OCR B Physics A Level

Module 3.2: Mechanical Properties of Materials

Notes

Macroscopic Properties of Materials

Deformation

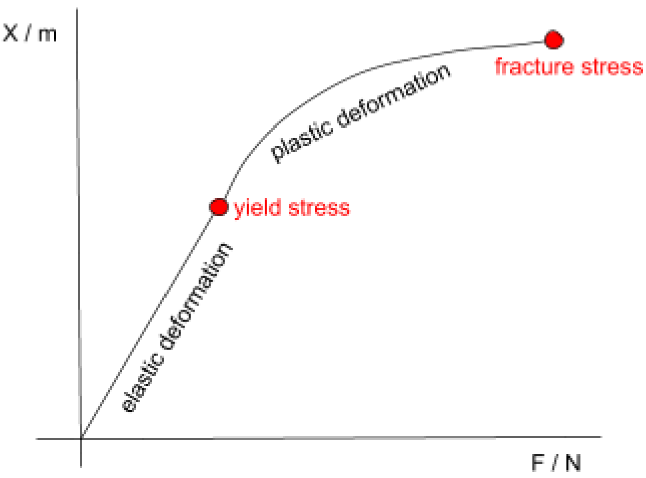
Materials **deform** when multiple forces are applied to them. This means that they change shape, which often means being **stretched** or **compressed**.

Elastic deformation occurs within the **limit of proportionality** for a material, and is only a temporary change to the shape of an object. When the forces (or **stresses**) are removed, the material returns to its original shape. **Plastic** deformation is more permanent, as the object will not return to its original shape when stresses are removed.

Forces which deform materials can be tensile or compressive. **Tension** occurs when two forces act in opposite directions on an object to make it stretch. **Compression** occurs when two forces act in opposite directions on an object to make it squash.

The **yield stress** is the stress which produces plastic deformation. Any stresses less/weaker than the yield stress will produce elastic deformation. The **fracture stress** is the stress which causes the material to break.

On a graph of force against extension, the linear part of the graph represents elastic deformation, and the non-linear part shows plastic deformation. The graph stops at the fracture stress.



Describing Materials [Key Terms]

Stiff	Small extension per unit force (high Young modulus).
Elastic	Returns to unstretched form when stresses are removed.
Plastic	Permanent deformation.
Ductile	Can be drawn into wires.
Hard	Resists indentation on impact.
Brittle	Undergoes little/no plastic deformation before fracture.
Tough	Absorbs a lot of energy (deforms plastically) before fracture.
Strong	Can withstand high stresses.

Stretching Wires and Springs

Within the limit of proportionality, elastic objects such as wires and springs follow **Hooke's Law**.

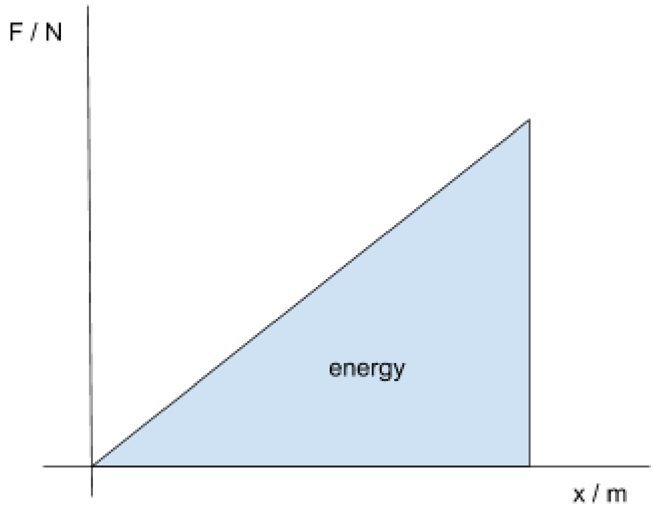
This states that the extension produced is **directly proportional** to the force applied, or, in an equation form:

$F = kx$

Where k is the spring constant, measured in N/m. The spring constant is different for every material and sample; it is not a specific value.

When something is stretched or compressed, it stores **elastic potential energy**.

$E = \frac{1}{2} kx^2$



This is the area under a force/extension graph.

Young's Modulus

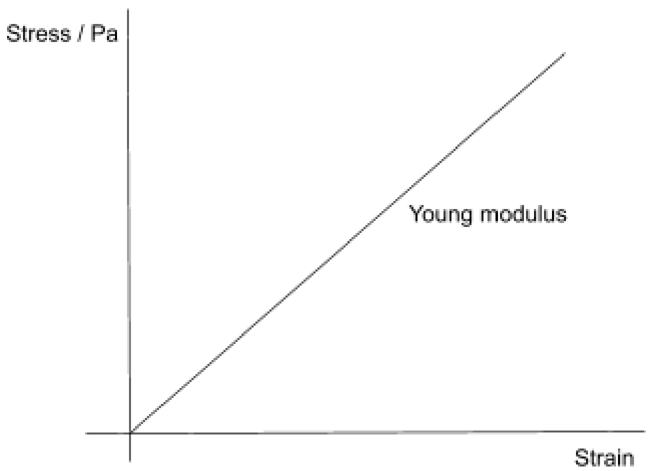
Stress is the force per unit area on an object. $stress = \frac{force}{area}$

Strain is the ratio of extension to original length.

$$strain = \frac{extension}{original\ length}$$

The **Young Modulus, ε** is the ratio of stress to strain. $\varepsilon = \frac{stress}{strain} = \frac{F\ L}{A\ x}$

This can also be found from the gradient of a stress/strain graph.



The units of stress are **Pascals,** Pa. Strain has **no units**, as it is a ratio. This means that the Young modulus has the same units as stress, and it is also measured in **Pascals**.

The Young modulus is often a very large number. A high value means that there is a small strain for a large stress, so indicates a **stiff** object.

Microscopic Properties of Materials

Rayleigh's Oil Drop Experiment

Rayleigh's Oil Drop Experiment was originally used to estimate the size of an atom:

1. An oil drop of known volume was placed on the surface of the water in a wide bowl.
2. The drop formed a film, **one molecule thick**, on the surface, becoming an oil patch with a measurable diameter.
3. The two shapes are known to have the same volume.
4. The height of the oil patch can then be calculated, giving a measure of the diameter of an atom.

$$volume\ of\ drop = volume\ of\ patch$$

$$\frac{4}{3}\pi r^3 = \pi R^2 h$$

$$\text{So } h = \frac{4r^3}{3R^2}$$

Metal Structure

The structure of materials is grouped into two broad categories: **crystalline**, with regular, organised particles, and **amorphous**, with a random and disordered arrangement of particles.

Polycrystalline structures have regular crystalline fragments (or **grains**), but the grains are arranged in a random/disordered way, disrupting the perfect structure.

Metals are modelled as crystalline or polycrystalline. Pure metals are **malleable** and **ductile**, meaning they can be easily shaped or drawn into wires. This is explained by the **crystalline** structure and the presence of structures called **dislocations**.

The crystalline structure means that planes of particles can easily slide over each other. However, this takes a significant amount of energy. Metals can be deformed much more easily (with less energy) due to **dislocations**. These are effectively gaps in the crystalline structure, which are mobile. These dislocations can shift through the metal, causing the metal to deform one atom at a time as they move through it.

Metals can be made less ductile by **alloying**. Alloys contain multiple types of atoms, which are different sizes, so there are no slip planes. These can **pin dislocations in place**, preventing them from moving through the metal.

Crack Propagation

Amorphous materials such as glass can be **brittle**. This is due to the **propagation of cracks** through the metal.

Two atoms are pulled apart at a crack in the material, followed by the next two atoms. This continues all the way down the material. This is relatively easy because the atoms cannot move relative to each other; they are pinned in place by their irregular arrangement. Even weak forces produce high stresses, because the area of a crack is so small (stress = F / A).

Tough materials can **deform plastically** around a crack to reduce the stress, making them less brittle.

Bonding

The bonds between atoms in a material affect its properties. Bonds in **ceramics** are directional, making it harder for them to deform plastically, whereas bonds in metals are non-directional, so ions can slip over each other and rearrange themselves relatively easily.

All materials behave elastically up to a point; the bonds between atoms have some ability to stretch/compress, allowing the interatomic spacing to increase or decrease. However, when bonds are broken, they deform plastically.

Polymers

Polymers are long chains of repeating **monomers**. These have a wide range of properties.

Crosslinks between chains can reduce the rotation and flexibility of chains, making the material stiffer. They can also have crystalline and amorphous regions, which behave differently.