Loughborough University

23MPA201
Introductory Materials Science

Semester 1 2023/24 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).

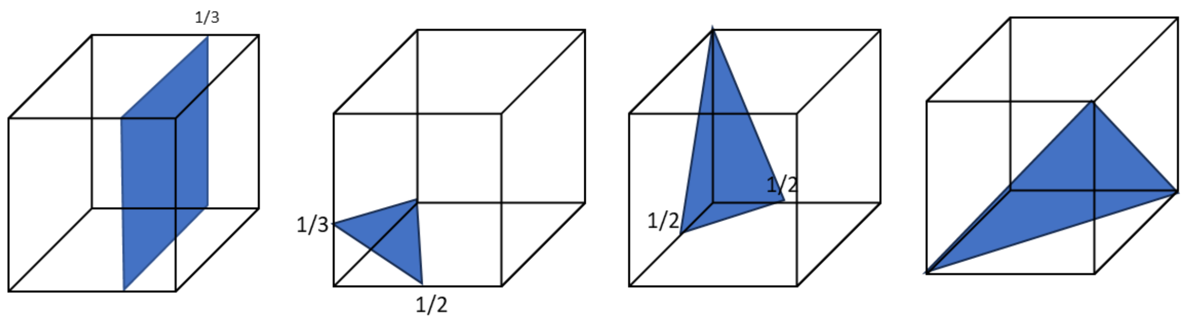
Answer **THREE** questions only. Each question carries 20 marks.

A List of Equations is included at the end of the paper.

1. (a) In separate cubes, draw and label all the {113} planes that contain only positive integers.

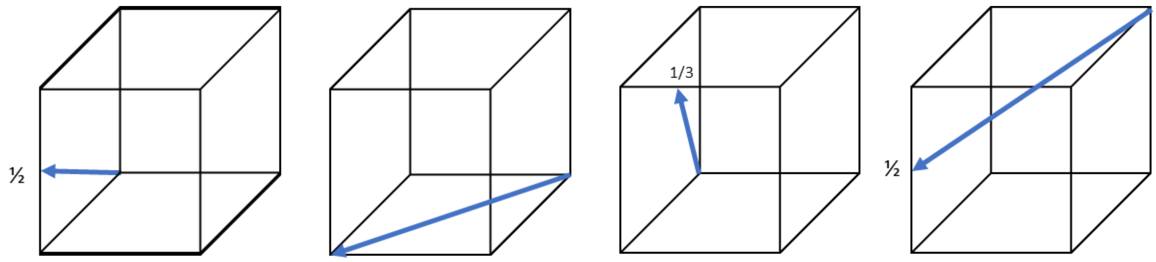
[3 marks]

(b) Index the following crystal planes. [4 marks]



(i) (ii) (iii) (iv)

(c) Index the following crystal directions. [4 marks]



(i) (ii) (iii) (iv)

(d) A BCC sample has an atomic spacing of 0.365 nm. What would be the 2θ values of the first three reflections in the X-ray Diffraction pattern when measured with Mn radiation (λ=0.2104nm)? [9 marks]

2. Wrist fractures can be difficult to align to allow natural healing and are often stabilised with titanium inserts to stabilise the joint. These inserts remain in the body and are designed to ensure full function on the wrist. Many designs have been tried with varying success and some examples are shown in Figure Q2a with an X-ray of an insert in position in the wrist.

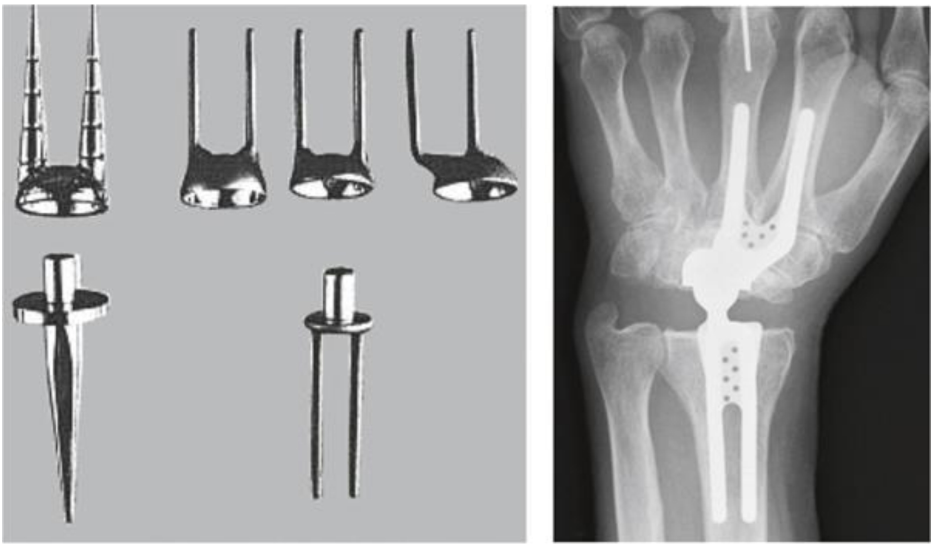


Figure Q2a: Metallic wrist support inserts and X-ray of an example in position.

A schematic of a new design is shown in Figure Q2b made from Ti-6Al-7Nb. The two pins are tensile tested between A and B by holding the component in the machine above position A and 10 mm from the bottom of the pins below position B. The component is tested in the as-manufactured and heat-treated condition and the results can be seen in Figure Q2b.

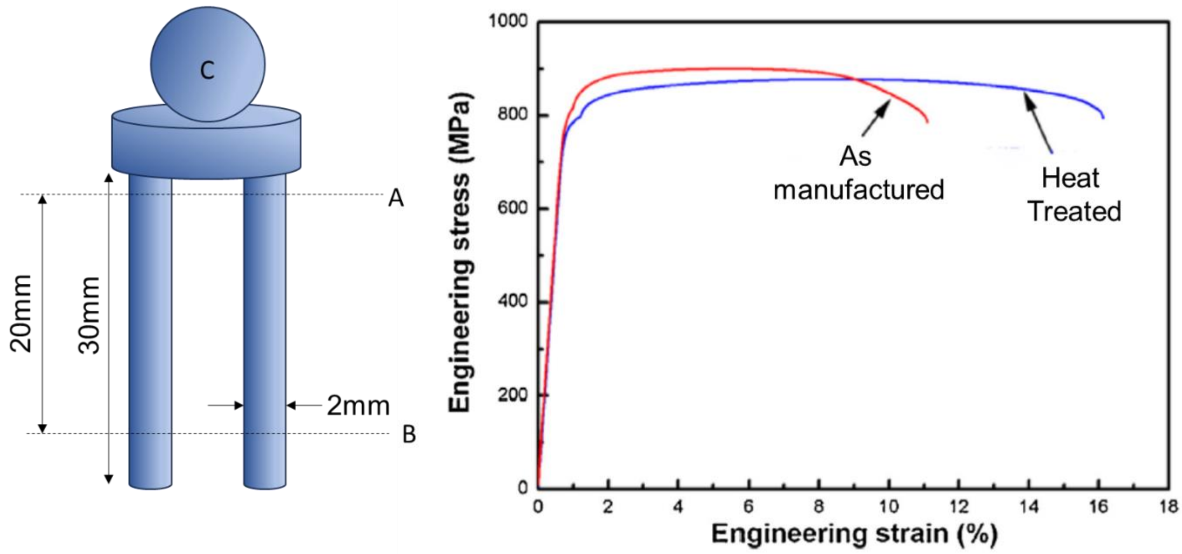


Figure Q2b: New design and the stress/strain curves for the as-manufactured and following heat treatment

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Q2 Continued/…

(a) Why is the linear portion of the curve the same for both the as-manufactured and heat-treated material? [2 marks]

(b) What do the plastic parts of the curves tell us about the properties of each sample and how could you quantify it? [2 marks]

(c) The Yield point is at a stress of 776 MPa and a strain of 0.64%. Calculate showing all working:

(i) The load at yield; [3 marks]

(ii) The elongation at yield; [2 marks]

(iii) The Young's modulus. [2 marks]

(d) The upper part of the design marked as C forms a rotation joint with the secondary part (not shown).

(i) What mechanical properties should be considered in this part of the component and why? [3 marks]

(ii) Suggest the best method for testing this property, giving the advantages, and disadvantages of the technique. [6 marks]

3. Polyvinylidene fluoride (PVDF) is a semi-crystalline thermoplastic fluoropolymer, with the chemical structure shown in Figure Q3.

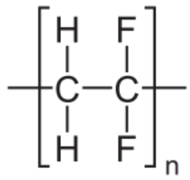

Figure Q3: Repeating unit of PVDF.

(a) What would be the expected polymerisation method to produce PVDF from vinylidene fluoride (VDF) monomer? Justify your answer. [2 marks]

(b) Calculate the molecular mass of one repeating unit. (Carbon: 12 g/mol; Hydrogen: 1 g/mol; Fluorine: 19 g/mol) [2 marks]

(c) During polymerisation, a variety of molecular weights have been obtained. Data in Table Q3c shows the fraction of each molecular weight in this PVDF.

Table Q3c: Molecular weight of PVDF

Fraction	Molecular weight (g/mol)
0.1	200,000
0.2	250,000
0.3	300,000
0.3	350,000
0.1	400,000

(i) Calculate the number average molecular weight ($\overline{M}_n$). [3 marks]

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

(iii) If the weight average molecular weight ($\overline{M}_w$) is 350,000 g/mol, calculate the molecular weight distribution. Give your answer to 2 decimal places. [2 marks]

(d) From the polymer structure, describe the intra and intermolecular bonding presented in PVDF. [3 marks]

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Q3 Continued/…

(e) Thermoplastic and thermoset have very different properties and are used in various applications.

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

(ii) Thermoset materials cannot be reheated to soften, shape and mould. Explain the reason. [2 marks]

(iii) List the one advantage and one disadvantage for thermoset materials. [2 marks]

4. (a) Polystyrene (PS) is a versatile synthetic polymer with a wide range of applications in various industries. It is known for its lightweight, rigid, and insulating properties. The chemical structure shown below in Figure Q4a.

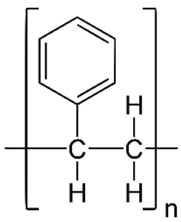

Figure Q4a: Repeating unit of PS

(i) Give two key physical properties of polystyrene and briefly explain their significance. [4 marks]

(ii) What type of polymer is polystyrene (homopolymer or copolymer)? Explain your answer. [2 marks]

(b) Polyethylene Terephthalate (PET) is widely used in packaging materials, such as plastic bottles for beverages and food containers. Explain why PET is a popular choice for packaging materials in the food and beverage industry. [4 marks]

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Q4 Continued/…

(c) Impact testing is carried out on samples of both PS and PET. The results of the tests are given in Table Q4c.

Table Q4c: Charpy Impact data

Test Number	PS (J/m)	PET (J/m)
1	21	59
2	24	55
3	19	49
4	22	52
5	20	51
6	-	58

(i) Briefly explain the difference between Izod and Charpy impact testing. [2 marks]

(d) 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 Q4d.

[8 marks]

Table Q4d: 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

Dr RL Higginson, Dr Y Liu

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