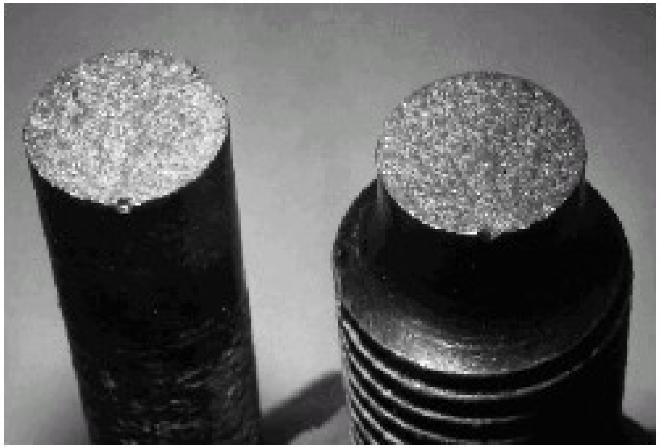
Where,

- e is half of the crack length,
- γ is the true surface energy
- E is the Young's modulus.
- the stress is inversely proportional to the square root of the crack length. Hence the tensile strength of a completely brittle material is determined by the length of the largest crack existing before loading.
- For ductile materials there is always some plastic deformation before fracture. This involves an additional energy term γp. Therefore the fracture strength is given by

$$\sigma = \left[\sqrt{\frac{2E\gamma}{\pi e}}\right]^{\frac{1}{2}}$$

Brittle Fracture





Brittle fracture in a mild steel

- No appreciable plastic deformation
- Crack propagation is very fast
- Crack propagates nearly perpendicular to the direction of the applied stress
- Crack often propagates by cleavage - breaking of atomic bonds along specific crystallographic planes (cleavage planes).

Ductile Fracture

- Ductile fracture is defined as the fracture which takes place by a slow propagation of crack with considerable amount of plastic deformation.

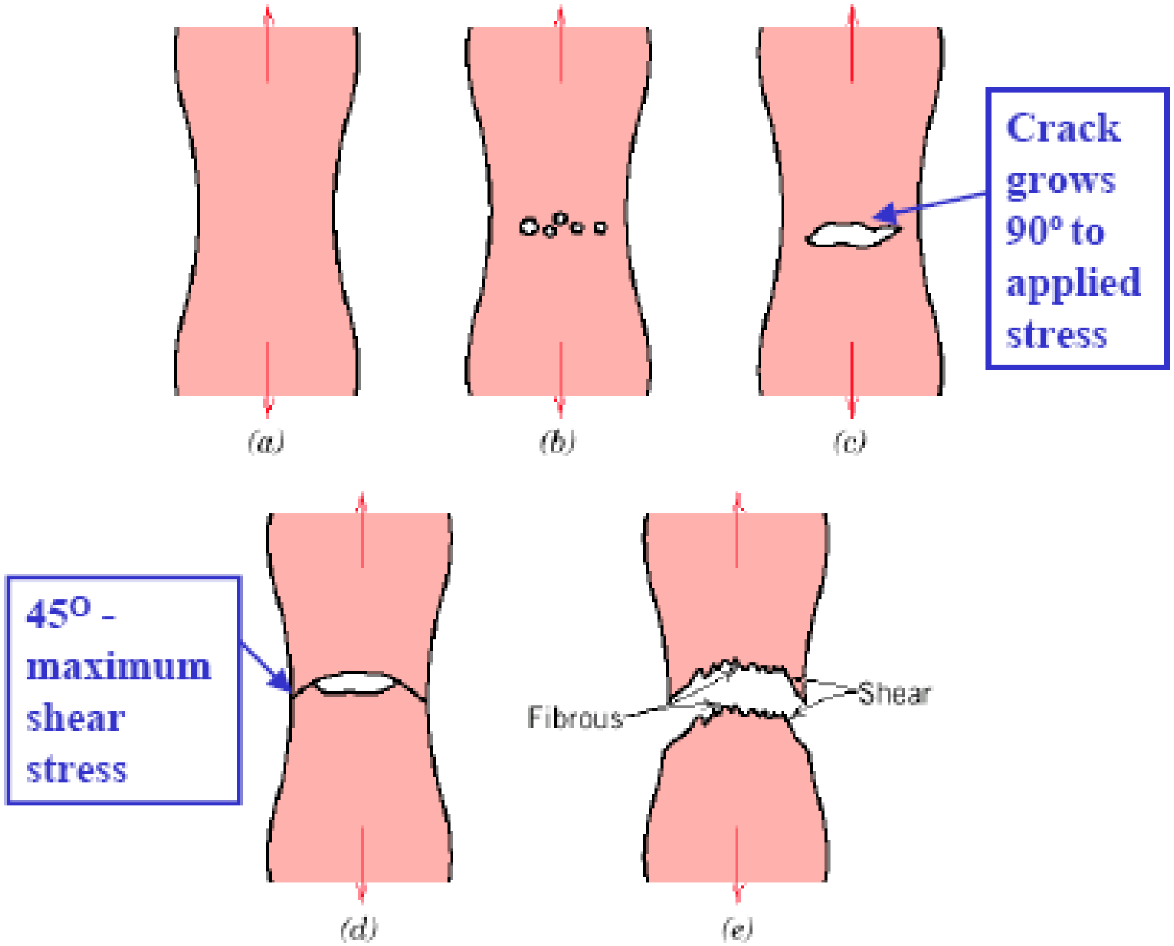
There are three successive events involved in a ductile fracture.

- The specimen begins necking and minute cavities form in the necked region. This is the region in which the plastic deformation is concentrated. It indicates that the formation of cavities is closely linked to plastic deformation.
- It has been observed that during the formation of neck small micro cracks are formed at the centre of the specimen due to the combination of dislocations.
- Finally these cracks grow out ward to the surface of the specimen in a direction 45° to the tensile axis resulting in a cup-end-cone-type fracture 0

Ductile Fracture

- An important characteristic of ductile fracture is that it occurs through a slow tearing of the metal with the expenditure of considerable energy.
- The fracture of ductile materials can also explained in terms of work-hardening coupled with crack-nucleation and growth.
- The initial cavities are often observed to form at foreign inclusions where gliding dislocations can pile up and produce sufficient stress to form a void or micro-crack.
- Consider a specimen subjected to slow increasing tensile load. When the elastic limit is exceeded, the material beings to work harden.
- Increasing the load, increasing the permanent elongation and simultaneously decrease the cross sectional area.
- The decrease in area leads to the formation of a neck in the specimen, as illustrated earlier.

Ductile Fracture



(a) Necking, (b) Cavity Formation,

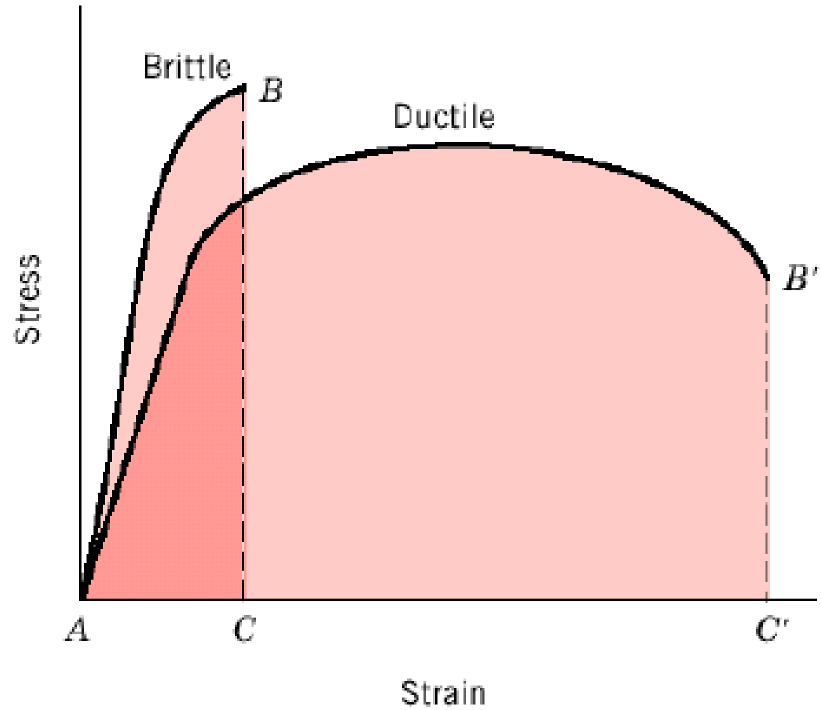
(c) Cavity coalescence to form a crack,

(d) Crack propagation, (e) Fracture

Ductile Fracture

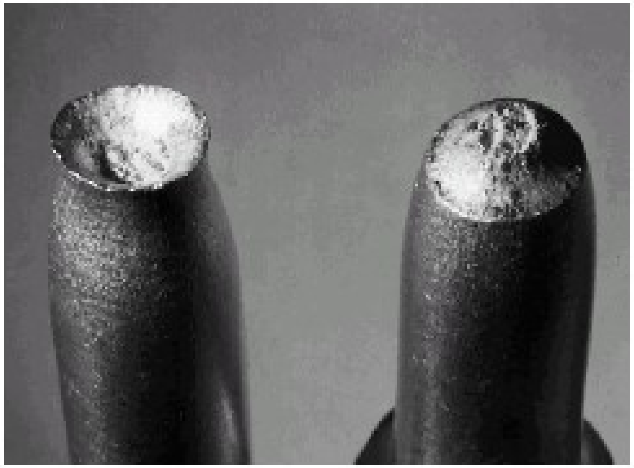
- The neck region has a high dislocation density and the material is subjected to a complex stress.
- The dislocations are separated from each other because of the repulsive inter atomic forces.
- As the resolved shear stress on the slip plane increase, the dislocation comes closed together.
- The crack forms due to high shear stress and the presence of low angle grain boundaries.
- Once a crack is formed, it can grow or elongated by means of dislocations which slip.
- Crack propagation is along the slip plane for this mechanism.
- Once crack grows at the expense of others and finally cracks growth results in failure.

Brittle vs. Ductile Fracture

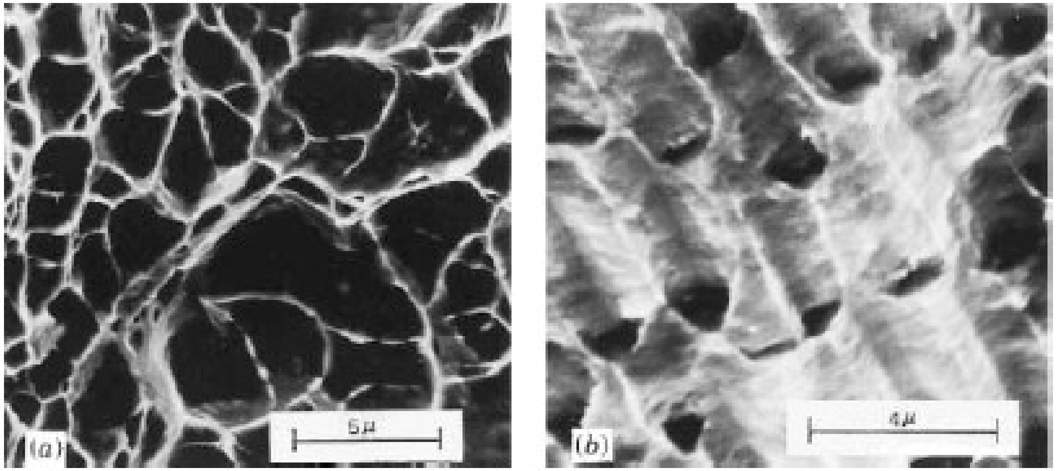


- **Ductile materials** - extensive plastic deformation and energy absorption ("toughness") before fracture
- **Brittle materials** - little plastic deformation and low energy absorption before fracture

Ductile Fracture



(Cap-and-cone fracture in Al



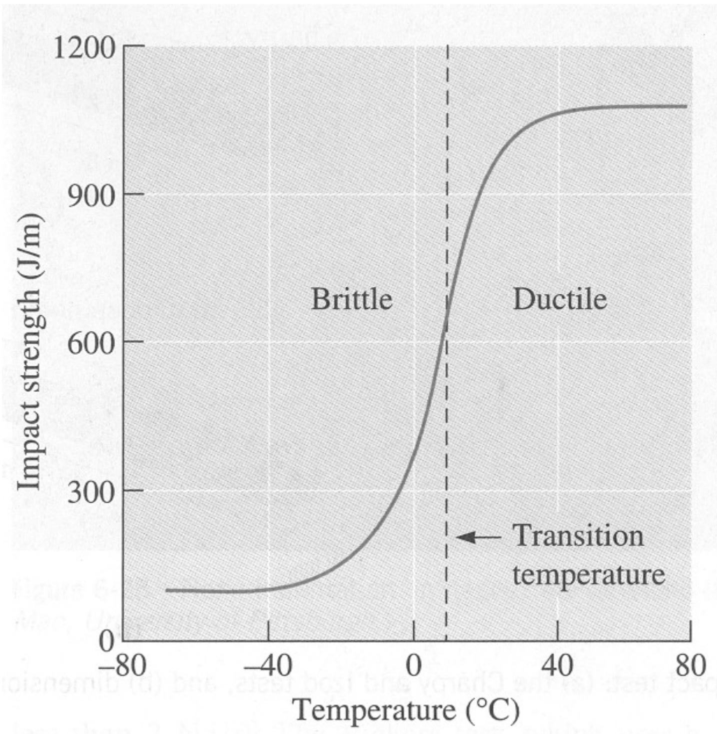
Scanning Electron Microscopy: *Fractographic* studies at high resolution. Spherical "dimples" correspond to micro-cavities that initiate crack formation.

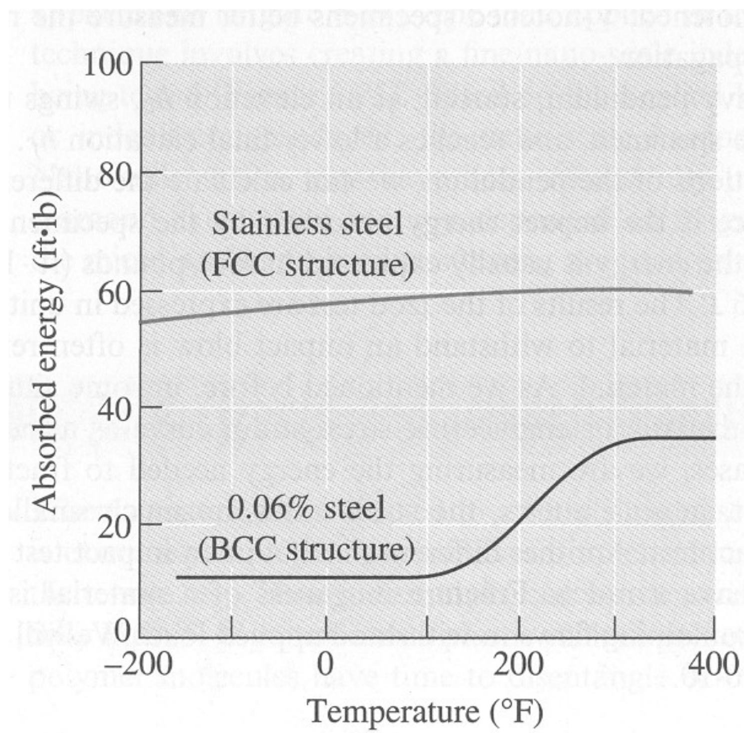
Comparison between Brittle and Ductile fracture

Ductile fracture	Brittle fracture
• Material fractures after plastic deformation and slow propagation of crack	• Material fractures with very little or no plastic deformation.
• Surface obtained at the fracture is dull or fibrous in appearance	• Surface obtained at the fracture is shining and crystalling appearance
• It occurs when the material is in plastic condition.	• It occurs when the material is in elastic condition.
• It is characterized by the formation of cup and cone	• It is characterized by separation of normal to tensile stress.
• The tendency of ductile fracture is increased by dislocations and other defects in metals.	• The tendency brittle fracture is increased by decreasing temperature, and increasing strain rate.
• There is reduction in cross – sectional area of the specimen	• There is no change in the cross – sectional area.

Ductile to Brittle Transition

The results of impact tests are absorbed energy, usually as a function of temperature. The ABSORBED ENERGY vs. TEMPERATURE curves for many materials will show a sharp decrease when the temperature is lowered to some point. This point is called the ductile to brittle transition temperature (***relatively narrow temperature range)*** .





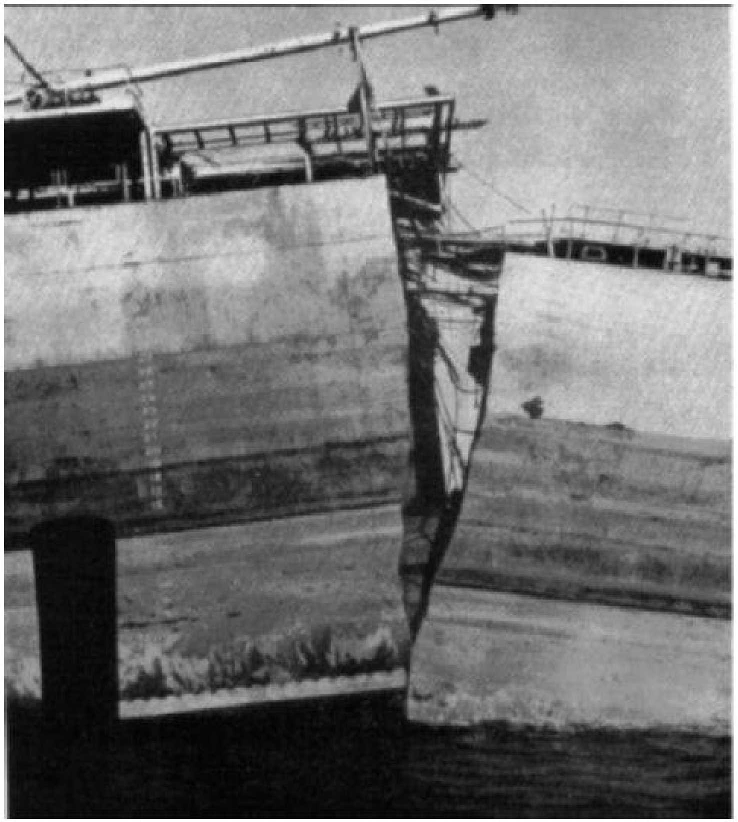
A typical ductile to brittle transition as a function of temperature. The properties of BCC carbon steel and FCC stainless steel, where the FCC crystal structure typically leads to higher absorbed energies and no transition temperature.

Transition Temperatures

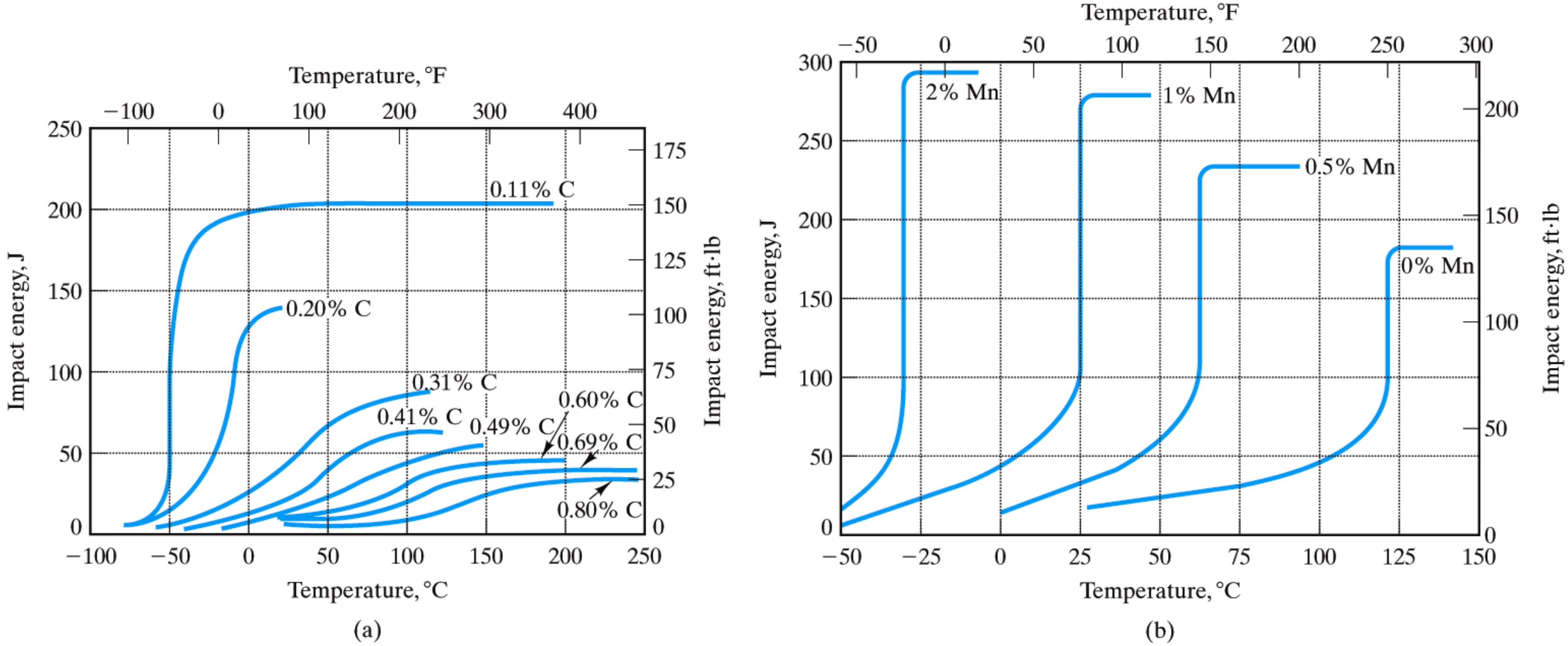
- BCC metals have transition temperatures
- FCC metals do not
- Can use FCC metals at low temperatures (eg Austenitic Stainless Steel)

Brittle Fracture

Failure of Liberty ships in WW II - Low-carbon steels were ductile at RT tensile tests, they became brittle when exposed to lower-temperature ocean environmets.The ships were built and used in the Pacific Ocean but when they were employed in the Atlantic Ocean, which is colder, the ship's material underwent a ductile to brittle transition.



Alloying usually shifts the ductile-to-brittle transition temperature



Carbon content increases the brittleness

Figure 8.3

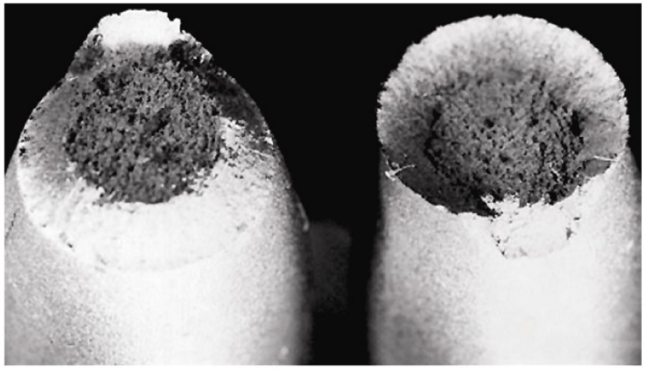
Variation in ductile-to-brittle transition temperature with alloy composition. (a) Charpy V-notch impact energy with temperature for plain-carbon steels with various carbon levels (in weight percent). (b) Charpy V-notch impact energy with temperature for Fe–Mn–0.05C alloys with various manganese levels (in weight percent). (From Metals Handbook, *9th ed., Vol. 1, American Society for Metals, Metals Park, OH, 1978.)*

Transition Temperatures

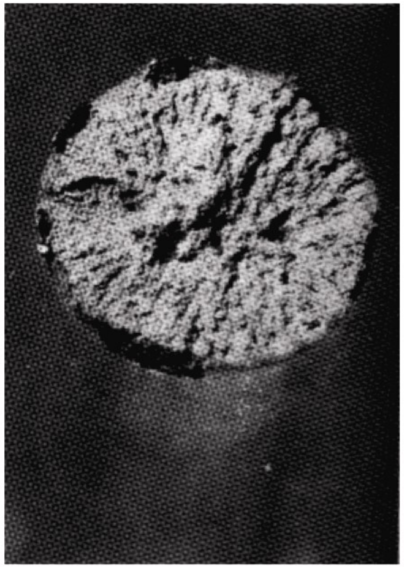
- As temperature decreases a ductile material can become brittle - ductile-to-brittle transition
  - The transition temperature is the temp at which a material changes from ductile-to-brittle behavior
- Alloying usually increases the ductile-to-brittle transition temperature. FCC metals remain ductile down to very low temperatures. For ceramics, this type of transition occurs at much higher temperatures than for metals.

The fracture surface

Ductile → a dimpled texture



(a)



(b)

Brittle → cleavage surface

Figure 8.4

(a) Typical "cup and cone" ductile fracture surface. Fracture originates near the center and spreads outward with a dimpled texture. Near the surface, the stress state changes from tension to shear, with fracture continuing at approximately 45°. (From Metals Handbook, *9th ed., Vol. 12, ASM International,* Metals *Park, Ohio, 1987.)*
(b) Typical cleavage texture of a brittle fracture surface. (From Metals Handbook, *8th ed., Vol. 9, American Society for Metals, Metals Park, OH, 1974.)*

cleavage : The tendency of certain minerals to break along distinct planes in their crystal structures where the bonds are weakest

Near the ductile-to-brittle transition temperature, the fracture surface exhibits a mixed texture

Fatigue Fracture

- Fatigue fracture is defined as the fracture which takes place under repeatedly applied stresses.
- It will occur at stresses well before the tensile strength of the materials.
- The tendency of fatigue fracture increases with the increase in temperature and higher rate of straining.
- The fatigue fracture takes place due to the micro cracks at the surface of the materials.
- It results in, to and fro motion of dislocations near the surface.
- The micro cracks act as the points of stress concentration.
- For every cycle of stress application the excessive stress helps to propagate the crack.
- In ductile materials, the crack grows slowly and the fracture takes place rapidly.
- But in brittle materials, the crack grows to a critical size and propagates rapidly through the material.

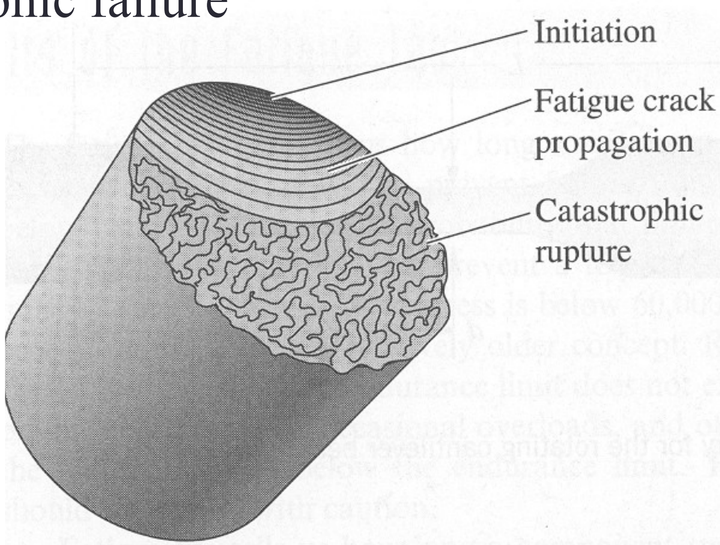
Fatigue

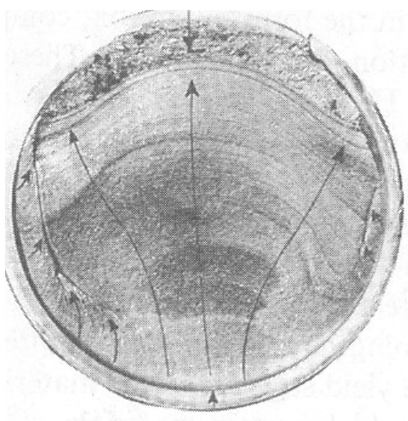
Fatigue failures are often easy to identify.

The fracture surface near the origin is usually smooth (Beach mark-crack initiation point). The surface becomes rougher as the crack increases in size.

Striations (concentric line patterns): the slow cyclic build up of crack growth from a surface intrusion. Striations are on a much finer scale and show the position of the crack tip after each cycle.

Granular portion of the fracture surface: rapid crack propagation at the time of catastrophic failure



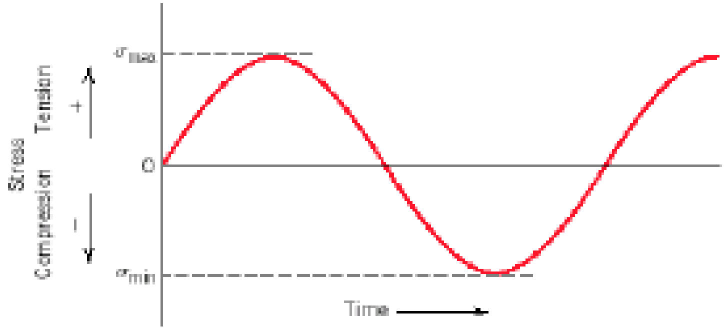


(a)

Fatigue

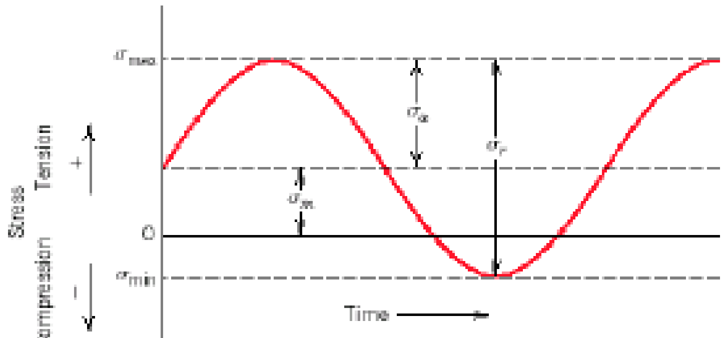
- Repeated, also called cyclic loads resulting in cyclic stresses can lead to microscopic physical damage.
- Accumulation of this microscopic damage with continued cycling is possible until it develops into a macroscopic crack such as cracks that may lead to failure
- **Fatigue**: Damage progression to failure due to repeated or cyclic loading at amplitudes considerably ***lower than tensile or yield strengths of material under a static load***
- Estimated to causes 90 % of all failures of metallic structures (bridges, aircraft, machine components, etc.)
- Fatigue failure is brittle-like (relatively little plastic deformation) - even in normally ductile materials. Thus sudden and catastrophic!

Dynamic Loading and Fatigue



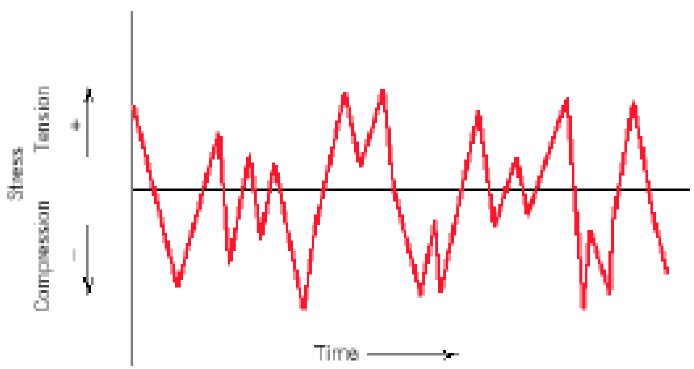
(a)

Periodic and symmetrical about zero stress



(b)

Periodic and asymmetrical about zero stress



Random stress fluctuations

Types of fatigue loading

1.Completely reversed cycle of stress:

2. repeated stress cycles

3. irregular or random stress cycle:

Completely reversed cycle of stress

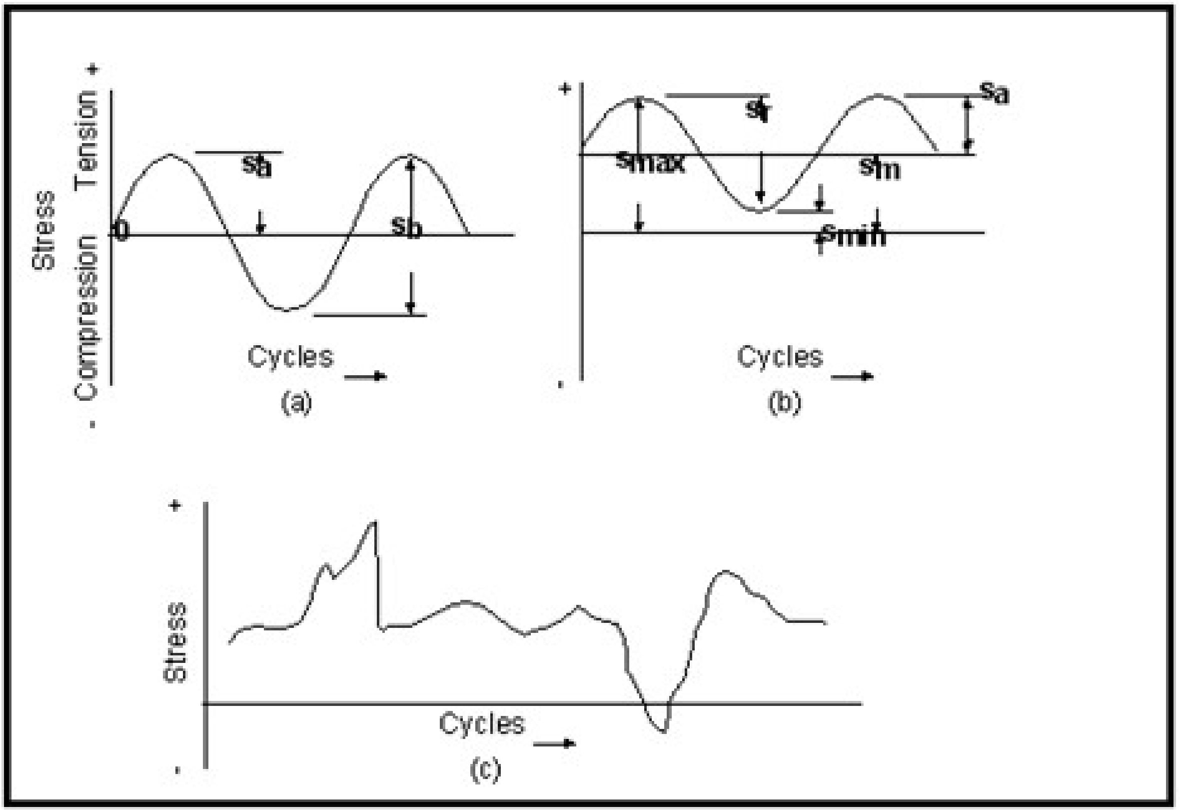
- Illustrates the type of fatigue loading where a member is subjected to opposite loads alternately with a means of zero.
- For example bending of steel wire ***continuously in either direction leads to alternate tensile and compressive stresses on its surface layers and failure fatigue.***
- If the applied load changes from any magnitude in one direction to the same magnitude in the opposite direction, the loading is termed *completely reversed,*

Repeated stress cycles

- ***Type of fatigue loading where a member is subjected to only tension but to various degrees.***
- A spring subjected to repeated tension as in a toy would lead to fatigue failure.

Irregular or random stress cycle

This type of fatigue loading where a member could be subjected to irregular loads just as in the case of an aircraft wing subjected to wind loads



Fatigue limit or Endurance limit (σ_E)

- It is stress below which a material will not fail for any number of cycles.
- For ferrous materials it is approximately half of the ultimate tensile strength.
- For non-ferrous metal since there is no fatigue limit.

- **Endurance limit**

It is taken to be the stress at which it endures, N number of cycles without failure .N is usually taken as 5×10^8 cycles for non-ferrous metals.

Factors affecting fatigue

Effect of stress concentration

Size effect

Surface Roughness

Surface Residual Stress

Effect of temperature

Effect of metallurgical variables

EFFECT OF STRESS CONCENTRATION

- It is most responsible for the majority of fatigue failures
- All m/c elements contain stress raisers like fillets, key ways, screw threads, porosity etc. fatigue cracks are nucleated in the region of such geometrical irregularities.

- The actual effectiveness of stress concentration is measured by the fatigue strength reduction factor K_f

$$K_f = \sigma_n / \sigma_n^I$$

σ_n = the fatigue strength of a member without any stress concentration

σ_n^I = the fatigue strength of the same member with the specified stress concentration.

- Fatigue failure by stress concentration can be minimized by
- Reducing the avoidable stress-raisers
- Careful design and
- The prevention of stress raisers by careful machining and fabrication.

SIZE EFFECT:

The strength of large members is lower than that of small specimens.

This may be due to two reasons.

- The larger member will have a larger distribution of weak points than the smaller one and on an average, fails at a lower stress.
- Larger members have larger surface Ares. This is important because the imperfections that cause fatigue failure are usually at the surface.

Effect of size:

- Increasing the size (especially section thickness) results in larger surface area and creation of stresses.
- This factor leads to increase in the probability of crack initiation.
- This factor must be kept in mind while designing large sized components.

SURFACE ROUGHNESS:

- Almost all fatigue cracks nucleate at the surface of the members.
- The conditions of the surface roughness and surface oxidation or corrosion are very important.
- Experiments have shown that different surface finishes of the same material will show different fatigue strength.

SURFACE RESIDUAL STRESS:

- Residual stresses are nothing but locked up stresses which are present in a part even when it is not subjected to an external force.

- Residual stresses arise during casting or during cold working when the plastic deformation would not be uniform throughout the cross section of the part.

Effect of metallurgical variables

- Fatigue strength generally increases with increase in UTS
- Fatigue strength of quenched & tempered steels (tempered martensitic structure) have better fatigue strength
- Finer grain size show better fatigue strength than coarser grain size.
- Non-metallic inclusions either at surface or sub-surface reduces' the fatigue strength

EFFECT OF TEMPERATURE:

- Fatigue tests on metals carried out at below room temperature shows that fatigue strength increases with decreasing temperature.

Environmental Effects

- Environment. Corrosion has complex interactive effect with fatigue (attacks surface and creates brittle oxide film, which cracks and pits to cause stress concentrations).
- Often in practice, there are modifying factors for the above applied to the equation for the endurance limit.

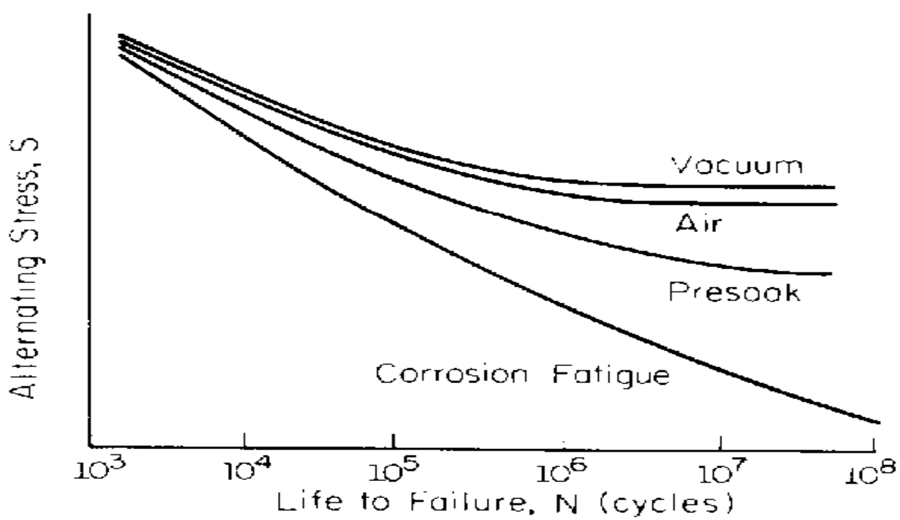
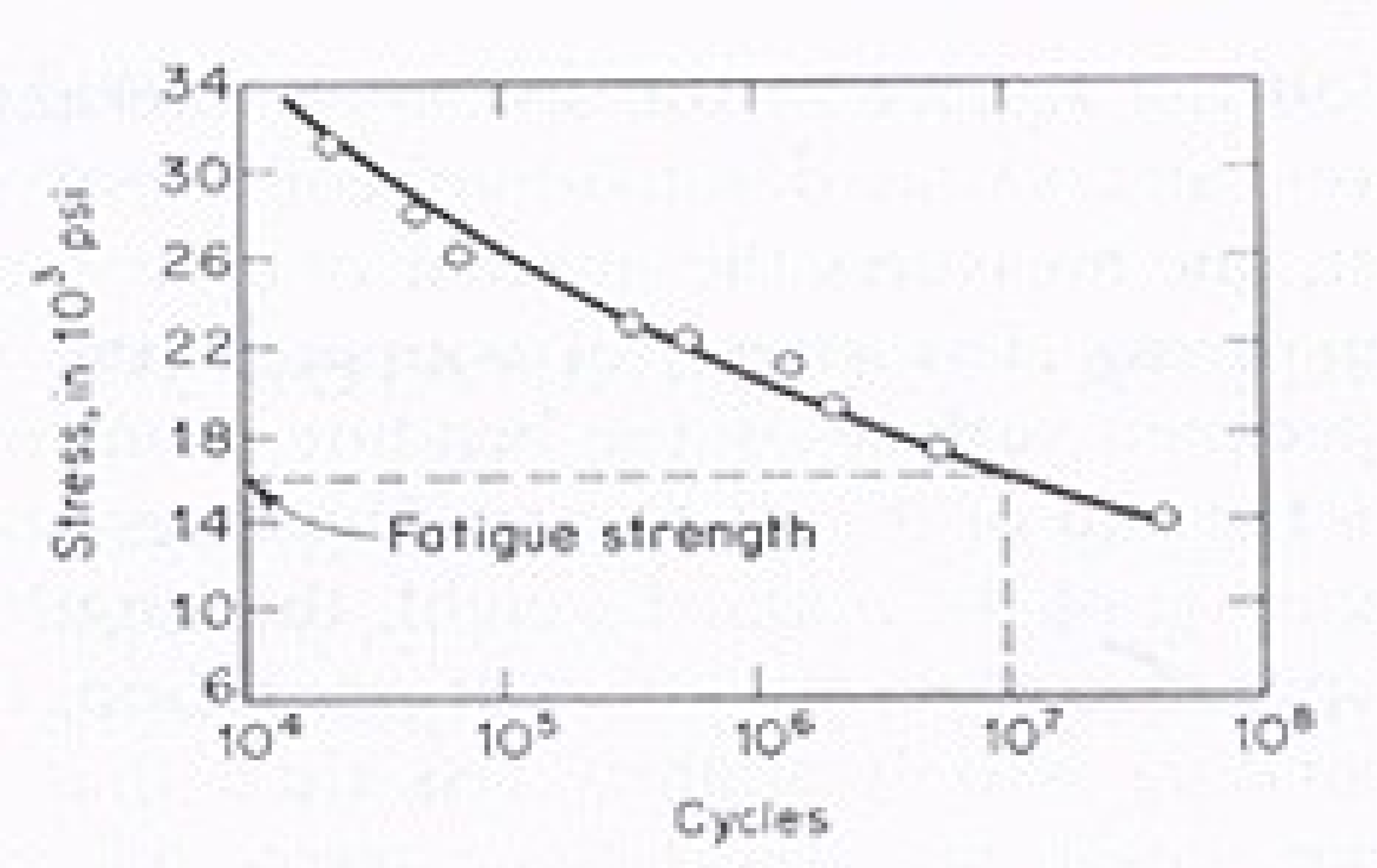


Figure 1.25 Effect of various environments on the S–N curve of steel. (H. O. Fuchs and R. I. Stephens, *Metal Fatigue in Engineering*, John Wiley and Sons, New York, 1980. Reprinted with permission.)

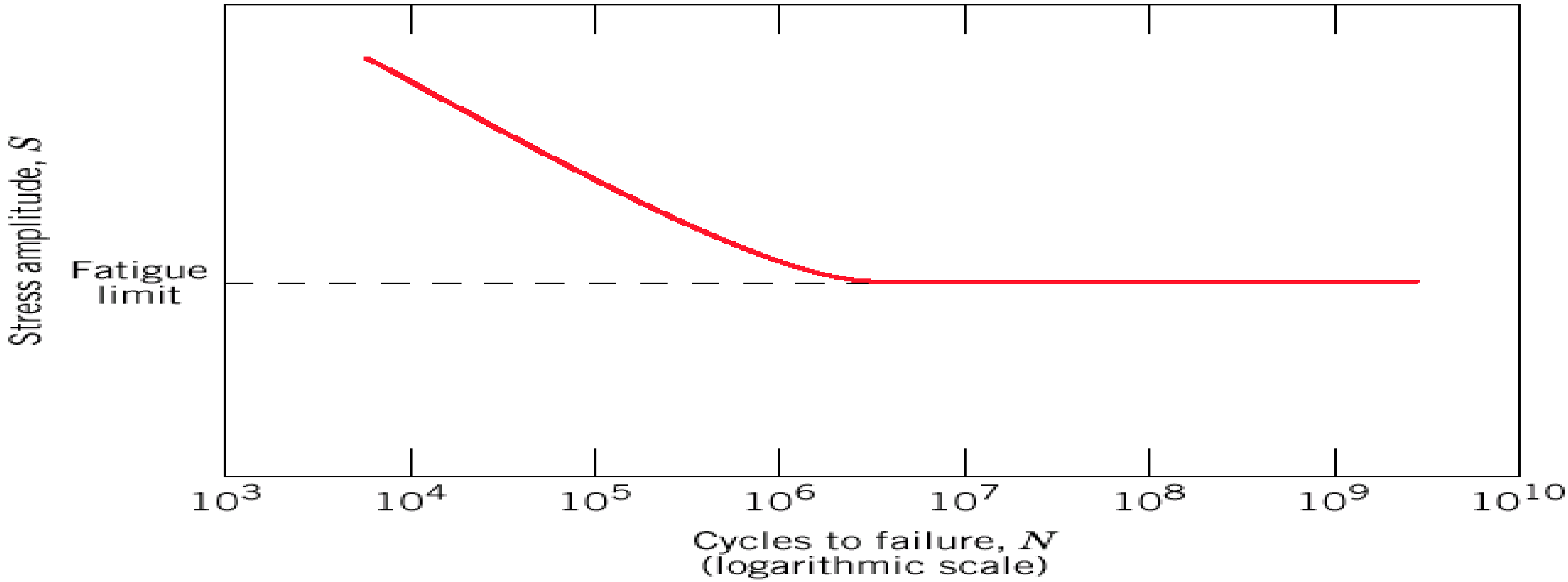
The S-N curve

- A very useful way to visualize time to failure for a specific material is with the S-N curve.
- The "S-N" means stress verse cycles to failure, which when plotted uses the stress amplitude, s_a plotted on the vertical axis and the logarithm of the number of cycles to failure.

- The significance of the fatigue limit is that if the material is loaded below this stress, then it will not fail, regardless of the number of times it is loaded.
- Material such as aluminum, copper and magnesium do not show a fatigue limit, therefor they will fail at any stress and number of cycles.
- Other important terms are fatigue strength and fatigue life.
- The stress at which failure occurs for a given number of cycles is the fatigue strength.
- The number of cycles required for a material to fail at a certain stress in fatigue life.


34
30
26
22
18
14
10
6
Stress, in 10³ psi
Fatigue strength
10⁴
10⁵
10⁶
10⁷
10⁸
Cycles

Fatigue: S—N curves (II)

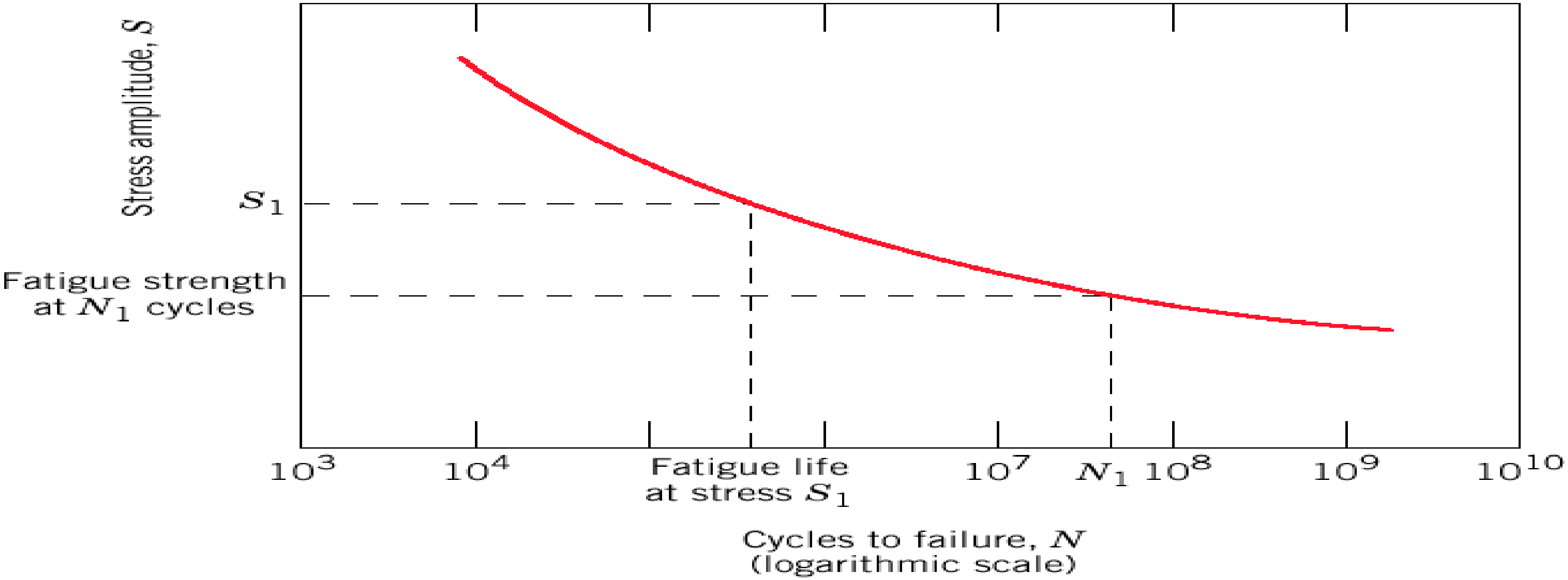


Fatigue limit (some Fe and Ti alloys)

S—N curve becomes horizontal at large N

Stress amplitude below which the material never fails, no matter how large the number of cycles is

Fatigue: S—N curves (III)



Most alloys: S decreases with N.

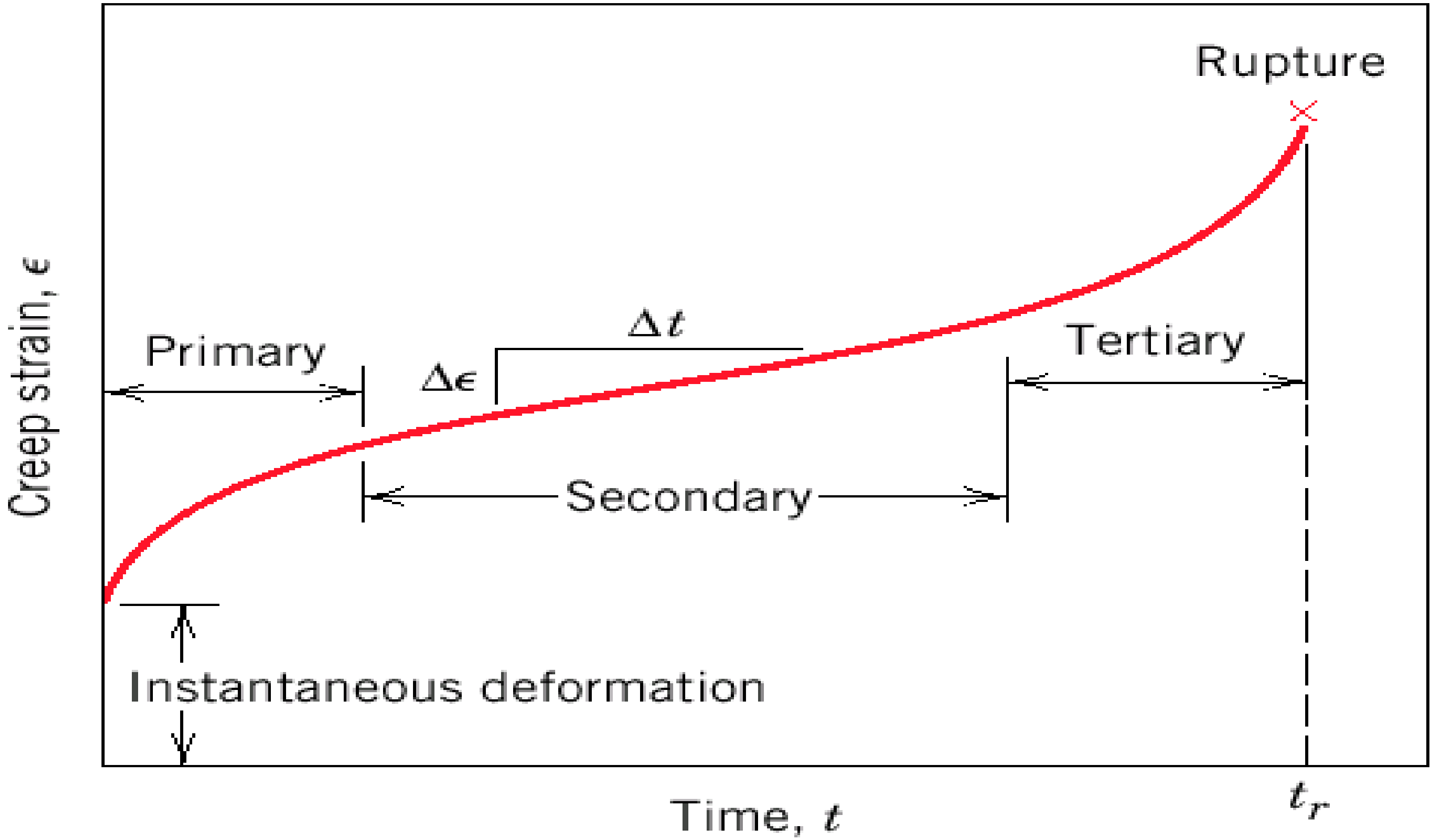
Fatigue strength: Stress at which fracture occurs after specified number of cycles (e.g. 10^7)

Fatigue life: Number of cycles to fail at specified stress level

Creep Fracture

- Creep fracture is defined as the fracture which takes place due to creeping of materials under steady loading.
- It occurs in metals like iron, copper & nickel at high temperatures. The tendency of creep fracture increases with the increase in temperature and higher rate of straining.
- The creep fracture takes place due to shearing of grain boundary at moderate stresses and temperatures and movement of dislocation from one slip to another at higher stresses and temperatures.
- The movement of whole grains relation of each other causes cracks along the grain boundaries, which act as point of high stress concentration.
- When one crack becomes larger it spreads slowly across the member until fracture takes place.
- This type of fracture usually occurs when small stresses are applied for a longer period.
- The creep fracture is affected by grain size, strain hardening, heat treatment and alloying.

Stages of creep



Stages of creep

1. Instantaneous deformation, mainly elastic.
2. Primary/transient creep. Slope of strain vs. time decreases with time: work-hardening
3. Secondary/steady-state creep. Rate of straining constant: work-hardening and recovery.
4. Tertiary. Rapidly accelerating strain rate up to failure: formation of internal cracks, voids, grain boundary separation, necking, etc.

Parameters of creep behavior

Secondary/steady-state creep:

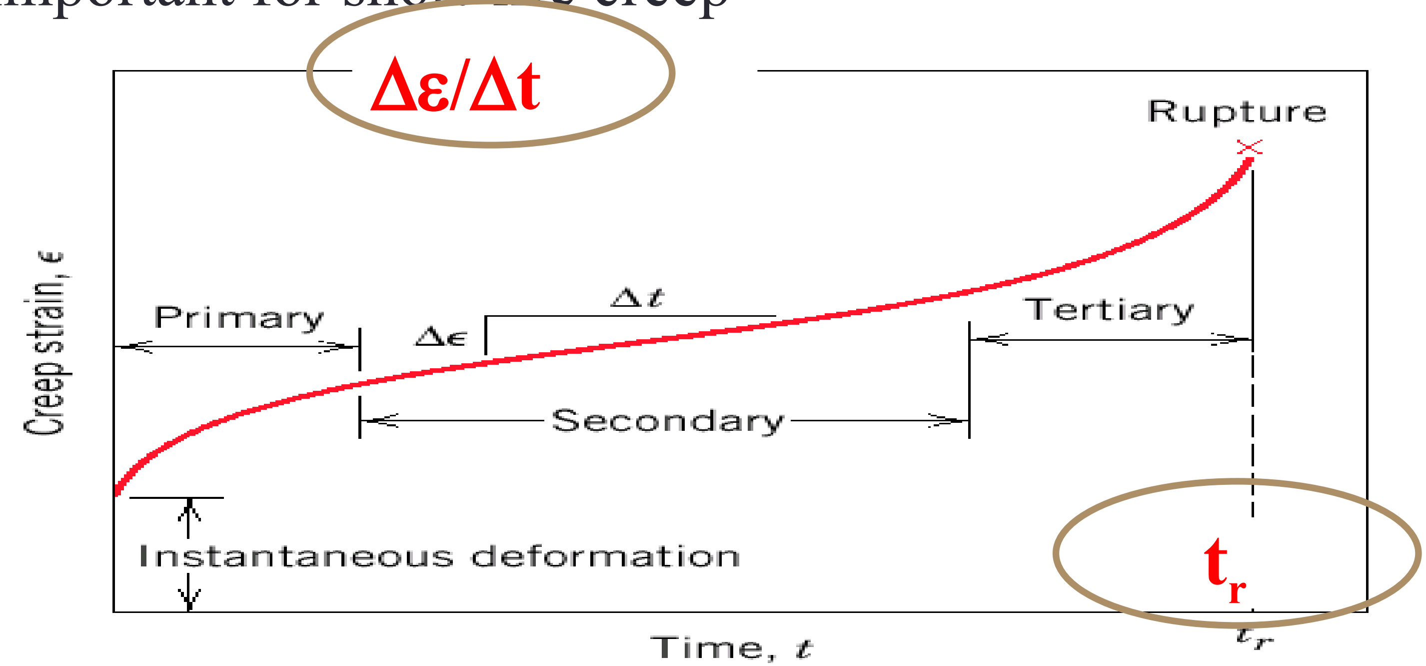
Longest duration

Long-life applications

$$\dot{\varepsilon}_s = \Delta\varepsilon / \Delta t \text{ (creep rate)}$$

Time to rupture (rupture lifetime, t_r):

Important for short-life creep

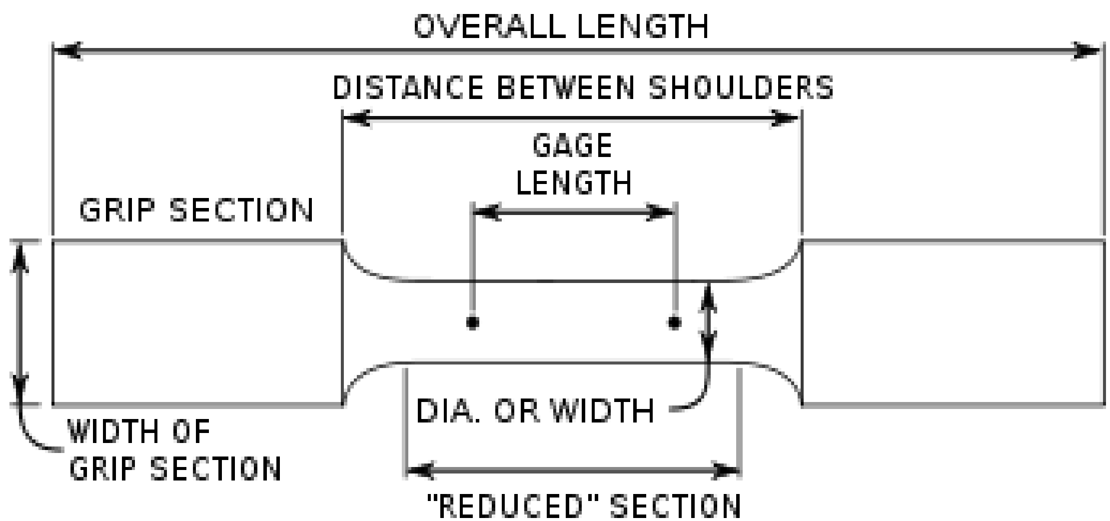


MECHANICAL TEST OF METALS

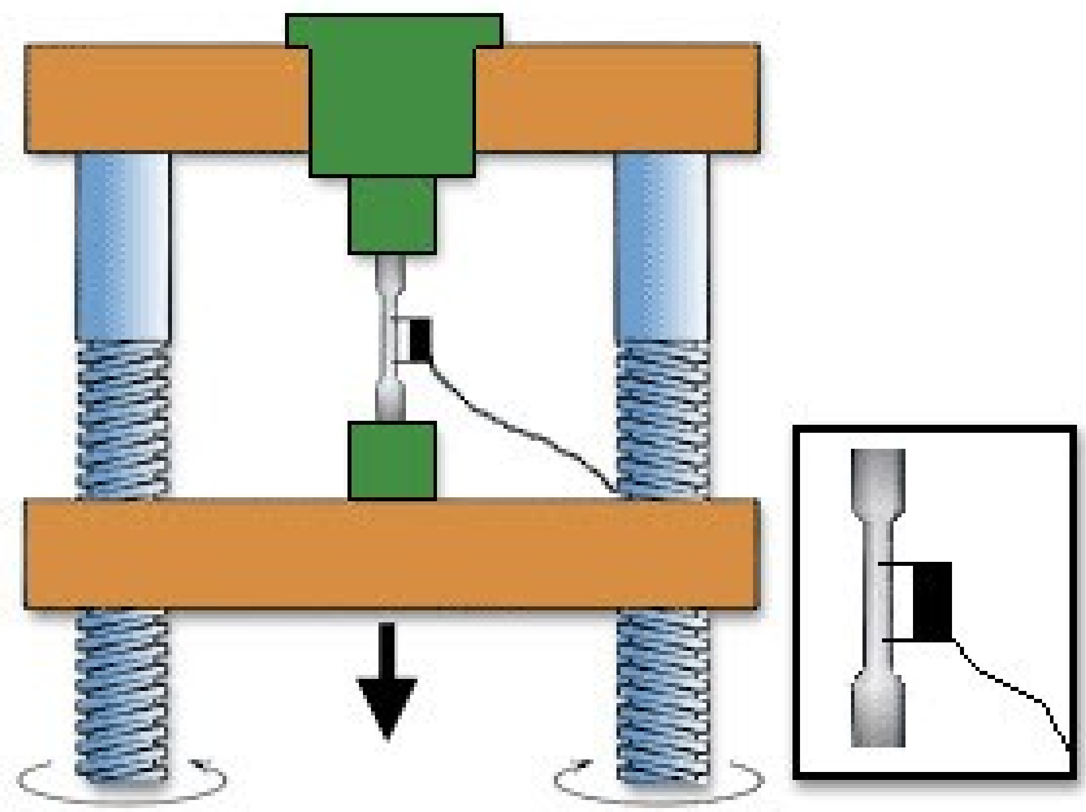
TENSILE TEST

- Tensile testing, also known as tension testing, is a fundamental materials science test in which a sample is subjected to a controlled tension until failure.
- The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces.
- From these measurements the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics.

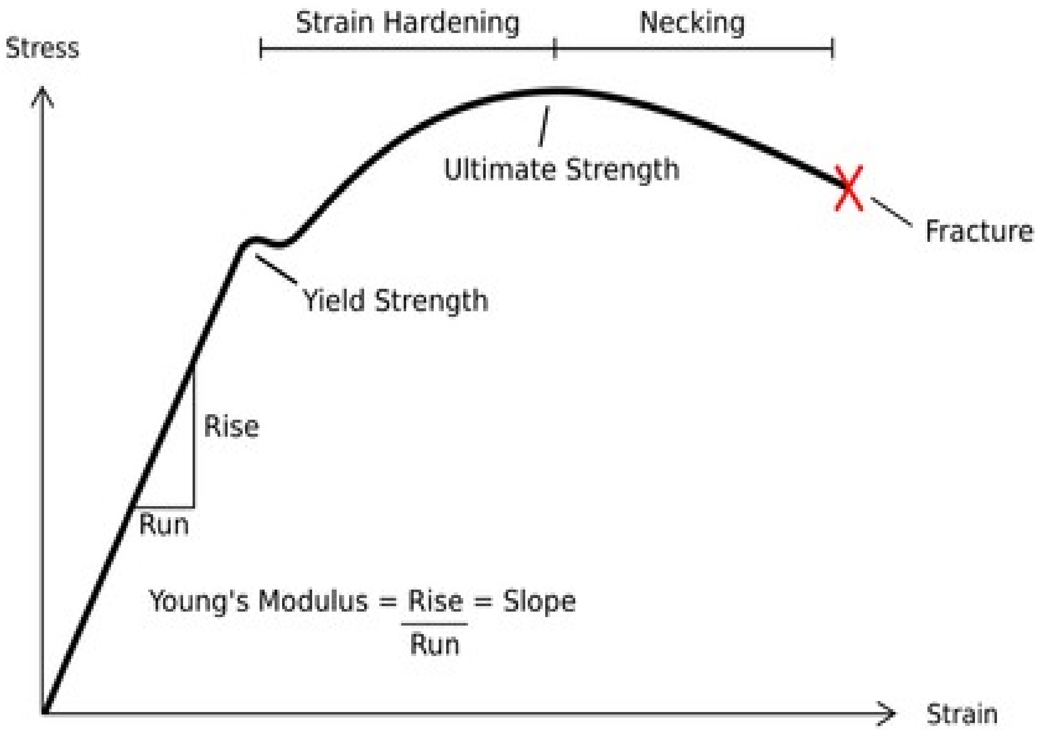
- **Tensile specimen**



- EQUIPMENT



- **STRESS–STRAIN CURVE**



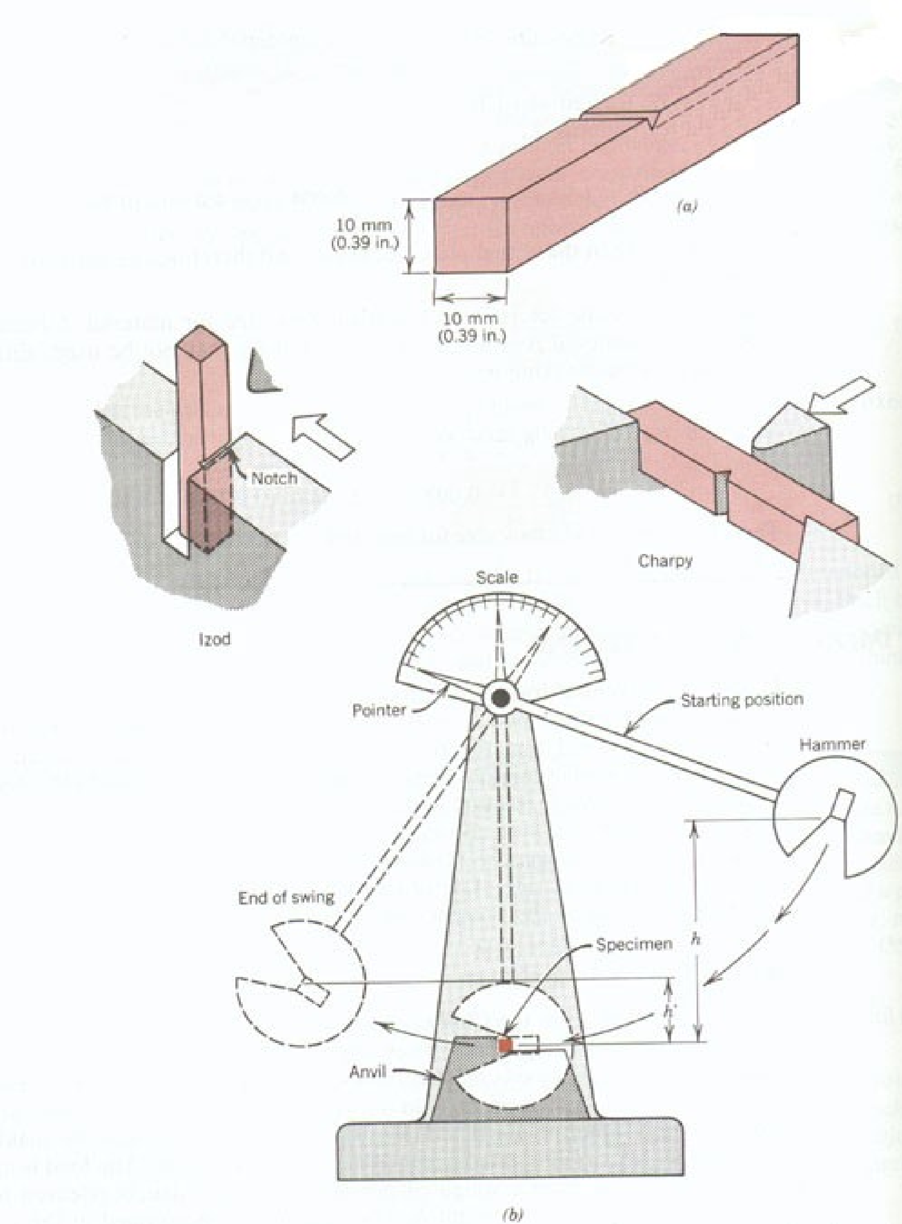
HARDNESS TEST

- Hardness, as a mechanical property, is the resistance of a material to surface penetration.
- Therefore, most hardness tests involve measuring the amount of force required to implant a specified indentation in the surface of a specimen OR the size of the indentation produced from applying a specified load.
- The indenter used varies with the test selected, but is generally hardened steel or diamond.

- Common hardness tests include the Rockwell and Brinell. Other test procedures used include the scleroscope, surface abrasion testing, Vickers, and Tukon-Knoop.
  - Brinell Hardness Test
  - Vickers hardness Test
  - Rockwell Hardness Test

Impact Test

- **Impact Testing, ASTM E23 and IS/ BS Standard**
- The impact test is a method for evaluating the toughness and notch sensitivity of engineering materials. It is usually used to test the toughness of metals, but similar tests are used for polymers, ceramics and composites. Metal industry sectors include Oil and Gas, Aerospace, Power Generation, Automotive, and Nuclear.



10 mm
(0.39 in.)
10 mm
(0.39 in.)
(a)
Notch
Izod
Charpy
Scale
Pointer
Starting position
Hammer
End of swing
Specimen
h
h'
Anvil
(b)

Charpy Impact Test

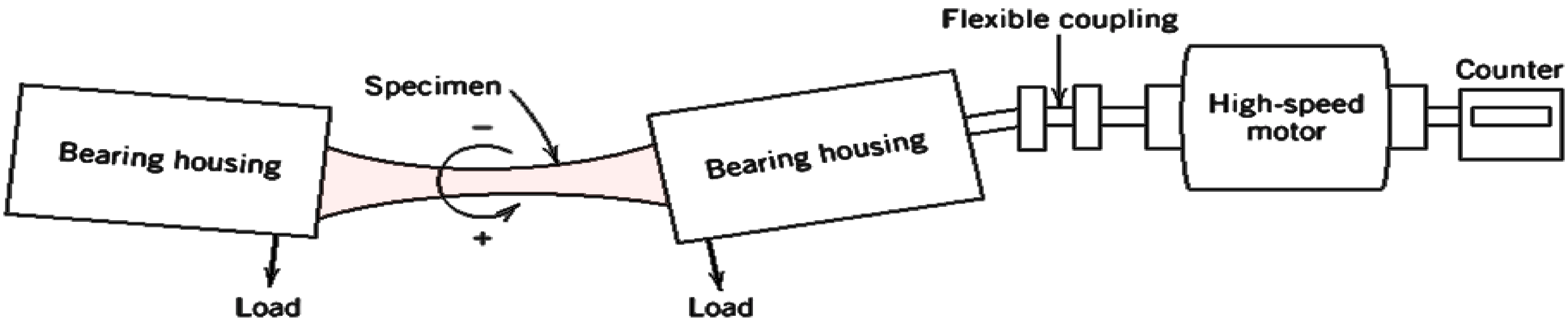
- A test specimen is machined to a 10mm x 10mm (full size) cross-section, with either a "V" or "U" notch. Sub-size specimens are used where the material thickness is restricted. Specimens can be tested down to cryogenic temperatures.
- The Charpy impact test is a dynamic test in which a test piece U-notched or V-notched in the middle and supported at each end, is broken by a single blow of a freely swinging pendulum. The energy absorbed is measured. This absorbed energy is a measure of the impact strength of material.

Izod Impact Test

- The test specimen is machined to a square or round section, with either one , two or three notches. The specimen is clamped vertically on the anvil with the notch facing the Hammer.
- The Izod impact test is a dynamic test in which a test piece V-notched test piece, gripped vertically, is broken by a single blow of a freely swinging pendulum. The blow is struck on the same face as the notch and at the fixed height above it. The energy absorbed is measured. This absorbed energy is a measure of the impact strength of material.

Fatigue

- It has long been known that a component subjected to fluctuating stresses may fail at stress levels much lower than its monotonic fracture strength, due to a process called *Fatigue*.
- In several applications, components have to withstand different kinds of load at different times .
- Materials subjected to these fluctuating or repeated load tends to show a behavior which is different from what they show under steady loads.

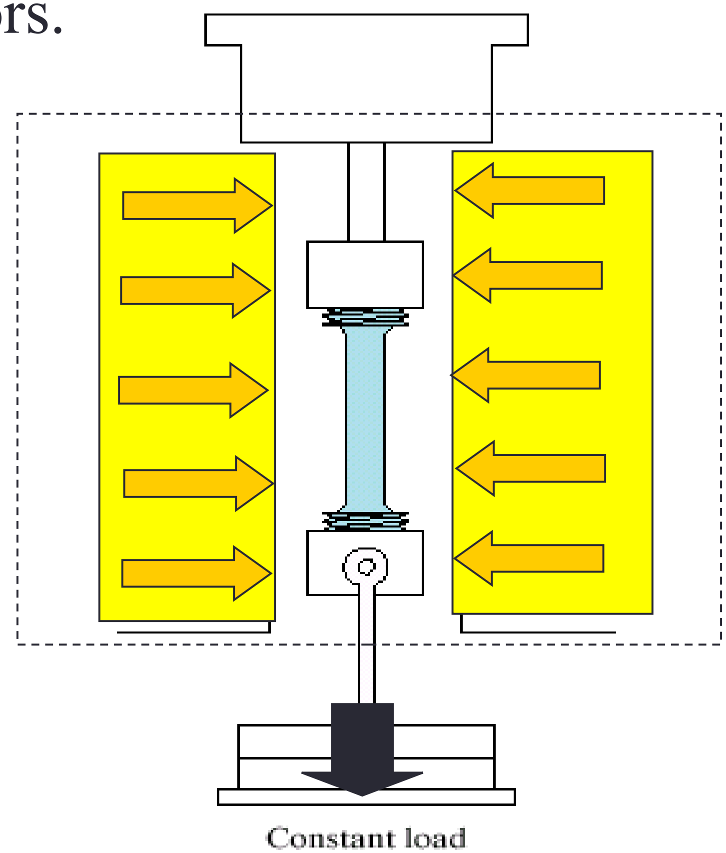

Flexible coupling
Counter
Specimen
High-speed motor
Bearing housing
Bearing housing
−
+
Load
Load

Creep

Time-dependent deformation due to constant load at high temperature ($> 0.4\ T_m$)

Examples: turbine blades, steam generators.

Creep test:



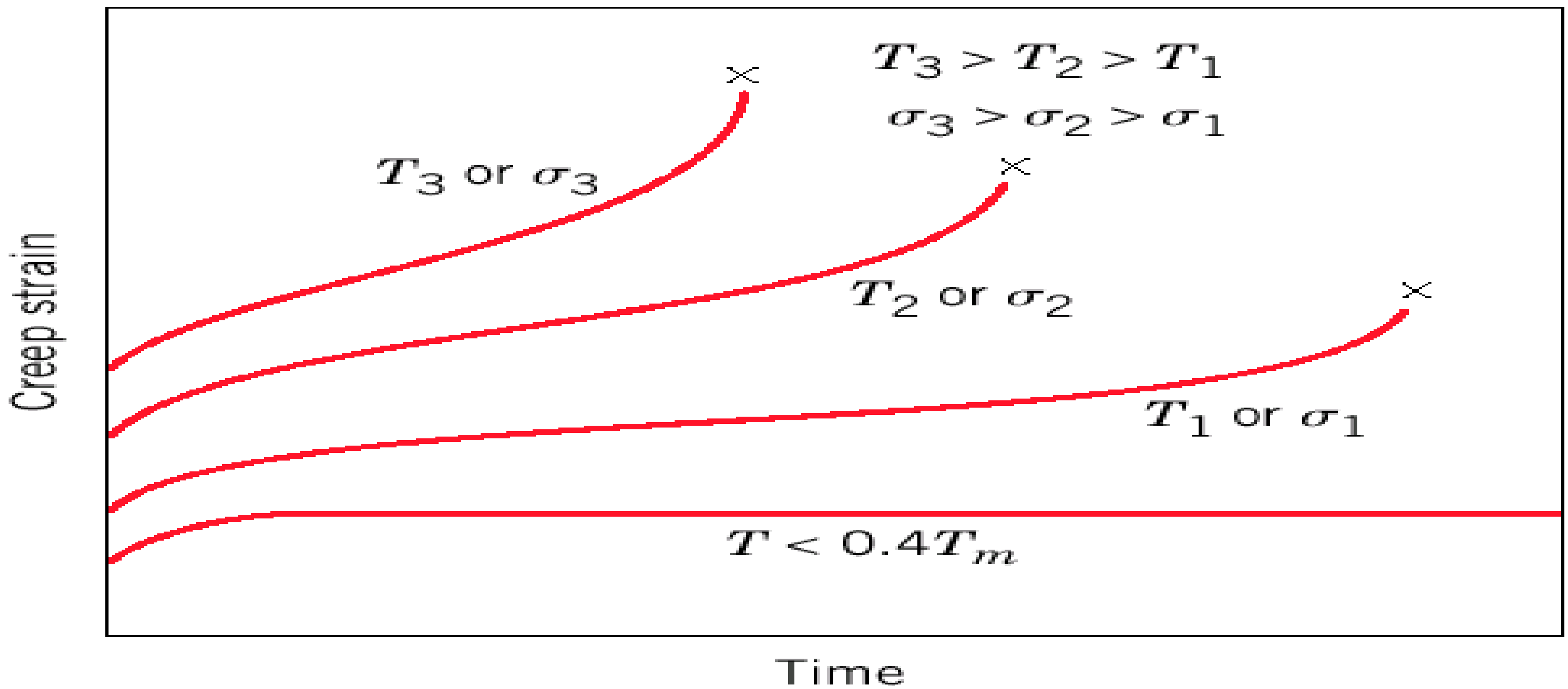
Furnace

Creep testing

Creep: stress and temperature effects

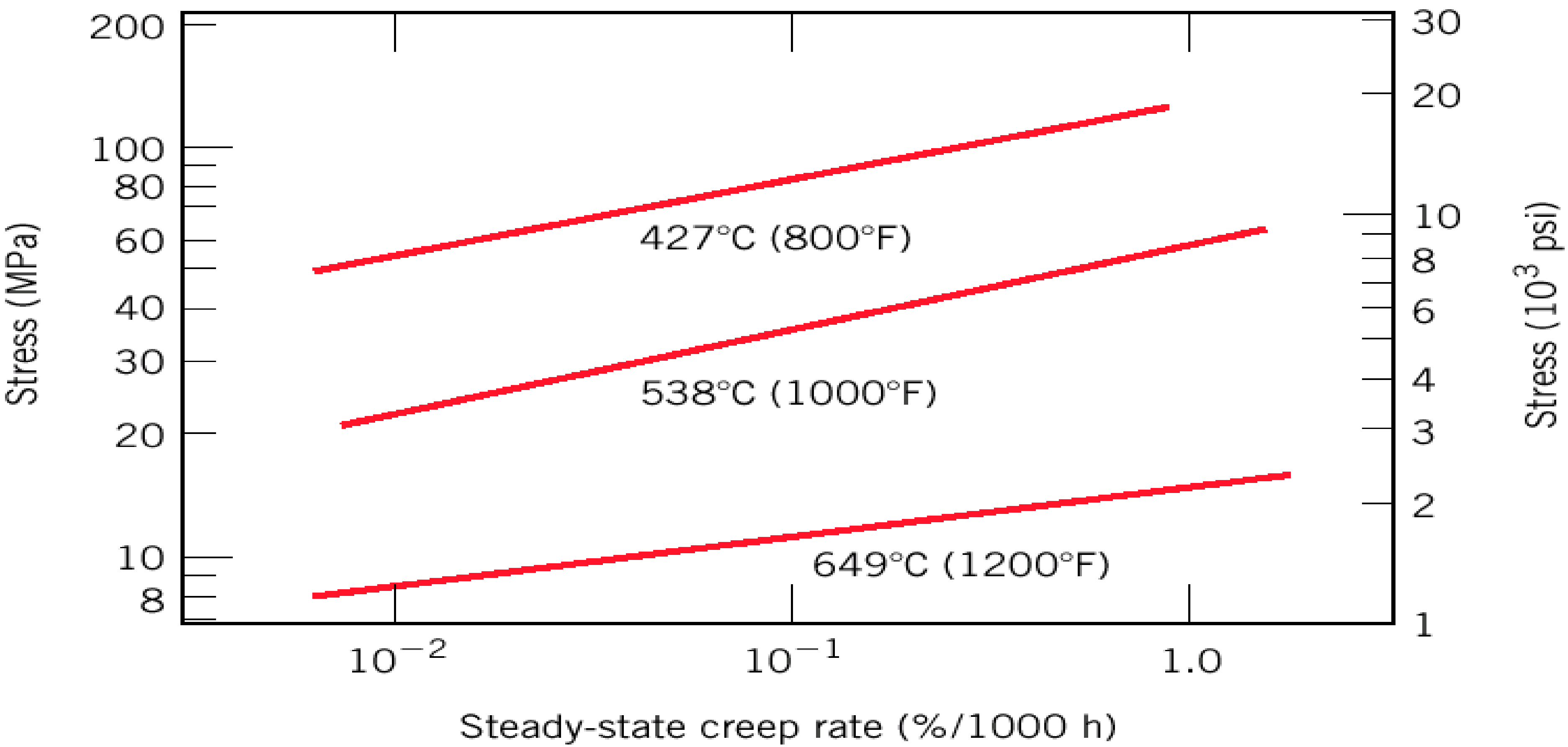
With increasing stress or temperature:

- The instantaneous strain increases
- The steady-state creep rate increases
- The time to rupture decreases



Creep: stress and temperature effects

Stress/temperature dependence of the steady-state creep rate can be illustrated by

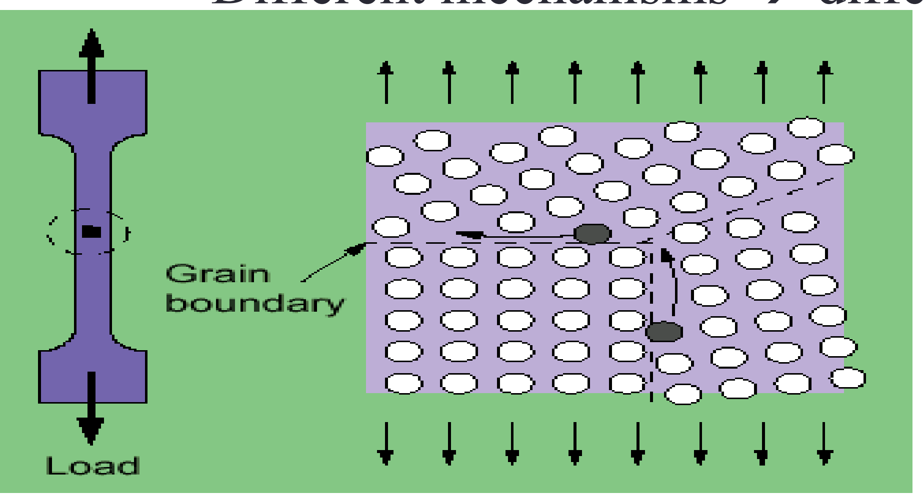


Mechanisms of Creep

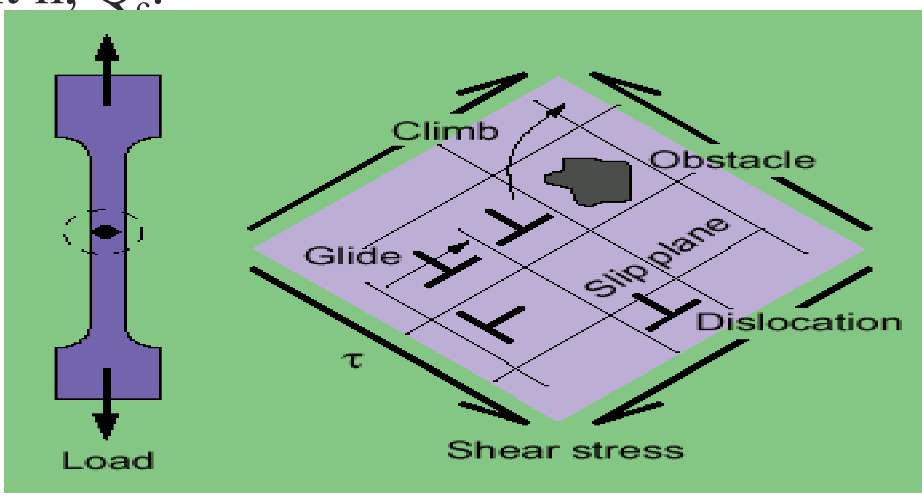
Different mechanisms act in different materials and under different loading and temperature conditions:

- Dislocation Glide
- Dislocation Creep
- Diffusion Creep
- Grain boundary sliding

Different mechanisms → different n, Q_c.



Grain boundary diffusion



Dislocation glide and climb

Mechanisms of Creep

Dislocation glide- Involves dislocations moving along slip planes and overcoming barriers by thermal activation. This mechanism occurs at high stress levels.

Dislocation creep- Involves the movement of dislocations which overcome barriers by thermally assisted mechanisms involving the diffusion of vacancies or interstitials.

Mechanisms of Creep

Diffusion creep- Involves the flow of vacancies and interstitials through a crystal under the influence of applied stress. This mechanism occurs at high temperatures and low stress levels.

Grain boundary sliding- Involves the sliding of grains past each other.