Loughborough University

23MPA220

Introductory Materials Science and Processing

Semester 2 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.

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

1. Copper tube is used extensively in chemical, power, food, and pharmaceutical industries as well as for domestic plumping and heating.

(a) Give two properties of copper that make it ideal for these applications. [2 marks]

(b) Give three methods to produce tubes from solid billets of copper. [3 marks]

(c) To allow complex structures to be constructed, tubes must be joined together. Give three examples of ways to join two copper tubes together discussing the advantages and disadvantages of each selected. [9 marks]

(d) A copper tube of external radius 10mm, internal radius of 8.5mm and an initial gauge length 70mm was subjected to a tensile test. The data from the test is giving the data in Table Q1d. Using this data, and showing all working, calculate:

(i) Yield Stress [2 marks]

(ii) Yield Strain [1 mark]

(iii) Youngs Modulus [1 mark]

(iv) The UTS [1 mark]

(v) Percent Elongation [1 mark]

Table Q1d: Tensile test data

Load at Yield	13598N
Sample length at Yield	70.086mm
Peak load	21358N
Final sample length	74.512mm

2.(a) Low-density polyethylene (LDPE), high-density polyethylene (HDPE), and linear low-density polyethylene (LLDPE) are three major types of polyethylene, each with unique properties and applications.

(i) What is the polymerisation method for polyethylene? [1 mark]

(ii) Draw the chemical formula of polyethylene. [1 mark]

(iii) Describe and discuss the molecular structure of each type of polyethylene, focusing any chain differences. [3 marks]

(iv) Which type of polyethylene has the highest density? Justify your answer. [2 marks]

(v) Suggest a suitable processing route to produce a HDPE container designed to store chemicals. Justify your choice and give a detailed description of the process. [6 marks]

(b) In manufacturing processes involving materials like polymers and ceramics, shrinkage can alter the final product's dimensions and volume. Given a cubic ceramic sample that experiences isotropic shrinkage, shrinking from an initial side length of 10 cm to a final side length of 9 cm, calculate the percentage volume shrinkage. [3 marks]

(c) Water's role is pivotal in the traditional ceramics shaping process. Identify the four conventional shaping methods for traditional ceramic components and specify their associated water content ranges. [4 marks]

3. (a) In separate cubes draw the following planes and directions:

(i) $(\bar{1}\bar{1}1)$

(ii) $(\bar{1}31)$

(iii) $(0\bar{3}1)$

(iv) [021]

(v) $[\bar{1}\bar{2}2]$

(vi) $[2\bar{2}\bar{1}]$ [6 marks]

(b) An FCC metal sample has a lattice parameter, a, of 0.412nm. Showing all working, calculate the 2θ values of the first three reflections in the X-ray Diffraction scan when measured with Co radiation (λ=0.1790nm)? [7 marks]

(c) The metal in Q3b was alloyed and cast into a small ingot. A section was taken, and six hardness tests carried out, as shown in Figure Q3c.

(i) What kind of hardness test was carried out? [1 mark]

(ii) Give two possible reasons why the size of the indents might be very different. [2 marks]

(iii) The results of the three larger indents are shown in Table Q3c. Calculate the mean and 95% confidence interval for the results. The data for c=0.025 are shown in Table Q3d. [4 marks]

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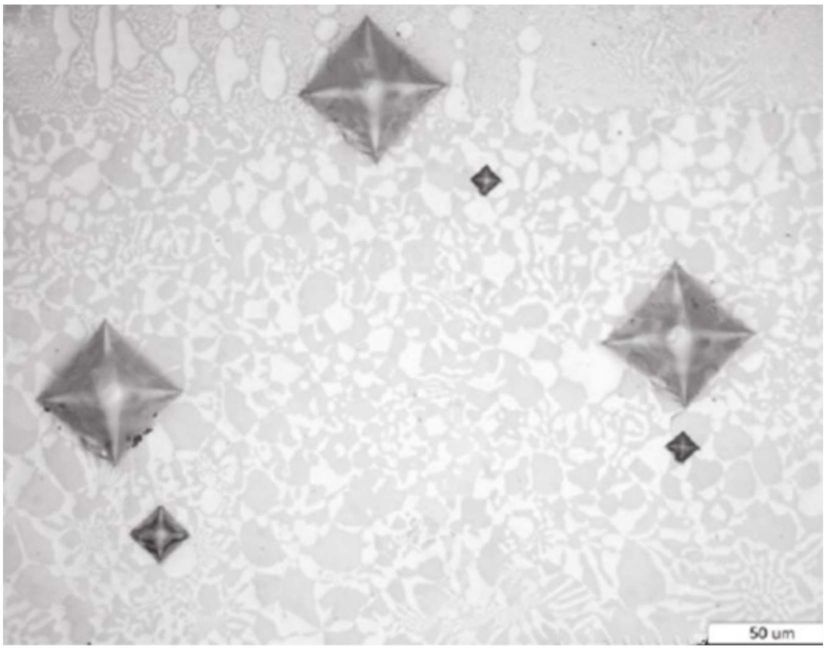

Figure Q3c

Table Q3c

Position	1	2	3
Hardness value	156	164	147

Table Q3d: 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		

4. (a) The chemical structure of polytetrafluoroethylene (PTFE) is shown in Figure Q4a. Calculate the molecular mass of one repeating unit. (carbon: 12 g/mol; fluorine: 19 g/mol)

[2 marks]

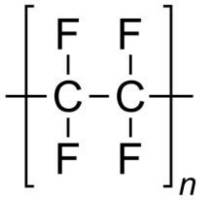

Figure Q4a

(b) During polymerisation, a variety of molecular weights have been obtained. The data in Table Q4b shows the fraction of each molecular weight in this PTFE.

Table Q4b: Molecular weight of PTFE

Fraction	Molecular weight (g/mol)
0.1	200,000
0.2	250,000
0.4	300,000
0.3	350,000

(i) Calculate the number average molecular weight ($\bar{M}_n$). [2 marks]

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

(iii) If the weight average molecular weight ($\bar{M}_w$) is 305,000 g/mol, calculate the molecular weight distribution. Give your answer to 2 decimal places. [2 marks]

(iv) From the polymer structure, describe the intra and intermolecular bonding presented in PTFE. [2 marks]

(c) Thermoplastics and thermosets exhibit distinct behaviours and properties, influencing their processing techniques, including injection moulding. Compare and contrast the injection moulding process for thermoplastics and thermosets, highlighting the key differences in their processing conditions. [4 marks]

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(d) In the context of polymer extrusion, the extruder is segmented into several critical zones, each with specific functions that contribute to the successful transformation of polymer pellets into a final product. Describe the roles and characteristics of the three zones within an extruder. [6 marks]

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

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

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

Molecular Weight Distribution MWD = M_w/M_n

Properties

Thermal diffusivity $\alpha = \frac{k}{\rho c_p}$

Fourier Number $F_0 = \frac{\alpha t}{x^2}$

Linear shrinkage $\frac{\Delta L}{L_0} = \frac{L_0 - L_f}{L_0}$

% Linear shrinkage $= \frac{\Delta L}{L_0} \times 100$

Volume shrinkage $\frac{\Delta V}{V_0} = \frac{V_0 - V_f}{V_0}$

% Volume shrinkage $= \frac{\Delta V}{V_0} \times 100$

Isotropic volume shrinkage $\frac{\Delta V}{V_0} = 1 - \left(1 - \frac{\Delta L}{L_0}\right)^3$

Draw ratio $\lambda = \frac{L}{L_0}$

Lankford coefficient $\bar{r} = \frac{r_0 + 2r_{45} + r_{90}}{4}$

<u>Mechanical Testing</u>

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

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

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

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, $\tau = G\gamma$

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

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

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

Data analysis

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

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

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