Kurdistan Region
Salahaddin University-Erbil
College of Engineering
Mechanic & Mechatronics Engineering Department

Fundamentals of Design

For Second Stage Students
In Mechanic & Mechatronics Dept.

Prepared By:
Mr. Abdulbasit Abdulqadir Hamza

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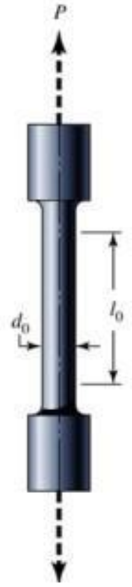
Chapter Two

Materials

Choosing the appropriate material is an important step in mechanical design.

Material Strength and Stiffness

Standard tensile test is used to determine many of the mechanical properties of the materials.
Load, P, and deflection, $\delta = (l - l_o)$, are recorded and from that the engineering stress vs. strain curve is determined.



d_o: original diameter

l_o: gauge length (original length)

Engineering stress: $\sigma = \frac{P}{A_o}$

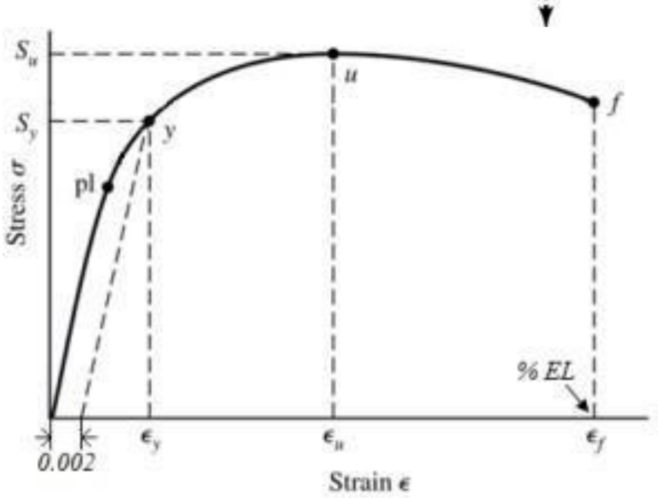
Strain: $\epsilon = \frac{l - l_o}{l_o}$

Elastic region: no permanent deformation takes place (if the load is removed, the specimen goes back to its original length).

- Stress & strain are related linearly by

Hook's law: $\sigma = E * \epsilon$

E: Young's modulus or modulus of elasticity (slope of the linear part)



- Proportional limit: the curve starts to deviate from straight line.
- Yield strength, S_y : the end of elastic deformation, plastic (*permanent*) deformation starts.

- Usually determined using the 0.002 yield criterion.

- Ultimate strength, S_u : is the maximum stress reached on the "engineering" stress strain diagram.

- Necking starts after S_u (for ductile materials) until fracture at point "f".
- The elongation at fracture is referred to as (*%EL*).

➢ Strength of a material usually refers to the yield strength.

➢ Stiffness refers to the amount of deformation the material shows under applied load. The lesser the deformation, the stiffer the material.

➢ In the elastic region, “stiffness” refers to Young’s modulus. The higher the

⍰, the higher the stiffness.

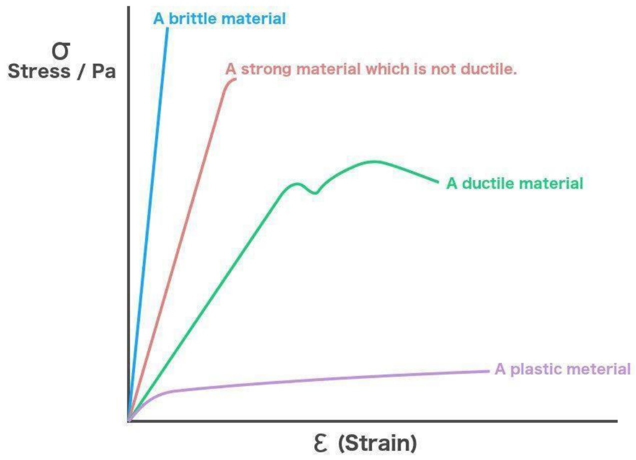
Ductile and Brittle Materials

Ductility measures the degree of plastic deformation sustained at fracture.

• ***A Ductile material*** is one that exhibits a large amount of plastic deformation before failure.

- It shows necking before fracture.

Example: Steels *%EL > 20%*



• ***A Brittle material*** exhibits little or no yielding before fracture.

- Usually defined as materials having *%EL < 5%* at fracture.

- It shows little or no necking before fracture.

- It is much stronger in compression than in tension.

Examples: gray cast iron & glass

❖ **Table A-5** gives the physical constants for some materials.

❖ **Table A-20** gives the mechanical properties for some steel alloys.

❖ **Table A-24** gives the mechanical properties for some cast irons.

Strength and Cold Work

Cold working is a process in which the material is plastically deformed at a temperature below the recrystallization temperature.

Heat Treatment of Steel

Heat treatment refers to time & temperature-controlled process that relieves residual stresses and/or modifies material properties.

- **Annealing**

When a material is cold (or hot) worked, residual stresses are introduced in the material. Also, the strength of the material is usually increased. Annealing is a heat treatment process in which the residual stresses are removed, the material is softened (strength is reduced) and the material is made to be more ductile.

- The material to be annealed is heated to a temperature that is approximately *50℃* above the critical temperature and is held at this temperature for a sufficient time for the carbon to be dissolved and defused in the material. Then the object is allowed to cool-down slowly.

- **Quenching**

Quenching is a process in which the material is hardened.

- The material is heated to a temperature above the critical temperature then the material is cooled at a fast rate (*using water or oil*) to a temperature below the critical temperature.

- **Tempering**

When a material is quenched, residual stresses are introduced because of the uneven fast cooling. Tempering is used to remove the residual stresses from the fully hardened material (which is very brittle) and it reduces the hardness of the material.

- After the material has been quenched, tempering is done by reheating the material to some temperature below the critical temperature for a certain period of time, then allowing it to cool in still air.

- **Case Hardening**

The purpose of case hardening is to produce a hard-outer surface on a specimen of low carbon steel while maintaining the ductility in the core.

- Case hardening is usually done by increasing the carbon content at the surface by surrounding the surface by a carburizing material for a certain time at a certain temperature. Then the material is quenched down from this temperature and tempered.

- Another method of case hardening is to heat the surface using a flame (or induction coil) then quenching and tempering.

Table A-21 gives the mechanical properties for some heat-treated steels. (*Q&T*: Quenched and Tempered)

Classification of Solid Materials

Engineering materials fall into four major classes: Metals, Ceramics (including glasses), Polymers, and Composites.

Metals

Metals are combinations of metallic elements. They are strong and deformable, making them important materials in machine design.

- Metals are good conductors of heat and electricity and not transparent to visible light.
- Metals are usually ductile which helps in accommodating stress concentrations by deforming plastically such that loads are redistributed more evenly.
- Metals can be made stronger by alloying and by mechanical and heat treatment.
- Metals are initially cast then they can be further processed to achieve desired shape. Further processes include casting, bulk forming, sheet forming, and machining.

Ceramics and Glasses

Ceramics are compounds of metallic and non-metallic elements, most frequently oxides, nitrides, and carbides.

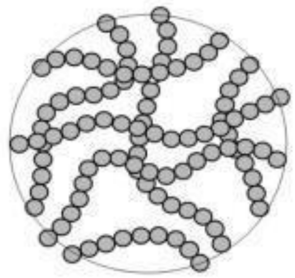
- Glasses are similar to ceramics in composition but they have no clear crystal structure.
- Ceramics are stiff, hard, brittle, and much stronger in compression than in tension.
- Ceramics are made from ceramic slurry then it is fired to solidify.

Polymers

Polymers include plastic and rubber materials.

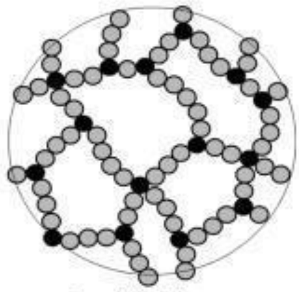
Polymers are of two basic types: thermoplastics & thermosets

• ***Thermoplastics*** are long chain molecules, sometimes with branches, where strength arises from interference between chains and branches. Thermoplastics are more ductile than thermosets and they soften significantly and melt at elevated temperatures.



Long chains (no cross-linking)

• ***Thermosets*** have higher degree of cross-linking (like a sponge). They are more brittle, do not soften with temperature as much as thermoplastics and usually chemically degrade before melting.



Cross-linked chains

- Mechanical properties of polymers depend largely on temperature and they can not stand high temperatures (*less than 250°C*).

Composites

Composite materials are formed from two or more materials (that remain distinct from each other) each of which contributes to the final properties. It combines the attractive properties of each component material.

- The main advantages of composites are tailor ability (provides strength in the needed region and direction only) and light weight (for example the strength-to weight ratio of graphite is about 40 times as that of steel).