Polymer Engineering – Processing and Manufacture

23MPC012

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.

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1. (a) Within the context of extrusion of polymers,

(i) Define elastic behaviour of melts and explain why polymer melts could exhibit such behaviour; [2 marks]

(ii) Discuss the effects of strain rate and molecular weight on the elastic behaviour of polymer melts. [2 marks]

(b) With the use of appropriate diagrams and equations, discuss the correction factors that should be applied in capillary rheometry measurements to obtain true values of both shear stress and shear strain rate. [6 marks]

(c) Capillary rheometry measurements were carried out on a polymer melt at a temperature of 180 ˚C, using a cylindrical capillary die with a diameter of 2 mm and a length of 25 mm. When the pressure drop was 5.4 MPa, the flow rate of the polymer melt through the die was 8.0 x10^{-7} m^3s^{-1}. The flow rate through the same die decreased to 4.2x10^{-7} m^3s^{-1} when the pressure drop was 4.0 MPa. Calculate the following:

(i) The apparent shear rate at both flow rates; (one decimal place for final answers) [2 marks]

(ii) The power law index, n; (three decimal places for final answer) [2 marks]

(iii) The true shear rate at both flow rates. (one decimal place for final answers) [2 marks]

(d) A grade of polylactic acid (PLA) was found to have a melt viscosity of 2035 Pa·s when tested at 175 ˚C at a shear strain rate of 47 s-1. When tested at a shear strain rate of 100 s-1 the viscosity was found to be 1344 Pa·s. Assuming that the polymer melt obeys the power law model, calculate:

(i) the power law index, (n) (three decimal places for the final answer); [2 marks]

(ii) the consistency index, (K). (one decimal place for the final answer) [2 marks]

2. (a) Polystyrene (PS) rods were produced by single screw extrusion under Newtonian conditions and no leakage flow. 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 kg·hr^{-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]

(3 significant figures for final answers)

State clearly all steps taken to obtain your answer and quote any assumptions used.

PS Properties:

Shear viscosity	η = 1100 Pa·s (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.

(b) Describe two extensional deformations which occur in extrusion blow moulding (EBM), making reference to the respective strain rates and viscoelastic effects. Comment on their importance in the manufacturing process and polymer molecular weight (MW) requirements. [6 marks]

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(c) With reference to heat transfer material deformation,

(i) explain why process cycle times in rotational moulding processes are often extremely long. [2 marks]

(ii) state how the cycle times can be reduced. [1 mark]

(iii) State whether high MW or low MW grades of polymer would be required for this process, explaining why. [1 mark]

3 (a) For a typical injection moulding machine, briefly describe the two main specification parameters relating to the injection unit and the mould clamp unit, respectively. State how they are calculated. [4 marks]

(b) (i) State what is meant by flow balancing in injection moulding tools, referring to changes in pressure between component parts. [2 marks]

(ii) Using a sketch to support your answer, explain how flow balancing might be achieved when injection moulding two cavities of different thickness in the same tool.

[4 marks]

(c) A circular-section runner (length, L = 120 mm, diameter, D = 6 mm) is being designed to feed a grade of ABS to the cavity during injection moulding at a predicted volumetric flow rate, $Q = 2.16 \times 10^{-5}\ m^3\ s^{-1}$.

The flow properties of the ABS grade selected can be represented by power law constants:

ABS $K = 5000\ N{\cdot}s{\cdot}m^{-2}$ (Pa s) $n = 0.33$

(i) Use the information below to estimate the pressure drop for shear flow along this runner section, initially for a hot runner system. [4 marks]

(ii) Repeat the calculation for a cold runner design, assuming a 'frozen layer' thickness of 0.4 mm (ΔR = 0.4 mm). Use the result to estimate the percentage increase in pressure for the cold runner option. [2 marks]

(iii) State any assumptions used in the calculations and comment briefly on their validity for thermoplastics injection moulding. [4 marks]

END OF PAPER

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23MPC012 Examination – Formula / Information Sheet

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

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

- 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}:

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

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

- For a circular section flow channel, shear stress and apparent shear rate are given (respectively) by:

$$\tau = \frac{R\Delta P}{2L} \qquad \dot{\gamma} = \frac{4Q}{\pi R^3}$$

(L = channel length, R = radius, ∆P = pressure drop; Q = volumetric flow rate)

- Pressure drop (**Isothermal Filling)** **<u>Circular Section</u>**

$$\therefore\ \Delta P = \frac{2LK}{R^{3n+1}}\left(\frac{4Q}{\pi}\right)^n$$