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**Material Categories,
Bonding and Structures**

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**Acknowledgement**

Mr John Gibson is a highly regarded educator and engineer. John taught Industrial Arts at a number of high schools before taking a position at Sydney Teachers’ College, then University of Sydney. He had an engineering education consultancy and has extensive experiencing working with NESA on Engineering Studies syllabus development and the HSC examination committee. The STEM Industry School Partnerships (SISP) Program asked John for his responses to the iTeachSTEM topic discussion questions. SISP is grateful to John for submitting these example discussion responses.

# Why do engineers classify materials?

Engineers classify materials into groups that have common features; this enables engineers to select possible alternative materials for a specific task.

Group categories might include:

* chemical
* physical
* metallurgical
* thermal
* electrical
* magnetic

1. **Discuss the typical properties of each category.**

A common classification of engineering materials is the broad grouping of metals, ceramics and, polymers. This is a very basic classification of the materials used by engineers, but it does allow some useful selection.

* polymers are general categorised as being soft, low strength and, ductile
* metals are generally categorised as being hard, very strong, low in ductility
* ceramics are generally categorised as very hard, unreactive and, weak
1. **Classify materials based on bonding, structure and properties.**

A more useful classification of engineering materials is one based on the atomic/crystalline structure of the material. This system is much more complex than the previous model, and allows comparisons to be made using a larger set of categories, eg. atomic structure, crystalline structure, amorphous structure and, physical strength etc.

1. **Describe materials based on atomic structure, properties, elements, compounds or, alloys.**

As an example from metals, each of the above criteria can be used effectively to discriminate a particular sample from quite a range of samples. This can be done by applying strength, ductility, electrical conductivity and, magnetism to the test.

1. **Associate engineering properties of materials with a typical category of material.**
2. **Define the term *amorphous*.**

This is a term related to the structure of the atom itself (protons, neutrons and electrons) and the way in which atoms join together to form crystal lattices (BCC, FCC, HCP). The term **amorphous** refers to atomic structures that do not have a **crystalline** **structure**.

1. **Define the term *crystalline*.**

Crystalline materials are those that possess a formal, regular relationships between the lattice atoms. When allowed to grow in a fluid, the result is a crystalline shape. Examples could be copper sulphate, quartz.

**Bonding and Structure**

1. **Discuss the structure of the atom.**

The atom has three components: a core made up of protons and neutrons surrounded by a specific number of electrons. Protons are positively charged and the electrons are negatively charged.

1. **Describe the primary atomic bonds – ionic, covalent and metallic.**

* **ionic bond**: some elements have outer electrons short of the optimal number, whilst others have some in excess. When these two elements bond they allow a transfer of these electrons to establish the optimal number of electrons for each shell, thus forming an ionic bond
* **covalent bond**: in the covalent bond, a certain number of electrons are shared between two or more atoms to produce a stable particle called a molecule
* **metallic bond**: in most pure metals, atoms have insufficient valence electrons to form covalent bonds. The valence electrons of each atom are donated to common ‘cloud’ shared by all atoms. The atoms are held in a regular pattern by mutual attraction/repulsion.
1. **What are van der Waal forces?**

Van der Waal forces occur in neutral atoms where a separation of positive and negative charges results in a weak attractive force to hold the bond together.

1. **Describe bonds in ceramic materials and the effect on properties.**

The main type of atomic bond in ceramic materials is the ionic bond. This bond is very strong and it shows up in the material as strength and hardness.

1. **Describe bonds in polymer materials and the effect on properties.**

The main type of atomic bond in polymeric materials is the covalent bond. The strong bond is due to the attraction of shared electrons by the positive nuclei to form a strong chain. But the forces that hold these chains together are weak van der Waals forces. It is these that are responsible for the low strength and softness in polymers.

1. **Describe bonds in metallic materials and the effect on properties.**

In the metallic bond, electrons of each atom are donated to a common ‘cloud’ shared by all atoms. The atoms are held in a regular pattern by mutual attraction/repulsion. The most significant properties caused from the metallic bond is electrical conductivity, also strength and ductility.

1. **Describe the formation of metallic structures during the heating/cooling process.**

The stages in the transformation of metals due to heating/cooling are:

* nucleation
* dendritic growth of crystals
* solidification
* grain formation
1. **What material properties can be explained by analysing metals through a microscope?**

Macro/microanalysis enable the scientists to examine particle structures not visible to the human eye. Typical features can be:

* grains
* phases
* compounds
* coring
* laminates
* stressed areas
* crystalline forms
* non-metallic

Understanding these enables us to determine the ways these forms impact on the strength, ductility, etc. of the metal.

1. **Describe the crystal structures BCC, FCC and, HCP in metals.**
* **BCC (body-centred cubic)**: one atom is fixed at the corners of a regular cube with one atom in the centre of the cube – represents 2 atoms
* **FCC (face-centred cubic)**: one atom at the corners of a regular cube, and one atom at the centre of each face of the cube – represents 4 atoms
* **HCP (hexagonal closest packed)**: 2 base planes as regular hexagons, and an intermediate plane having 3 atoms – represents 1.633 atoms