Notes
on
"Mechanical properties of materials"

Introduction

A **material's property** (or **material property**) is an intensive property of some material, i.e. a physical property that does not depend on the amount of the material.

Often materials are subject to forces (loads) when they are used. Mechanical engineers calculate those **forces** and material scientists how materials deform (elongate, compress, twist) or break as a function of applied load, time, temperature, and other conditions.

Various Mechanical Properties

- Anelasticity
- Ductility
- Elastic deformation
- Engineering strain
- Engineering stress
- Hardness
- Modulus of elasticity
- Plastic deformation
- Poisson's ratio
- Proportional limit
- Shear
- Tensile strength
- Toughness
- Yielding
- Yield strength
- Fatigue
- Creep
- Stiffness
- Strength

Here We will see the change in physical behavior of material due to external changes on it.

Anelasticity

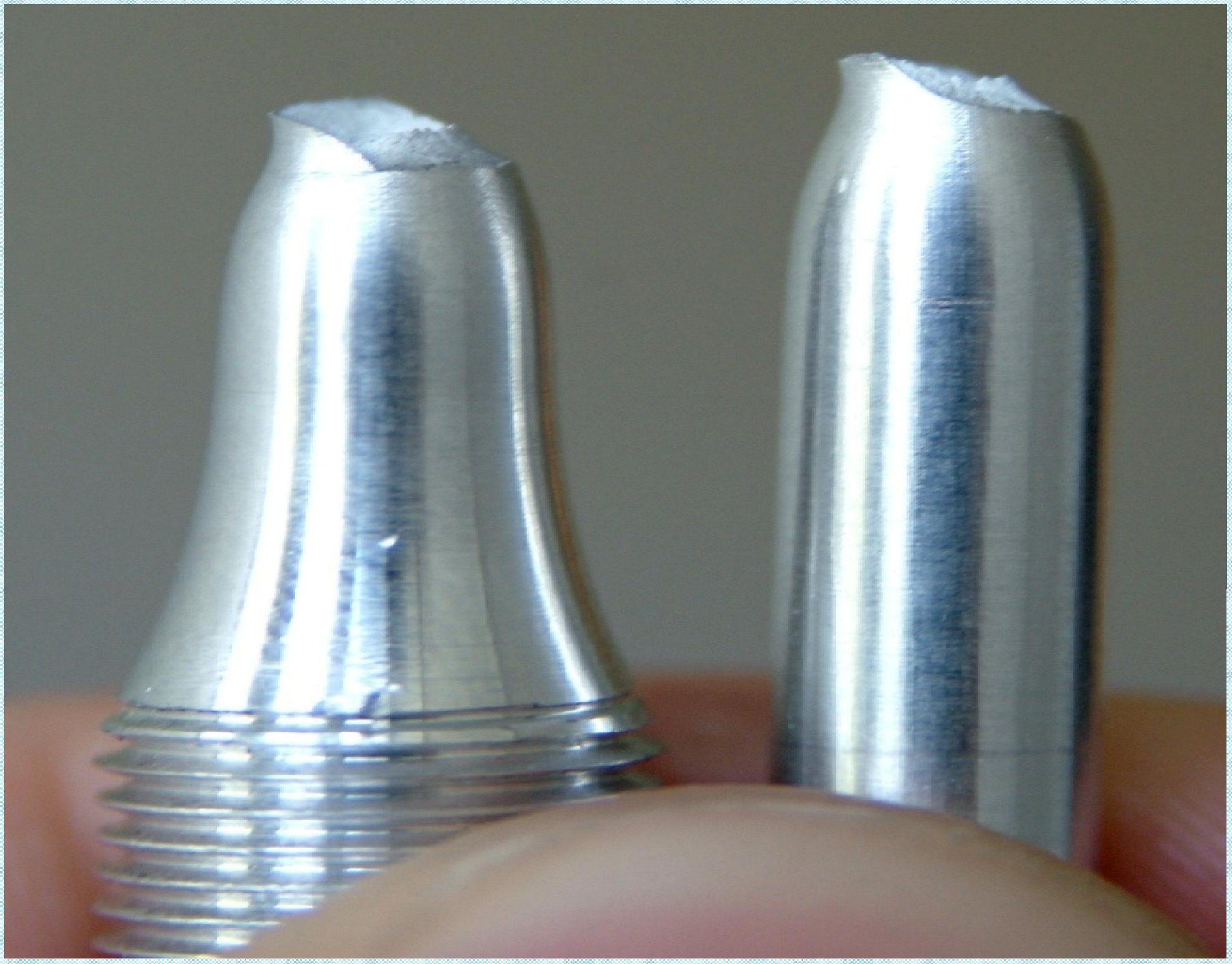
- Here the behavior is elastic but not the stress-strain curve is not immediately reversible. It takes a while for the strain to return to zero.
- The effect is normally small for metals but can be significant for polymers.

Brittleness

- Brittleness of a material indicates that how easily it gets fractured when it is subjected to a force or load.
- When a brittle material is subjected to a stress it observes very less energy and gets fractures without significant strain.
- Brittleness is converse to ductility of material. Brittleness of material is temperature dependent. Some metals which are ductile at normal temperature become brittle at low temperature.

Ductility

- ❖Ductility is a property of a solid material which indicates that how easily a material gets deformed under tensile stress.
- ❖Ductility is often categorized by the ability of material to get stretched into a wire by pulling or drawing.
- ❖This mechanical property is also an aspect of plasticity of material and is temperature dependent. With rise in temperature, the ductility of material increases.



Tensile test of an AlMgSi alloy. The local necking and the cup and cone fracture surfaces are typical for ductile metals.

Malleability

- Malleability is a property of solid materials which indicates that how easily a material gets deformed under compressive stress.
- Malleability is often categorized by the ability of material to be formed in the form of a thin sheet by hammering or rolling.
- This mechanical property is an aspect of plasticity of material.
- Malleability of material is temperature dependent. With rise in temperature, the malleability of material increases.

Elastic deformation

- **Elastic deformation**. When the stress is removed, the material returns to the dimension it had before the load was applied.

Engineering strain

- There is a change in dimensions, or deformation elongation, đ*L* as a result of a tensile or compressive stress. To enable comparison with specimens of different length, the elongation is also normalized, this time to the length *L*. This is called strain, e.
- **e =** đ***L*/*L***

Engineering and Engineering Stress

- When one applies a constant tensile force the material will break after reaching the tensile strength.
- The material starts necking (the transverse area decreases) but the stress cannot increase beyond s_{TS}.
- The ratio of the force to the initial area, what we normally do, is called the **engineering stress**. If the ratio is to the actual area (that changes with stress) one obtains the ***true stress.***

Hardness

- It is the ability of a material to resist to permanent shape change due to external stress.

There are various measure of hardness – Scratch Hardness, Indentation Hardness and Rebound Hardness.

- **Scratch Hardness** Scratch Hardness is the ability of materials to the oppose the scratches to outer surface layer due to external force.
- **Indentation Hardness** It is the ability of materials to oppose the dent due to punch of external hard and sharp objects.
- **Rebound Hardness** Rebound hardness is also called as dynamic hardness. It is determined by the height of "bounce" of a diamond tipped hammer dropped from a fixed height on the material.

- **Hardness** is the resistance to plastic deformation (e.g., a local dent or scratch).
- Thus, it is a measure of ***plastic*** **deformation**, as is the tensile strength, so they are well correlated.
- Historically, it was measured on an empirically scale, determined by the ability of a material to scratch another, diamond being the hardest and talc the softer. Now we use standard tests, where a ball, or point is pressed into a material and the size of the dent is measured.
- There are a few different hardness tests: **Rockwell, Brinell, Vickers,** etc. They are popular because they are easy and non-destructive (except for the small dent).

Hardenability

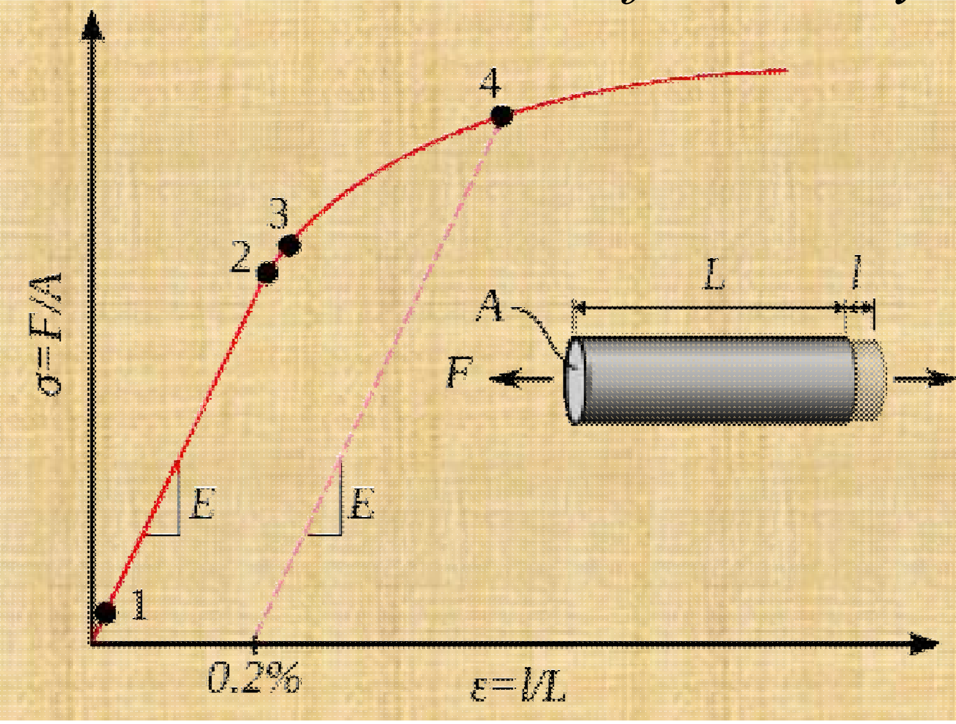
- It is the ability of a material to attain the hardness by heat treatment processing. It is determined by the depth up to which the material becomes hard.
- The SI unit of Hardenability is meter (similar to length).
- Hardenability of material is inversely proportional to the weld-ability of material.

Poisson's ratio

- Materials subject to tension shrink laterally. Those subject to compression, bulge. The ratio of lateral and axial strains is called the *Poisson's ratio* n.
- $\mathbf{n = e_{lateral}/e_{axial}}$
- The elastic modulus, shear modulus and Poisson's ratio are related by $E = 2G(1+n)$

Modulus of elasticity

- In tensile tests, if the deformation is *elastic*, the stress-strain relationship is called Hooke's law:
- **s = *E* e**
- That is, *E* is the slope of the stress-strain curve. E is *Young's modulus* or *modulus of elasticity*.



Elasticity

- Ability of a body to resist a distorting influence or stress and to return to its original size and shape when the stress is removed.
- It is the ability of a body to resist a distorting influence and to return to its original size and shape when that influence or force is removed.
- Solid objects will deform when adequate forces are applied on them. If the material is elastic, the object will return to its initial shape and size when these forces are removed.

Tensile strength

- **Yield point**. If the stress is too large, the strain deviates from being proportional to the stress. The point at which this happens is the *yield point* because there the material yields, deforming permanently (plastically).
- **Yield stress**. Hooke's law is not valid beyond the yield point. The stress at the yield point is called *yield stress*, and is an important measure of the mechanical properties of materials. In practice, the yield stress is chosen as that causing a permanent strain of 0.002 (strain offset, Fig. 6.9.)
- *The yield stress measures the resistance to plastic deformation*.
- The reason for plastic deformation, in normal materials, is not that the atomic bond is stretched beyond repair, but the motion of dislocations, which involves breaking and reforming bonds.
- *Plastic deformation is caused by the motion of dislocations*.

- **Tensile strength**. When stress continues in the plastic regime, the stress-strain passes through a maximum, called the *tensile strength* (s_{TS}) , and then falls as the material starts to develop a *neck* and it finally breaks at the *fracture point* .
- Note that it is called strength, not stress, but the units are the same, MPa.
- *For structural applications, the yield stress is usually a more important property than the tensile strength, since once the it is passed, the structure has deformed beyond acceptable limits.*

Toughness

- It is the ability of a material to absorb the energy and gets plastically deformed without fracturing. Its numerical value is determined by the amount of energy per unit volume. Its unit is Joule/ m^3. Value of toughness of a material can be determined by stress-strain characteristics of a material. For good toughness, materials should have good strength as well as ductility.
- For example: brittle materials, having good strength but limited ductility are not tough enough. Conversely, materials having good ductility but low strength are also not tough enough. Therefore, to be tough, a material should be capable to withstand both high stress and strain.

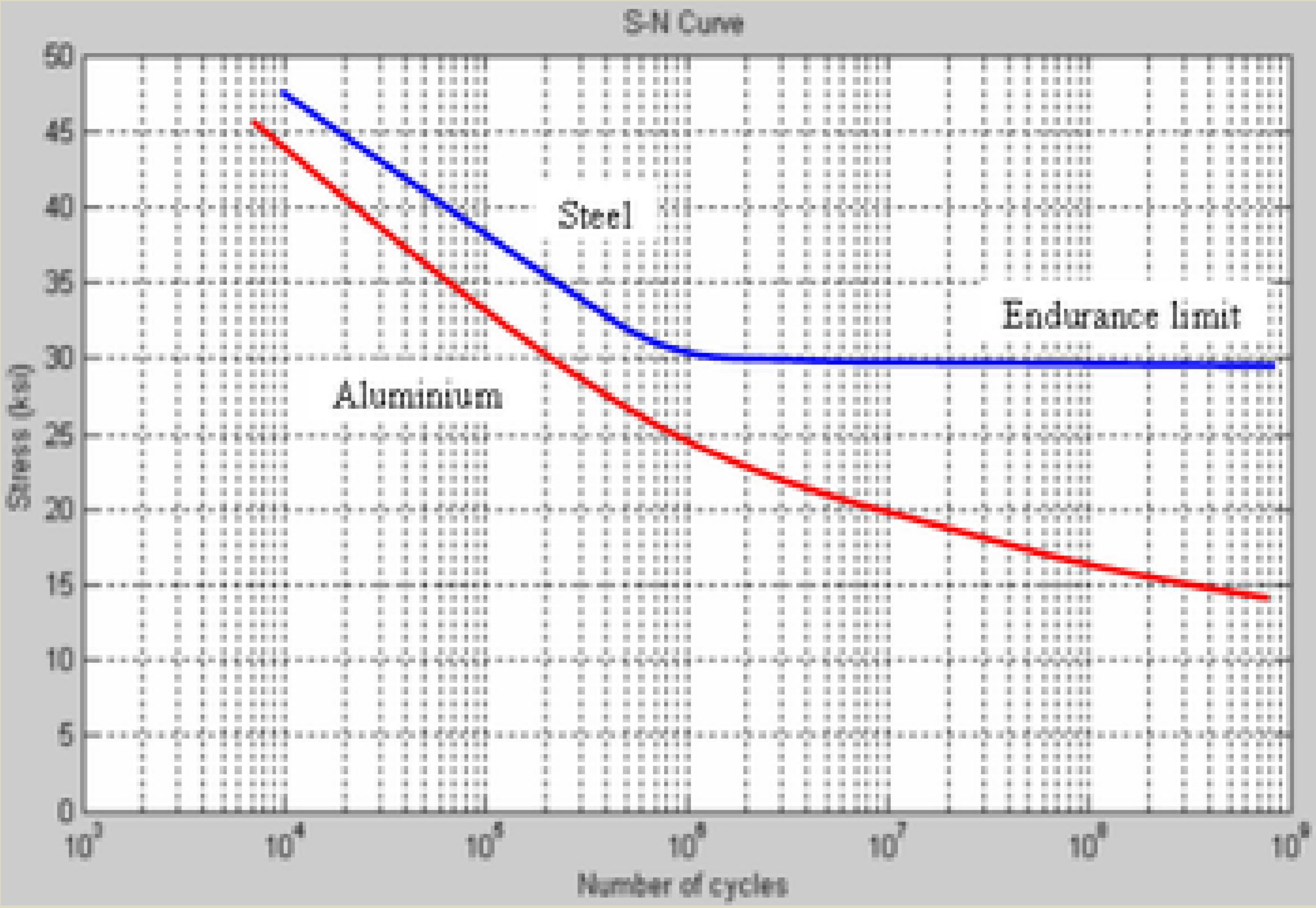
Yielding

- ***For structural applications***, the **yield stress** is usually a more important property than the tensile strength, since once the it is passed, the structure has deformed beyond acceptable limits.

Fatigue

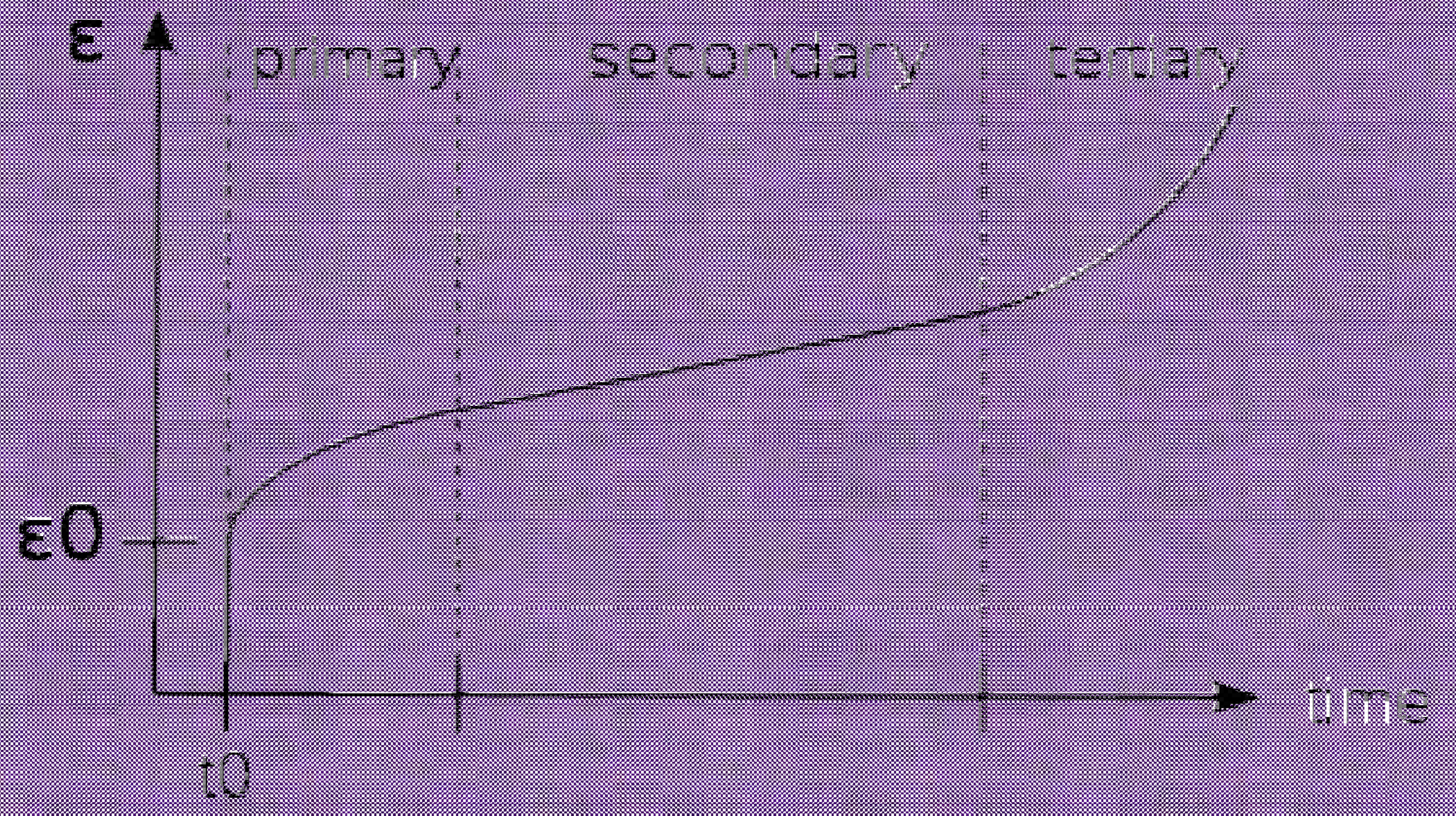
- Fatigue is the weakening of material caused by the repeated loading of the material.
- When a material is subjected to cyclic loading, and loading greater than certain threshold value but much below the strength of material (ultimate tensile strength limit or yield stress limit), microscopic cracks begin to form at grain boundaries and interfaces. Eventually the crack reaches to a critical size.
- This crack propagates suddenly and the structure gets fractured. The shape of structure affects the fatigue very much. Square holes and sharp corners lead to elevated stresses where the fatigue crack initiates.

- **Fatigue limit**, **endurance limit**, and **fatigue strength** are all expressions used to describe a property of materials: the amplitude (or range) of cyclic stress that can be applied to the material without causing fatigue failure.
- Ferrous alloys and titanium alloys have a distinct limit, an amplitude below which there appears to be no number of cycles that will cause failure. Other structural metals such as aluminium and copper do not have a distinct limit and will eventually fail even from small stress amplitudes. In these cases, a number of cycles (usually 10^7) is chosen to represent the fatigue life of the material.
- Fatigue limit is used in plotting S-N curves (Strength Vs Number of Cycles)


S-N Curve
Steel
Endurance limit
Aluminium
Stress (ksi)
Number of cycles

Creep

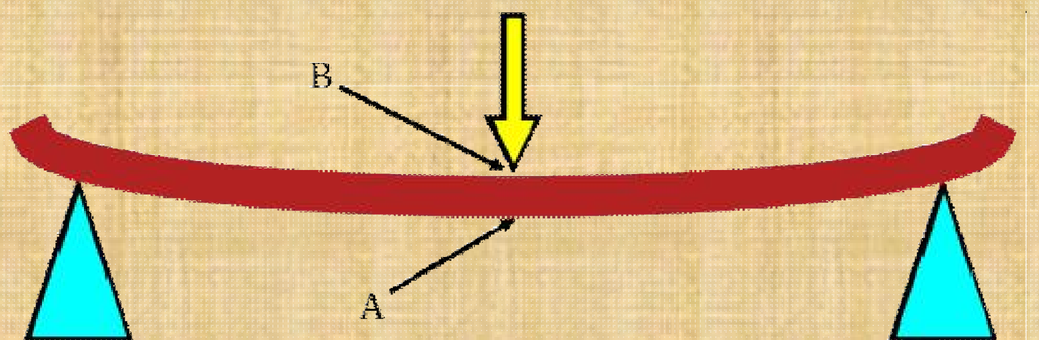
- Creep is the property of a material which indicates the tendency of material to move slowly and deform permanently under the influence of external mechanical stress.
- It results due to long time exposure to large external mechanical stress with in limit of yielding.
- Creep is more severe in material that are subjected to heat for long time. Slip in material is a plane with high density of atoms.


ε
primary
secondary
tertiary
ε0
t0
time

- It is the tendency of a solid material to move slowly or deform permanently under the influence of mechanical stresses. It can occur as a result of long-term exposure to high levels of stress that are still below the yield strength of the material. Creep is more severe in materials that are subjected to heat for long periods, and generally increases as they near their melting point.
- The rate of deformation is a function of the material's properties, exposure time, exposure temperature and the applied structural load. Depending on the magnitude of the applied stress and its duration, the deformation may become so large that a component can no longer perform its function — for example creep of a turbine blade will cause the blade to contact the casing, resulting in the failure of the blade. Creep is usually of concern to engineers and metallurgists when evaluating components that operate under high stresses or high temperatures. Creep is a deformation mechanism that may or may not constitute a failure mode.

Stiffness

Ability of an object to resist deformation in response to an applied force; rigidity; complementary to flexibility



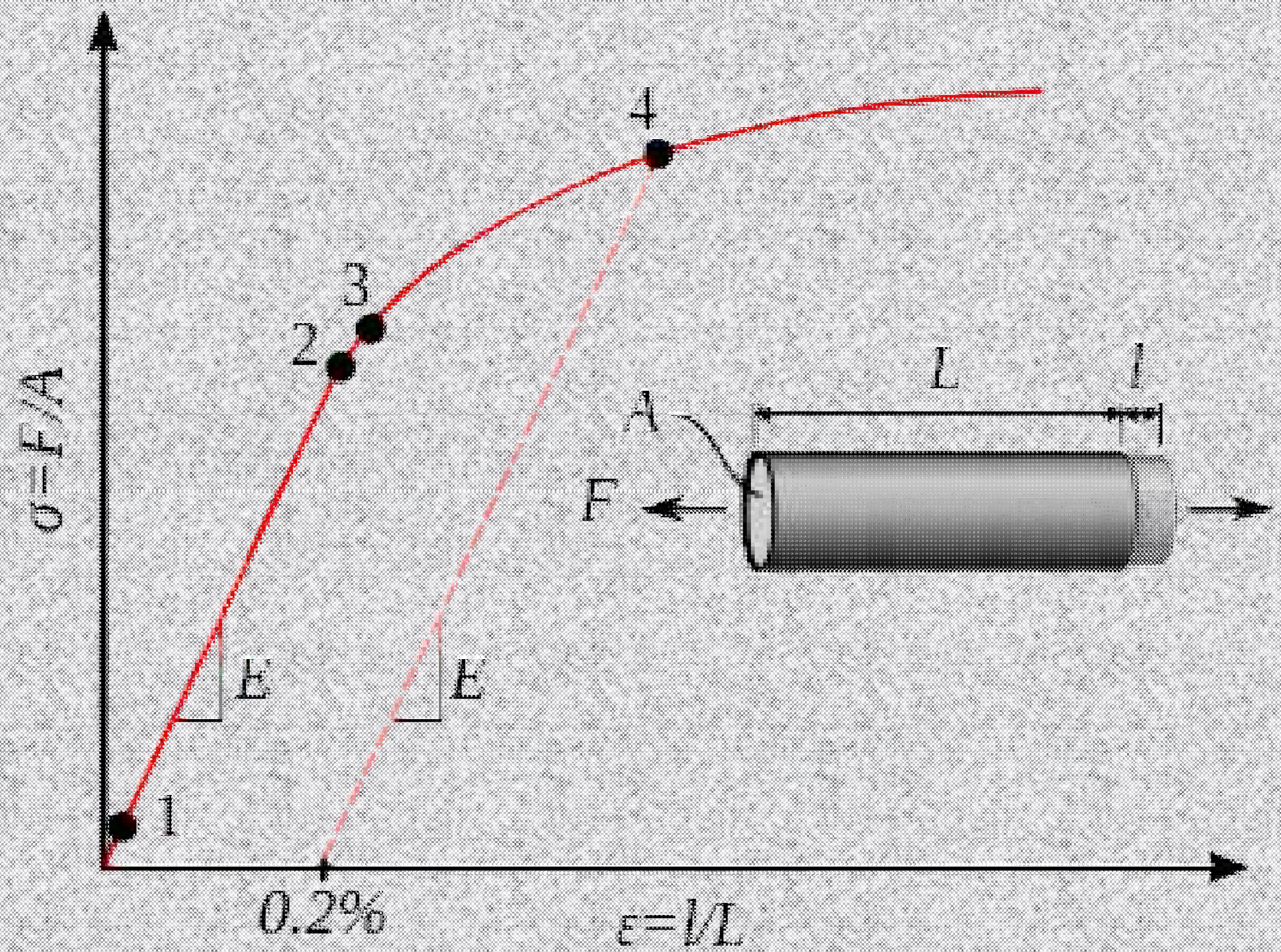
Strength

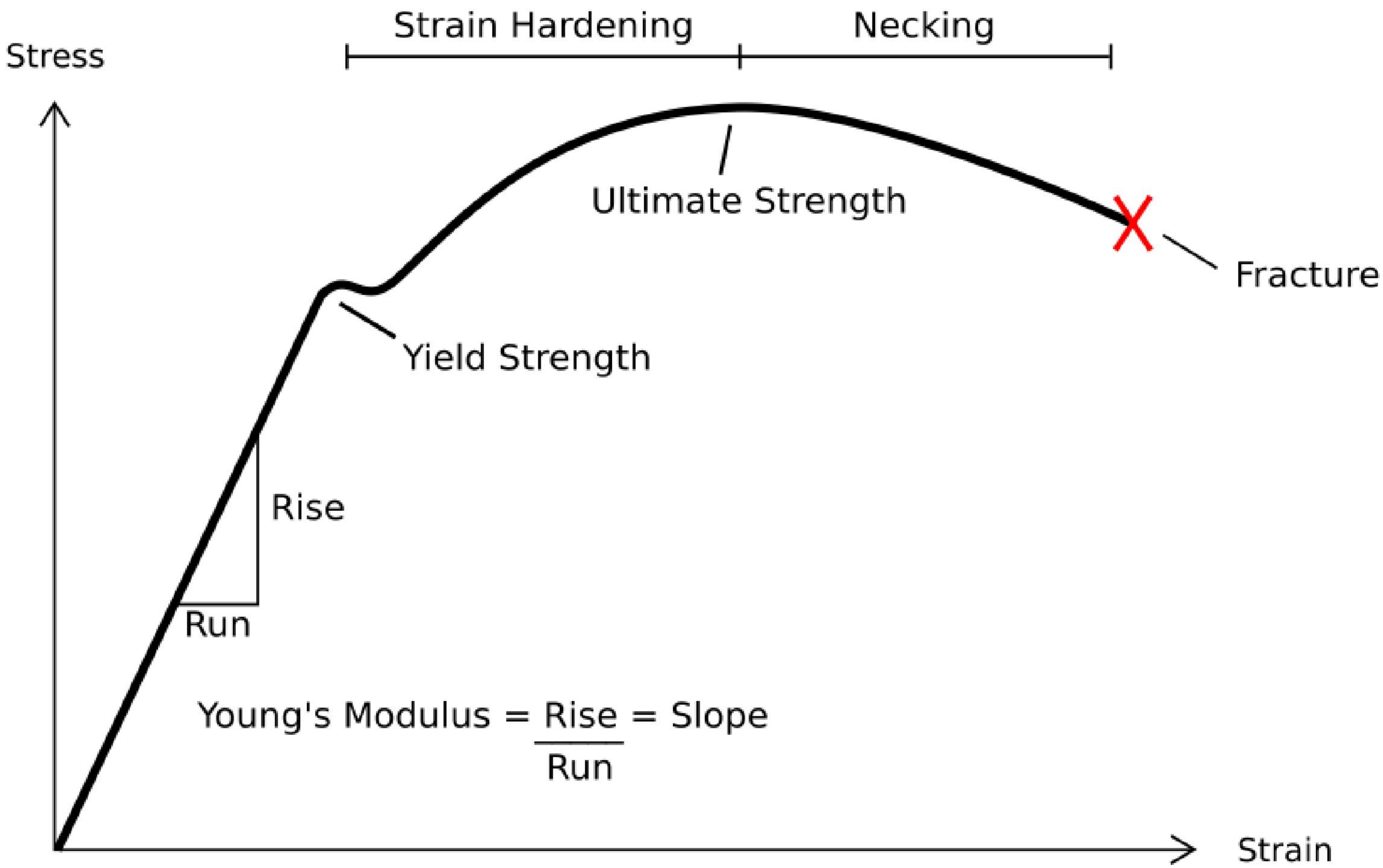
- It is the **property of a material** which opposes the deformation or breakdown of material in presence of external forces or load.
- Materials which we finalize for our engineering products, must have suitable mechanical strength to be capable to work under different mechanical forces or loads.

Resilience

- **Capacity to absorb energy *elastically*. The energy per unit volume is the *area under the strain-stress curve in the elastic region.***
- Resilience is the ability of material to absorb the energy when it is deformed elastically by applying stress and release the energy when stress is removed.
- Proof resilience is defined as the maximum energy that can be absorbed without permanent deformation.
- The modulus of resilience is defined **as the maximum energy that can be absorbed per unit volume without permanent deformation.** It can be determined by integrating the stress-strain cure from zero to elastic limit. Its unit is joule/m^3.

- Capacity to absorb energy *elastically*. The energy per unit volume is the *area under the strain-stress curve in the elastic region.*
- The area under the linear portion of a stress–strain curve is the resilience of the material
- In material science, **resilience** is the ability of a material to absorb energy when it is deformed elastically, and release that energy upon unloading. **Proof resilience** is defined as the maximum energy that can be absorbed up to the elastic limit, without creating a permanent distortion. The **modulus of resilience** is defined as the maximum energy that can be absorbed per unit volume without creating a permanent distortion.
- It can be calculated by integrating the stress–strain curve from zero to the elastic limit. In uniaxial tension, under the assumptions of linear elasticity,


σ=F/A
4
3
2
1
E
E
0.2%
ε=l/L
L
l
A
F


Strain Hardening
Necking
Stress
Ultimate Strength
Fracture
Yield Strength
Rise
Run
Young's Modulus = Rise = Slope
Run
Strain

Thanks

Any Query

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Contact me..