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Automotive Materials and Sustainability ACHA 6012

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Section A

Question 1

- a) One alternative fuel that can be implemented is Liquefied petroleum gas, LPG. Providing 15% lower ^{carbon dioxide} ~~CO₂~~ emissions, 30% lower carbon monoxide emissions, and 50% lower nitrogen oxides emissions than petrol when combusted, LPG can offer a solution. Another alternative fuel type is Dimethyl Ether, or DME. This is a synthetically produced fuel derived from coal or natural gas, which can also be blended with LPG to ~~lower its~~ allow it to ignite with a spark. A blend of the two gave a reduction of 27% in carbon dioxide emissions, and 50% in hydrocarbon emissions.
- b) LPG is already the third most popular fuel type globally, so impacts to the user can already be managed to some extent. However, LPG does have impacts as a fuel. High ignition system and valve seat/guide wear can lead to regular maintenance being needed. It can run economically in small quantities with a diesel engine, but will increase power in larger quantities. Particulate matter emissions are significantly decreased to below emissions standards.

DME when blended with LPG gave a greater fuel economy in miles-per-gallon than either petrol or LPG alone, so it can increase fuel economy. Its efficiency is therefore comparable with conventional vehicles, however it is very similar to diesel so adoption would require a shift to diesel infrastructure and diesel-capable engines. With petrol the most common fuel type, this would impact many people.

Section B

Question 2

a) Ionic bonding describes the bonding that occurs when the valence electron or electrons are transferred between atoms. This can alter the atom's charge, but typically happens between ions, where they gain or lose charge to become closer to neutral. Therefore, a donor ion and a receiver are required. A good example is sodium, which has an ion of +1 positive charge. This makes it likely to donate an electron, to get a balanced outer shell and no charge.

Covalent bonding involves the sharing of electrons between atoms. For example, hydrogen, which has one electron in its outer shell and requires two to be full. Two hydrogen atoms are likely to join together, sharing each other's electron and therefore both having a full outer shell. This type of bonding is common between non-metals or a metal and a non-metal close to each other on the periodic table, but rare amongst metals.

Metallic bonding is different to the other two forms as it does not involve the transfer of electrons in shells. Instead, ions become positively charged and form a lattice, while their ^{electrons} become delocalised and form a 'sea', filling the gaps in the lattice. The valency of the atom here ~~determines~~ ^{affects} how many the atom can donate to the 'sea', while the valency of an atom in the other two forms of bonding affect how many atoms the original atom can form single bonds with. For example, Carbon has a valency of four, as it can bond with four hydrogen atoms to fill its outer shell.

b) Since copper forms a face-centred cubic arrangement, $a = 2\sqrt{2}R$

$$\frac{a}{2} = \sqrt{2}R \quad \frac{1}{2} \left(\frac{a}{2} \right)^2 = R$$

$$R = \frac{1}{2} \left(\frac{0.362}{2} \right)^2$$

$$R = 0.016 \text{ nm}$$

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c)

d) Dislocation movement controls the speed of creep in its secondary phase. Dislocations within the structure move towards grain boundaries under load. They typically move to triple points, as they are the weakest, with triple points being the intersections of three boundaries. This stage is the most predictable.

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Question 4

- a) i. For the aluminium 7XXX series, the primary alloying element is zinc. Zinc increases the strength of the alloy by enabling it to be heat treatable. However, zinc is rarely the only addition, as it makes the alloy brittle.
- ii. The first digit in a steel grade denotes which type of steel based on the main alloying element. The third and fourth digits are the hundredths of a percentage of carbon content. In 1045 steel, the first digit denotes it as a carbon steel, while the third and fourth digits mean it is comprised of 0.45% carbon.
- b) The three classification groups for composites are: particle-reinforced, fibre-reinforced and structural. Particle-reinforced composites have particles distributed throughout the matrix to provide it with benefits. There are two different types of this: large particle, and dispersion strengthened. Large particle, so called because it interacts with the matrix above an atomic scale, involves particles spread evenly throughout the matrix. Dispersion-strengthened involve their particles bonding atomically to the matrix. Since the particulates are harder than the matrix, they can strengthen and stiffen it, while also improving mechanical behaviour. Examples include carbon black in tyre rubber, stiffening it, and aluminium oxide as sintered aluminium powder.

Fibre-reinforced composites are intended for the use of improving strength and stiffness based on weight. As such, they are measured often in specific properties: specific strength and specific modulus. Their structure can differ based on the length and orientation of the fibres. Fibres can be randomly aligned, but provide less strength benefit than aligned or woven fibres. Length of fibre is important in relation to critical fibre length; the length necessary to provide strengthening. Unlike particulates, the fibres are often brittle on their own. Since the matrix used typically deforms and bends, this allows the fibres to reinforce this while the matrix absorbs the forces and deformation that would cause fibres to fail. Uses include carbon fibre and fibreglass.

Structural composites utilise both composite and homogeneous materials, combining both to create a material with the combined properties. The properties again, like particle- and fibre-reinforced, depend on both the materials used and the construction of the composite. Laminar composites ~~com~~ are comprised of sheets layered face-to-face. Sandwich

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b-continued) panels are made up of faces with 'cores' in between. These are typically a less dense material, used to resist deformations perpendicular to the face plane, for example bending. Additionally, hexagonal interlocking cores can be seen, constructed from materials similar to the faces. Uses of structural composites include multi-ply carbon fibre and aluminium honeycomb.

$$c) 1 - 0.45 = 0.55 \quad V_m = 0.55 \quad E_m = 3.2 \times 10^9 \text{ Pa} \quad E_f = 65 \times 10^9 \text{ Pa}$$

$$A_f = 0.45 \times 300 \\ = 135 \text{ mm}^2$$

$$A_m = 0.55 \times 300 \\ = 165 \text{ mm}^2$$

$$E_c = E_m V_m + E_f V_f$$

$$E_c = (3.2 \times 10^9 \times 0.55) + (65 \times 10^9 \times 0.45) \\ = 3.1 \times 10^{10} \text{ Pa} \\ = 31.0 \text{ GPa}$$

$$\frac{\sigma_c}{E_c} = \epsilon_c \quad \epsilon_c = \frac{30 \times 10^6}{31 \times 10^9} = 9.68 \times 10^{-4}$$

Assuming is strain:

$$\sigma_m = E_m \epsilon_m$$

$$\sigma_m = 3.2 \times 10^9 \times 9.68 \times 10^{-4} \\ = 3.1 \times 10^6 \text{ Pa} \\ = 3.1 \text{ MPa}$$

$$\sigma_f = E_f \epsilon_f$$

$$\sigma_f = 65 \times 10^9 \times 9.68 \times 10^{-4} \\ = 62.92 \times 10^6 \text{ Pa}$$

$$F_m = \sigma_m A_m$$

$$= 3.1 \times 10^6 \times 165 \times 10^{-6} \\ = 511.5 \text{ N}$$

$$F_f = \sigma_f A_f$$

$$= 62.92 \times 10^6 \times 135 \times 10^{-6} \\ = 8494.2 \text{ N}$$