23MPP565

Advanced Processing of Materials

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.

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).

You are required to answer **ALL** questions

A formula sheet is provided on the final page

1. (a) Al-4Cu (wt.%) alloy is a typical age-hardening Al alloy.

   (i) Including diagrams where appropriate, give details of how dislocations interact with precipitates during deformation of this alloy. [5 marks]

   (ii) Sketch a graph to show the variation of strength in relation to precipitate radius. Explain the shape of the curve. [4 marks]

   (b) In the underaged condition, the strength increment $\Delta\tau$ of an aluminium alloy due to precipitates of radius r can be described using the following equation:

$$\Delta\tau = 4.1G\varepsilon^{1.5}\left(\frac{rV_f}{b}\right)^{0.5}$$

where G is the shear modulus, ε is a precipitate/matrix misfit strain, r is the precipitate radius, V_f is the volume fraction of precipitates and b is the magnitude of the Burgers vector.

In the overaged condition, the strength increment can be described using the following equation:

$$\Delta\tau = \frac{Gb}{\lambda}$$

λ is the precipitate spacing, where

$$\lambda^2 = \left(\frac{2\pi r^2}{3V_f}\right)$$

If ε = 0.012, V_f = 0.030, G = 28 GPa and b = 0.29 nm, calculate:

(i) the *precipitate radius* at peak strength and

(ii) the *strength increment* of the alloy at the peak radius.

Give your answers to three significant figures. [6 marks]

Continued/…

Q1 Continued/…

(c) Two densified ceramic samples have the same composition of $BaTiO_3$, but with different average grain sizes (20 μm and 1 μm). Plot the polarisation versus electric field hysteresis (P-E) loops at room temperature for BOTH samples. Justify the difference in ferroelectric behaviours if any. [5 marks]

2. (a) $BaTiO_3$ ceramics are often produced using a cold sintering processing step.

(i) Describe the role of the transient solution during cold sintering. [3 marks]

(ii) Describe the role of the applied pressure during cold sintering. [2 marks]

(iii) Explain why post-annealing is often necessary after cold sintering to enhance the properties of the final $BaTiO_3$ ceramics. [5 marks]

(b) Polystyrene (PS) rods were produced by single screw extrusion with the flow to be Newtonian with no leakage. Using the data provided below and equations in the formula sheet:

(i) Express the extruder characteristic (Q_{EXT}) as a function of the pressure P and screw speed N; [2 marks]

(ii) Express the die characteristic (Q_{DIE}) as a function of the pressure P; [2 marks]

(iii) Calculate the screw speed (N in rpm) required to produce the mass output of the extrusion of 13.4 $kghr^{-1}$; [4 marks]

(iv) If non-Newtonian flow is taken into account (assume n=0.34 for PS), calculate the change in viscosity, when the screw speed in part (iii) is doubled. [2 marks]

Show clearly all steps to obtain your answer and state any assumptions used. Give 3 final answers significant figures.

PS Properties:

Shear viscosity	η = 1100 Pas (melt viscosity)
Density (melt-state)	ρ_M = 945 kg m^{-3}
Power law index	n = 0.34

Extruder screw dimensions:

Diameter	D = 28.0 mm
Metering zone length	L_M = 300 mm
Helix angle	φ = 17.7°
Screw channel depth	H = 2.60 mm

Cylindrical die dimensions:

Diameter	D_{DIE} = 4.80 mm
Die length	L_D of 36.0 mm.

3. (a) The viscosity of a polymer melt is shown in Figure Q3 (a)

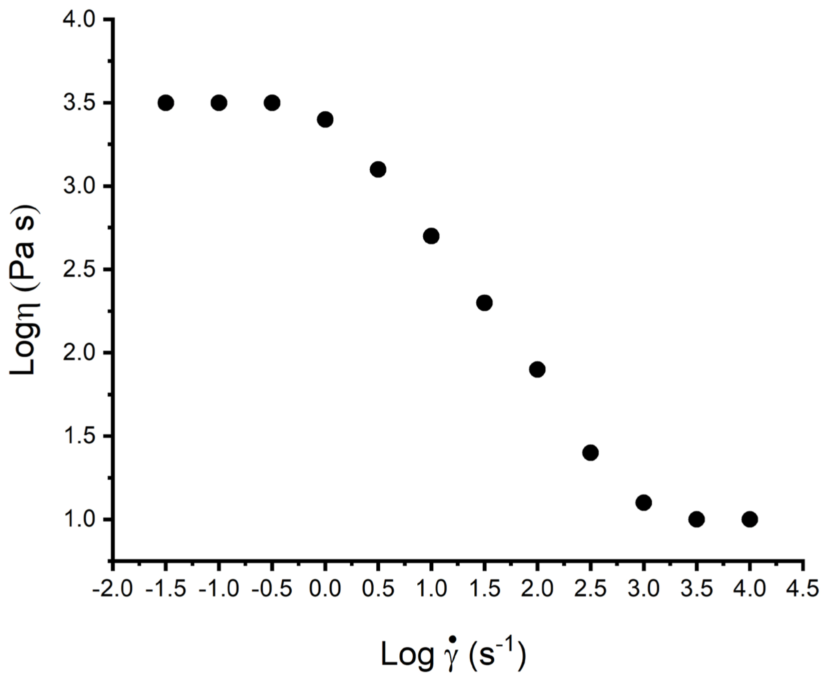

Figure 3 (a)

(i) Calculate the zero shear viscosity. [1 mark]

(ii) Attain the power law index n and constant factor K; and write a power law equation using the n and K values obtained. [5 marks]

(iii) Predict the viscosity at a shear rate of 800 s^{-1}. [2 marks]

Give 3 significant figures for final answers.

(b) Explain how shear viscosity affected by the change of shear rate of the following fine ceramic powders/water/dispersant suspensions with different solid fractions:

(i) very diluted suspension [2 marks]

(ii) moderately concentrated suspension [2 marks]

(iii) highly concentrated suspension [2 marks]

Use a plot of log (shear viscosity) as a function of log (shear strain rate) to illustrate the effects and give concise explanation.

(c) Use steady-state processing of thermoplastics in a single screw extruder as a reference, compare and contrast the flow mechanisms in a single screw extruder and counter-rotating twin screw extruder, including an output-pressure diagram to illustrate your answer. [6 marks]

END OF PAPER

Dr H Zhang, Dr X Bao

23MPP565 Examination – List of Equations

Rheological formulae

- The power Law model: $\tau = K\dot{\gamma}^{n}$
- The truncated (reduced) power law equation

$$\eta = \frac{\tau}{\dot{\gamma}} \qquad \eta = K\dot{\gamma}^{n-1}$$

- *WLF equation:*

$$\log\left(\frac{\eta}{\eta_g}\right) = -\frac{17.44(T - T_g)}{51.6 + (T - T_g)}$$

- *Capillary Rheometry*

$$\tau = \frac{R\Delta P}{2L} \qquad \dot{\gamma}_a = \frac{4Q}{\pi R^3} \qquad \dot{\gamma}_{true} = \left(\frac{3n+1}{4n}\right)\dot{\gamma}_a$$

$$\eta_a = \left(\frac{\pi R^4}{8Q}\right)\left(\frac{\Delta P}{\Delta L}\right)$$

$L_{effective} = L + eR$

Extrusion Processing

- Output due to drag flow, Q_D

$$Q_D = \frac{WH\pi DN\cos\varphi}{2} = \pi^2 D^2 \frac{HN\cos\varphi\sin\varphi}{2}$$

- Output due to pressure draw Q_P

$$Q_P = -WH^3\frac{\sin\varphi\,\Delta P}{12\eta L_M} = -\frac{\pi DH^3 sin^2\varphi\Delta P}{12\eta L_M}$$

- Total extruder output Q_{EXT}

$$Q_{EXT} = Q_D + Q_P$$

- Extruder Output Characteristic:

$$Q_{EXT} = \alpha N - \frac{\beta\Delta P}{\eta}$$

- Die Output Characteristic Q_{DIE}:

$$Q_{DIE} = \frac{K\Delta P}{\eta}$$

$$K = \frac{\pi R^4}{8L_D}\ (Circular\ Die) \qquad K = \frac{WH^3}{12L_D}\ (Slit\ Die)$$