24MPA201

Introductory Materials Science

Semester 1 2024/25 | In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

<u>Help during the exam</u>

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Answer **THREE** questions only.

1. Titanium is used in hip replacement joints due to its high strength and biocompatibility. Titanium has a hexagonal close packed (HCP) atomic structure.

   (a) Draw a schematic diagram of the HCP unit cell and state how many atoms are in the unit cell. Label your diagram to show how the atoms contribute to this number. [5 marks]

   (b) A cylindrical sample is machined from one of the components as shown in Figure Q1b. A compression test is carried out on the sample. With this information answer the following questions:

      (i) Why might a compression test be more suitable than a tensile test for this application? [1 mark]

      (ii) Give three examples of information that cannot be gained from a compression test that can from a tensile test. [3 marks]

      (iii) Draw and fully label a schematic of the expected stress versus strain curve for the compression test. [4 marks]

      (iv) What precautions should be taken to ensure the test is valid? [2 marks]

   (c) Data from the test is shown in Table Q1c. Using this and showing all working, calculate:

      (i) The yield stress [2 marks]

      (ii) The yield strain [1 mark]

      (iii) The Young's modulus [1 mark]

      (iv) The shear modulus, if the Poisson's ratio for the alloy is 0.25. [1 mark]

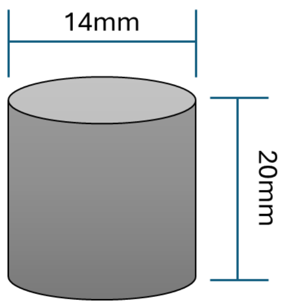

Figure Q1b: Compression sample dimensions

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Q1 Continued/…

Table Q1c

Load at Yield	44987N
Height at Yield	19.953mm

2. (a) Draw the following crystal planes in a cubic unit cell:

(i) (102) [1 mark]

(ii) (113) [1 mark]

(iii) $(\bar{1}\bar{2}2)$ [1 mark]

(iv) $(1\bar{1}4)$ [1 mark]

(b) Draw the following crystal directions in a cubic unit cell:

(i) [321] [1 mark]

(ii) [210] [1 mark]

(iii) $[\bar{1}\bar{1}2]$ [1 mark]

(iv) $[2\bar{1}2]$ [1 mark]

(c) (i) Wüstite is known to have a crystal structure similar to NaCl. Draw a schematic of the atomic structure labelling the Fe and O atoms. [3 marks]

(ii) X-ray diffraction was carried out on a sample of Wüstite (FeO) using copper radiation of wavelength 0.1542nm. Wüstite is known to have an FCC-type crystal structure similar to NaCl. The results are shown in Figure Q2c with the peak positions give in the figure. Showing all working calculate the interplanar spacing, d, for the first five reflections. [7 marks]

(iii) Calculate the lattice constant, a, for Wüstite. [2 marks]

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Q2 Continued/…

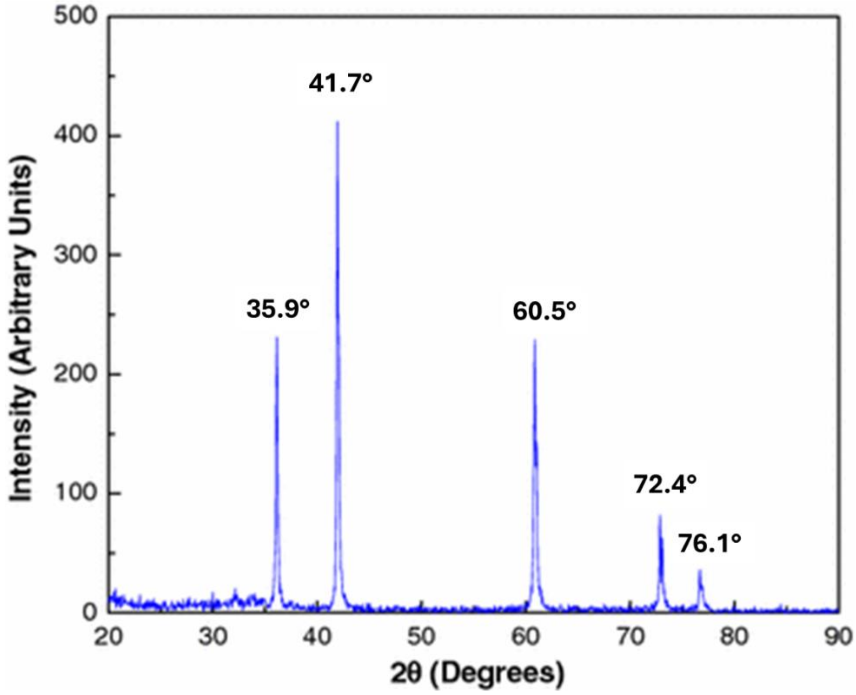

Figure Q2c

3. (a) Polytetrafluoroethylene (PTFE) is a semi-crystalline fluoropolymer known for its chemical resistance and low friction. Its repeating unit is shown in Figure Q3.

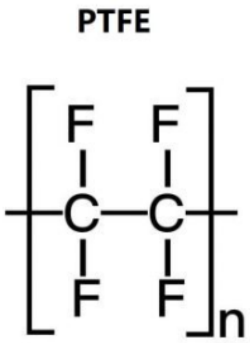

Figure Q3: Repeating unit of PTFE

(i) What are the two types of transition temperatures of PTFE? [2 marks]

(ii) Calculate the molecular mass of one repeating unit. (Carbon: 12 g/mol; Fluorine: 19 g/mol) [3 marks]

(b) Two grades of PTFE have been synthesised. The table below shows data obtained relating to the size of the polymer chains.

Table Q3 Molecular weights for those samples

Molecular weight (g/mol)	Sample 1 fraction (number)	Sample 2 fraction (number)
10,000	0.1	0
15,000	0.3	0.2
20,000	0.3	0.3
25,000	0.2	0.3
30,000	0.1	0.2

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Q3 Continued/…

(i) Calculate the number average molecular weight for both samples. [4 marks]

(ii) Calculate the degree of polymerisation (DP) of these two samples. [2 marks]

(iii) The weight average molecular weight for Sample 1 is 24,500 g/mol, and weight average molecular weight for Sample 2 is 27,000 g/mol. Calculate the molecular weight distribution (MWD) for both samples. Give your answer to 2 decimal places. [2 marks]

(iv) Will Sample 1 or Sample 2 have a wider melting range? Explain your reasoning. [2 marks]

(c) Two samples of polypropylene (PP) have been produced. One is semi-crystalline, whereas the other is amorphous. With reference to the polymer structure, what is the cause of this difference? [5 marks]

4. (a) Thermoplastics and thermosets have very different properties and are used for various of applications.

   (i) What are the main differences in their structure? [2 marks]

   (ii) List two common names of thermoplastics and describe the practical applications of each one. [2 marks]

   (iii) Compare the advantages of thermoplastics and thermosets for practical applications, providing one example of each. [2 marks]

   (iv) Discuss the disadvantages of thermoplastics and thermosets in terms of recyclability and mechanical performance. [2 marks]

   (v) Discuss the intra and intermolecular bonding presented in high density polyethylene (HDPE). [2 marks]

(b) Shore hardness testing was carried out on samples of LDPE and HDPE. The results of the tests are given in Table Q4b.

Table Q4b: Hardness data

Hardness LDPE	Hardness HDPE
45	54
47	55
49	62
44	66

   (i) What type of hardness test is Shore? [1 mark]

   (ii) Briefly explain how a Shore Scleroscope works. [3 marks]

   (iii) Showing all working, calculate the mean, standard deviation and 95% confidence intervals for each of the two polymers. The data for c=0.025 are shown in Table Q4c. [6 marks]

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Q4 Continued/…

Table Q4c: Data for the c=0.025

v	**t**	**v**	**t**	**V**	**T**
1	12.706	10	2.228	19	2.093
2	4.303	11	2.201	20	2.086
3	3.182	12	2.179	25	2.060
4	2.776	13	2.160	30	2.042
5	2.571	14	2.145	40	2.021
6	2.447	15	2.131	60	2.000
7	2.365	16	2.120	120	1.98
8	2.306	17	2.110		
9	2.262	18	2.101		

END OF PAPER

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List of equations

Structure and Diffraction

Packing Efficiency = $\frac{\text{(number of atoms per unit volume)(volume of one atom)}}{\text{volume of the unit cell}}$

$$n\lambda = 2d\sin\theta$$

$$d = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

Diffraction Rules

For simple cubic: All planes

FCC: h,k,l all odd or all even

BCC: h+k+l = even number

Polymer molecules

$$\bar{M}_n = \frac{\sum_{i=1}^{\infty} N_i M_i}{\sum_{i=1}^{\infty} N_i}$$

$$\bar{M}_w = \frac{\sum_{i=1}^{\infty} N_i M_i^2}{\sum_{i=1}^{\infty} N_i M_i}$$

Molecular Weight Distribution MWD = M_w/M_n

Mechanical Testing

Engineering Stress $\sigma = \frac{F}{A_0}$

Engineering Strain $\varepsilon = \frac{l - l_0}{l_0}$

Young's Modulus (E) $\sigma = E\varepsilon$

Young's Modulus $E=2G(1+\upsilon)$

Proof Strain $\%\varepsilon = \frac{l - l_0}{l_0} x100$

Percent Elongation $\%EL = \frac{l_f - l_0}{l_0}$

Percent reduction in area $\%RA = \frac{A_f - A_0}{A_0}$

Resilience $U = \int_0^{\varepsilon_y} \sigma d\varepsilon = \frac{\sigma_y^2}{2E}$

Shear Stress $\tau = \frac{16T}{\pi d^3}$

Shear Strain $\gamma = \frac{r\theta}{L}$

Shear Modulus, G, $\tau = G\gamma$

Poisson's ratio $\nu = -\frac{\varepsilon_x}{\varepsilon_z} = -\frac{\varepsilon_y}{\varepsilon_z}$

$E = 2G(1+\nu)$

Three-point bend rectangular cross section $\sigma_{fs} = \frac{3F_f L}{2bd^2}$

Three-point bend circular cross section $\sigma_{fs} = \frac{F_f L}{\pi r^3}$

Strain rate $\dot{\varepsilon} = \frac{d\varepsilon}{dt}$

<u>Data analysis</u>

Mean $\overline{x} = \frac{\sum x_i}{n}$

Standard deviation $s = \sqrt{\frac{\sum(x_i - \overline{x})^2}{n-1}}$

Confidence interval $\overline{x} \pm t_c \frac{s}{\sqrt{n}}$