

# AMME1362: MATERIALS 1

## CHAPTER 1: INTRODUCTION

The **structure** of a material refers to its internal components on an atomic level whilst the **properties** refer to the response of the material to a stimulus. However, the properties are heavily dependent on the structure itself. The six categories of properties include mechanical, electrical, thermal, optical, magnetic, and deteriorative (chemical reactivity).

With regards to the type of materials, the three main types are metals, polymers/plastics, and ceramics. **Metals** (including alloys) are arranged orderly and are densely packed, thus making them stiff, strong, and resistant to fracture whilst being ductile. Because of the cationic lattice structure of metals with the surrounding delocalized electrons, light reflects off them, resulting in the reflective surfaces of metals. They are also opaque, as well as having high thermal and electrical conductivity (as can be understood by the structure with the delocalized electrons providing the electrical conductivity and the densely packed atoms providing thermal conductivity).

**Polymers** are very long chains, often with a carbon backbone. They tend to have lower densities and resultantly, are not as hard or stiff when compared to ceramics and metals. However, comparisons done on a per mass basis demonstrate comparable strength. Polymers are generally soft and ductile whilst also acting as thermal and electrical insulators. They are chemically inert and optically translucent, giving rise to many potential applications.

**Ceramics** are compounds of metallic and non-metallic elements (oxides, carbides, nitrides, and sulfides) ionically bonded together, giving rise to their brittle, glassy and elastic nature. Despite this, they are generally strong and stiff. They are electrical insulators but thermally efficient conductors and thus can be used in cookware and automobile parts.

**Composites** occur when different material types are combined with the aim of forming a new material with properties borne from the constituent materials. The composite can then have strength due to its metallic nature, whilst being transparent due to the polymeric constituents.

With copper (a metal), the addition of impurity atoms has the effect of increasing resistivity with the same trend observed as the metal is deformed. This is because the path for the electron flow is impeded in both cases, be it due to the addition of other atoms or due to a physical deformation.

The performance of a material is dependent on its properties which itself can be derived from the structure. The structure arises from the processing and thus all four features are heavily linked.

The material selection process involves firstly choosing the desired **application**. To make this selection, the required **properties** must be considered. **Materials** are then selected based on whether they meet the required properties. However, materials may also require **processing** to change the structure or shape.

## CHAPTER 2: ATOMIC STRUCTURE AND INTERATOMIC BONDING

Interatomic bonding must be considered in a study of materials as they give rise to the material structure and hence the observable properties. The current model of the atom is the **quantum model** which proposes the notion that electrons exist in **discrete energy levels** and by absorbing or releasing energy, can change their energy levels. The principal quantum number of an electron is a measure of the distance of an electron from the nucleus and hence the smaller the number, the lower the energy level as they are closer to the nucleus. In terms of orbitals, the energy levels are as follows:  $s < p < d < f$ .

The **Pauli Exclusion principle** states that within each electron state, there can only be two electrons and these must be of **opposing spin** moments. The **ground state** of an electron is the configuration which yields the **lowest energy levels**. An example is seen with polymer chains and their distinctive tetrahedral angle because this results from the formation of a hybrid orbital (sp orbital) such that the valence electrons can be in the lowest possible energy state.

In terms of the periodic table, elements on the left (metals) are electropositive (readily give up electrons) and vice versa with the electronegative elements on the right, each forming ions. **Electronegativity** increases as you go up the periodic table as the valence electrons are closer to the nucleus, increasing the force of attraction for electrons and thus allowing them to **readily acquire electrons**, forming anions.

The bonding energy for two atoms is the energy when the attraction force is equal to the repulsion force and hence the net force is equal to 0. Solids have the greatest bonding energy and thus the greatest amount of energy is required to break these bonds, leading to a higher melting point. Furthermore, an increase in temperature causes a smaller dimensional change as a higher bonding energy ensures these atoms are bound together until more thermal energy is added.

Ionic bonds occur when metallic elements bond with non-metallic elements as the metal donates an electron/s which is then received by the non-metal and thus each element adopts a net charge. The force of attraction between opposing charges causes the **non-directional, coulombic bonding** between ions and hence the lattice structure is observed with alternating charged ions with a higher bond energy in each direction. In ceramics (which are ionically bonded as it occurs when a metal and non-metal bond), the melting temperatures are higher because greater thermal energy is required to break each bond.

Covalent bonds occur when **valence electrons are shared** across atoms, allowing each to adopt a stable state without donating electrons. The result is the formation of **directional bonds**, as noted in the case of non-metallic elements that bond with themselves or dissimilar atoms. However, the maximum number of bonds possible is 8 as there are only 8 valence electrons in most cases. The **greater the difference in electronegativity, the more ionic the bond and therefore the less covalent the bond**. In terms of the location of the elements on the periodic table, the wider the separation, the greater the difference in electronegativity. Covalent bonds are generally weak and hence the melting temperatures are lower.

Metallic bonding involves **an ionic core with a sea of delocalized electrons**, giving rise to the electrical and thermal conductivity. Contrastingly, there are no free electrons in ionic and covalent bonds and thus these are electrically and thermally insulative. The electrons are used to keep the core together and are seen between the ions to **minimise the repulsive force of the adjacent cations** and thus the lattice structure is maintained.

When **positive and negative charges are separated**, a **dipole** is formed (difference in electrical polarity) and hence, there is a **net attractive force** with this weak bond referred to as a secondary bond (or **van der Waal's forces**). The **constant vibration** of atoms causes transient moments of deformation from electrical symmetry, creating small dipoles which in turn, displace electrons in an adjacent atom (electrical charge differences) and this process continues, causing **induced dipoles that fluctuate temporally**. **Permanent dipoles** however, occur when molecules are **asymmetric** in polarity, meaning there are regions of net positive charge while others have a net negative charge. These molecules use this **charge difference to induce dipoles in non-polar molecules**

Due to the small size of hydrogen atoms, they can essentially act as protons in bonding. As such, in bonds with electronegative atoms such as Fluorine, Oxygen and Nitrogen, the **bond strength is significantly large as there is a large difference in electron charge density** and are referred to as **Hydrogen Bonds**.

## CHAPTER 6: MECHANICAL PROPERTIES OF METALS

When testing for material properties, the general method involves applying a tensile load, causing the material to deform until fracture, with the resulting stress-strain curve used to ascertain information regarding said properties.

Engineering stress is computed using the following equation:

$$\text{Engineering Stress} = \sigma = \frac{F}{A}$$

Where F is the force perpendicular to a cross-sectional area A. If the force applied is at an angle other than perpendicular, the force must be broken into its constituent forces (tensile is perpendicular to the cross sectional area and shear stress is due to the force parallel to the area) or the following geometric formulae are used:

$$\sigma' = \text{Tensile Stress} = \sigma (\cos\theta)^2$$

$$\tau' = \text{Shear Stress} = \sigma \sin\theta \cos\theta$$

As can be determined by inspection, the maximum tensile stress occurs at an angle of 0 degrees and this is because it is purely tensile. Conversely, the maximum shear stress occurs at an angle of 45 degrees.

Stress is generally measured in MPa with the prefix mega- referring to  $\times 10^6$ .