Loughborough University

24MPA220

Introductory Materials Science and Processing

Semester 2 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.

Help during the exam

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. (a) A company wants to cast a cylindrical component from an aluminium alloy, 15 cm high and 5 cm in diameter, as shown in Figure Q1a alongside the mould they are using. They are however finding it impossible to cast the shape they need using this mould. They come to ask you what they should do. Draw a diagram for each of the following casting terms and explain how they form:

   (i) Primary pipe [2 marks]

   (ii) Secondary pipe [2 marks]

   (iii) Chill crystals [2 marks]

   (iii) Columnar grains [2 marks]

   (v) Equiaxed grains [2 marks]

   (b) Give three suggestions as to how they can adapt the mould to ensure that they are able to get a good casting of the shape required. [3 marks]

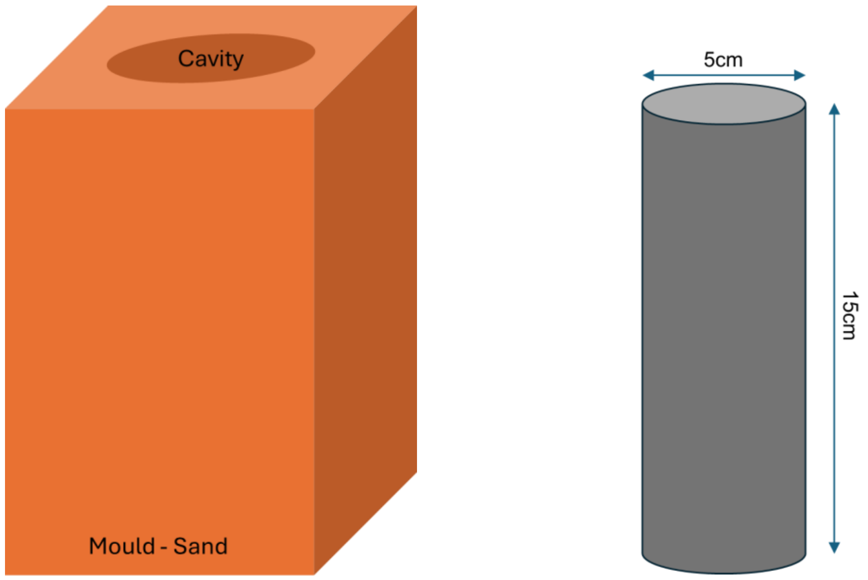

Figure Q1a: Schematic of the mould used and the required shape

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(c) With the aid of your advice, the company can cast some good samples. They machine out the centre 9 cm of the bars to give a new cross section with a diameter of 3 cm and perform tensile tests on them. From the data in Table Q1c calculate:

(i) The yield stress [2 marks]

(ii) The yield strain [1 mark]

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

(iv) The UTS [1 mark]

(v) The fracture stress [1 mark]

(vi) The percent elongation [1 mark]

Table Q1c

Load at Yield	45985N
Sample length at Yield	90.082mm
Maximum load	69756N
Load at failure	61655N
Final sample length	93.5mm

2. (a) In separate cubes draw the following planes:

(i) (121) [1 mark]

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

(iii) $(3\bar{2}2)$ [1 mark]

(iv) $(\bar{1}0\bar{1})$ [1 mark]

(b) In separate cubes draw the following directions:

(i) $[\bar{1}0\bar{1}]$ [1 mark]

(ii) $[\bar{1}1\bar{1}]$ [1 mark]

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

(iv) $[\bar{1}\bar{2}0]$ [1 mark]

(c) Pure iron changes it's crystal structure (or crystallographic form) as temperature increases.

(i) Draw and name the two crystal structures [4 marks]

(ii) State the number of atoms in each unit cell [2 marks]

(iii) Draw a schematic of how the volume of pure iron changes from room temperature up to its melting point. [3 marks]

(d) Explain how carbon influences the tensile testing results of annealed steel. [3 marks]

3. (a) A polyethylene sample has the following molecular weight distribution:

Number Fraction (x_i)	Molecular Weight (M_i) (g/mol)	Weight Fraction (w_i)	Molecular Weight (M_i) (g/mol)
0.2	100,000	0.1	100,000
0.3	150,000	0.3	150,000
0.3	200,000	0.4	200,000
0.2	250,000	0.2	250,000

(i) Draw the chemical structure of polyethylene and calculate the molecular mass of one repeating unit. (carbon: 12 g/mol; hydrogen: 1 g/mol) [3 marks]

(ii) Calculate the number average molecular weight ($\bar{M}_n$) and weight average molecular weight ($\bar{M}_w$). [3 marks]

(iii) Calculate the molecular weight distribution (MWD). Give your answer to 2 decimal places. [2 marks]

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

(b) Polyethylene is widely used in everyday products such as packaging films and containers. Identify two common additives used during the processing of polyethylene and explain the function of each additive. [2 marks]

(c) Polyethylene is also commonly used to make milk bottles due to its processability and mechanical properties.

(i) Sketch a single-screw extruder used in this production. Clearly label the solid conveying (compaction) zone, transition (melting) zone, and metering (pumping) zone, as well as the hopper and die. [4 marks]

(ii) Outline the key steps in the extrusion blow moulding process used to manufacture hollow plastic items such as milk bottles. [2 marks]

(d) Suggest a processing method for each of the following products, and give your reasons for the suggestion:

(i) A children's toy with detailed features and moving parts.

(ii) Carbon fibre reinforced composite boat. [2 marks]

4. (a) Fibre spinning is essential for transforming polymer materials into continuous fibres with controlled diameters and properties. Name and describe the three major fibre spinning techniques used in polymer processing. Highlight their differences in the process.

[4 marks]

(b) Thermoplastics and thermosets exhibit distinct behaviours and properties, which influence how they are selected and processed. Compare thermoplastics and thermosets by stating one key difference in each of the following areas:

(i) Chemical structure

(ii) Thermal behaviour

(iii) Mechanical properties

(iv) Recyclability

(v) Processing techniques [2 marks each, total 10 marks]

(c) During the sintering of a ceramic component, dimensional shrinkage occurs as porosity decreases and particles densify. A green body ceramic cube has an initial side length of 12 cm. After sintering, the final side length is 10.8 cm. Assuming the shrinkage is isotropic, calculate the percentage volume shrinkage. [2 marks]

(d) A manufacturer is developing a new polypropylene (PP) food storage container. During material selection, they must choose between isotactic, syndiotactic, and atactic polypropylene grades.

(i) Outline the structural differences between isotactic, syndiotactic, and atactic forms.

[3 marks]

(ii) The product requires high stiffness, thermal resistance, and good dimensional stability. Which type of polypropylene is most suitable, and why? [1 mark]

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

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