

MECH0007 Topic Notes  
UCL

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# Chapter 1

## Course Outline

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### 1.1 Coursework and exam

- Metallography and Microstructure - Lab week (week 26), held in Materials Lab Sub Basement Roberts.
- Manufacturing Case Study - Friday afternoon consultancy slots (14:30 onwards), Materials Lab Sub Basement Roberts.
- One three hour exam, consistent of two sections: MCQ (sort of?) and conventional. Timetabled revision slots in summer term.

Add notes about the following topics:

- Cracking - welding vs riveting, arrestment of cracks in a material.
- Casting and forging - in context of manufacturing processes, perocity of a liquid vs a solid.
- Crystalline and amorphous solids - materials which are one or the other, both or both in different capacities, look into molecular structure of each, crystallinity is a degree of structure which affects its properties.
- Plasticity and deformations in metals and other materials.

Structure - Property Relationship at the heart of all Material Science.

Manufacturing (Processing)	
Structure	Property

Categories of materials - these all have different structures and hence properties.

- Metals
- Ceramics
- Polymers
- Composites - a mix of the other three above (physical mix), provides an extra level of structure for scientists to work with.

# Chapter 2

## Properties of materials

### 2.1 Metals

#### 2.1.1 General Properties

- High electrical conductivity - "thermal".
- Heavy and plastically deformable.
  - Plastic - permanent change in dimension.
- Shiny when polished.

All of these properties are a function of the atomic bonding ("metallic bond"). A metallic bond is traditionally thought to be a sea of delocalised electrons "orbiting" a *regular* array of ions. A regular array is known as a *crystal*. In this structure, we see repulsive and attractive forces from the atoms and subatomic particles. These are all balanced and thus in *equilibrium*. The interatomic distance can be defined as  $a_0$ . The interatomic distance can be modelled as a spring. Initially a tensile (or a compressive) force will generate deformation and thus  $a_0$  but will attempt to restore to its original shape; i.e. the deformation is recoverable. This is the definition of *elastic* behaviour.

Beyond a certain deflection/deformation, *permanent* deformation is achieved. When the deforming force is removed, only some of the deformation is recovered (the elastic portion) and the plastic deformation remains.

#### 2.1.2 Mechanisms of plastic deformation in metals

##### Slip

this is where planes of atoms (ions) slip/slide past each other. Planes orientated at 45° to the tensile or compressive load will slip first. Slip (under tension) gener-

ates lengthening of the specimen. However, the *volume* of the specimen does not *change* i.e. the intermolecular distance stays the same. This means that under a tensile force, the specimen becomes *thinner*. Under compression, metals become *shorter/fatter*.

## 2.2 Polymers

### 2.2.1 Thermoplastics and Thermosets

#### General Properties

- Thermally and electrically poor conductors.
- Low density.
- Poor reflectors.
- Often flexible (low stiffness).
- Often deformable.
  - "Slip" is possible.
  - Behave plastically.

These properties (including the mechanical properties) are due to the *bonding* occurring in polymers. These bonds are *covalent* within a polymer molecule but the existence of secondary bonding (e.g. Van der Waals and H bonding) are very influential on the properties.

Polyethene (or PE) is a chain structure molecule made up of carbon and hydrogen atoms. This structure is *thermoplastic* or *thermopolymer*. Often these chains can be 100,000 carbon atoms long. The carbon-carbon bond is tetrahedral in reality. If such a polymer was to be stretched out linearly, its length would be approximately 20  $\mu\text{m}$ . Each molecule is *stable* i.e. all the covalent bonds are satisfied but there must be interaction between molecules; else PE would have no physical strength. Hence, intermolecular bonding *must* be present. There will be a degree of mechanical interaction with such "massive" molecules but secondary bonds (dipole interactions) dominate.

Not all polymers have this structure e.g. *thermosets*. Epoxy resin such as urea-formaldehyde are thermosetting. The molecular structure of thermosets are similar to thermoplastics. However, there are *real* covalent bonds between the chains instead of secondary bonding. These are called *crosslinks*. Crosslinks are created through chemical reaction during the *polymerisation* process. This creates a new substance and have no chemical formula. Thermoplastics are polymerised at the factory. Thermosets are sold as two products (*pre-polymers*), which are to be reacted together to make the thermoset. As a consequence of the crosslinks, the properties differ to those of thermoplastics such as being stiffer, harder and they can also be stronger. They are also brittle (which can lead to weak behaviour).

## 2.2.2 Elastomers

### General Properties

- Massive elastic deformation.
- No plastic deformation.
- Non recyclable (by melting).

Elastomers are effectively a subset of thermosets; they contain covalent crosslinks (not as many) and thus cannot be melted once formed. The crosslinks permit *freedom* of deformation (movement) of the carbon chains but ultimately restrict it and thereby stop *plastic* deformation. The degree of crosslinking *strongly* affects the stiffness of the elastomer. The stiffness increases with the number of crosslinks.

## 2.2.3 Ceramics

### General Properties

- Inorganic compounds, usually between a metallic and non metallic element.

Alumina ( $Al_2O_3$ ), silica (Quartz) ( $SiO_2$ ) and silicon carbide ( $SiC$ ) (hard, abrasive) are all examples of ceramics.

## 2.3 Properties

### 2.3.1 Stress and strain

Stress a.k.a load, strain a.k.a deflection. Doubling the stress will double the deflection. Deflection will depend on the specimen size. In order to compare these properties, we need to normalise for differences in dimension e.g.  $\delta L/L = \epsilon$  - strain. For stress, we divide the force by the area its being applied over i.e.  $F/A = \sigma$ . Strain is sometimes represented as percentage.

Note: stress is a variable. Strength is not, it is a fixed property of a material.

### 2.3.2 Hardness

Often quoted for metals as a design parameter as it is easy to measure and can be related to strength. Dimensions of indent can be related to the strength in compression, which can be measured in various ways. In the UK, Vickers hardness  $H_v$  (triangular indenter) is a test for the hardness of the material. Other systems, such

as Rockwell and Brinell hardness (circular indenter) exist. Scratching a specimen can also be used to test the hardness of a material e.g. Mohs scale, where diamond is at 10 and arbitrary hardness at the other end of the scale.

Indentation techniques are not suitable for brittle materials and is normally used for metals as they slip (plastically deform). They are also difficult to use on elastomers, where we use abrasion test or "bouncing ball" tests.

### 2.3.3 Stiffness

Also known as - Elastic Modulus, Modulus of Elasticity or the Young's Modulus (tension). May also be referred to as the opposite of floppiness. Refers to the flexibility of a material. Units are in Pascals Pa or  $\text{Nm}^{-2}$ . The following equation gives us the Young's Modulus of a material.

$$E = \frac{\sigma}{\epsilon} \quad (2.1)$$

This equation relates the normalised load and its normalised deflection. It measures how far something deflects per unit load. These only apply in the elastic regime of a material's behaviour i.e. only for elastic strain.

### 2.3.4 Strength

Defined as the stress required to "break" a material (there are different types of break, hence different strengths definable).

#### Tensile strength

Defined as the stress required to fracture a material in tension into two bits. Symbol used is  $\sigma_{UTS}$ , where UTS stands for ultimate tensile strength. This has units Pa.

#### Compressive strength

In most cases, this is similar to  $\sigma_{UTS}$ , but its often difficult to measure. This is because materials such as metals don't break into two pieces under a compressive force - they just squash. Other materials such as ceramics will shatter or crush at a specific load. Hence, a compressive strength is definable for such materials.

Metals and polymers often "fail" at much lower stresses than  $\sigma_{UTS}$  e.g. they will suffer plastic deformation before fracture. This is always less than  $\sigma_{UTS}$ , if slip can occur, slip will occur first - this is a form of failure. The stress at which this happens is called the yield strength  $\sigma_y$ , defined as the stress required to induce plasticity in a material.



In a ceramic, there is no easy mechanism for slip and thus no noticeable plastic deformation. We define  $\sigma_f$  or fracture strength for such materials. As there is no plasticity,  $\sigma_{UTS} = \sigma_y = \sigma_f$ .

### 2.3.5 Ductility

Defined as the degree of plastic deformation achievable in a material before it breaks into two/fractures. It is a materials parameter and so a strain (plastic strain to fracture). It is often seen as a percentage of strain. Often 0.1% for most metals and up to even 2000% for some polymers. Ductility is very important if we want to create/shape materials through plastic deformation - extrusion, drawing, forging, bending. Ceramics have almost no observable ductility (no slip). These need to be sintered from powder.

### 2.3.6 Toughness

Related to the work/energy required to fracture a material, the amount of "damage" a material can take before fracturing. Very different to strength - which is the *force* required to fracture. Strength and toughness are not absolutely related from an atomic viewpoint. The opposite of tough is *brittle*, where very little energy is required to fracture.

Fractured surfaces tend to be "clean" and fit back together again. Brittle is often confused with being 'weak' i.e. a low force to break. It is true that brittle materials often appear to be weak in practice but not necessarily intrinsically weak. They behave 'weakly' due to the presence of defects - some can be visible (scratches, cracks) while others can be minute (micro-cracking at the atomic level, porosity). Defects determine the failure load (stress) of brittle materials. These act as stress concentrators, raising the globally applied load to much higher values on a local level, so much so that local bonds are broken i.e. the intrinsic strength is exceeded. so failure occurs at an apparently lower stress. Manufacturing has a huge role to play in determining the presence and severity of defects. However, if there are mechanisms for plastic deformation e.g. slip, then as the stress rises at the defect, slip will begin to occur locally.

Note: "bad" stress concentrators are sharp and long e.g. cracks and holes (which are still stress concentrators, just not to the same degree).