Version AS/MS/2

MET2
MANUFACTURING ENGINEERING TRIPOS PART IIA

Thursday 1 May 2025 9:00 to 10:40

Paper 1

MODULE 3P1: MATERIALS INTO PRODUCTS

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS
8 page answer booklet x2
Rough work pad

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book

10 minutes reading time is allowed for this paper at the start of the exam.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

You may not remove any stationery from the Examination Room.

1 (a) Fig. 1 shows an asymmetric extrusion process. The input metal alloy billet is horizontal (parallel to the x axis) and of thickness H, which is much smaller than the billet dimension along the z axis. The horizontal ram moves at a speed v_i under an applied force per unit depth F. The output billet emerges downward at an angle θ and at a speed v_0. The shear yield stress of the material is k.

(i) Draw a velocity diagram and determine θ. [25%]

(ii) Use the upper bound method to find an expression for the force F, assuming the dies are frictionless. [20%]

(b) Material processing such as rolling, extrusion, drawing and machining are effected by temperature rise during the deformation process. An expression for estimating average temperature rise is given as

$$\Delta T = \frac{Power\ input}{(Volume\ deformed\ per\ second) \times (Volumetric\ heat\ capacity)}$$

(i) State the assumptions in this calculation. [10%]

(ii) Describe the temperature rise during machining using a suitable diagram, which includes features of primary and secondary shear zones as well as the direction of heat. [15%]

(iii) What is the significance of the secondary shear zone in the temperature rise? [10%]

(c) During extrusion, plastic deformation and heat may induce recrystallisation of the metal alloy.

(i) Sketch in a graph how the average size of recrystallised grains varies as a function of extrusion velocity and explain your reasoning. [10%]

(ii) Explain why the average grain size of recrystallised grains at the surface of the extruded part could be smaller than that in the bulk. [10%]

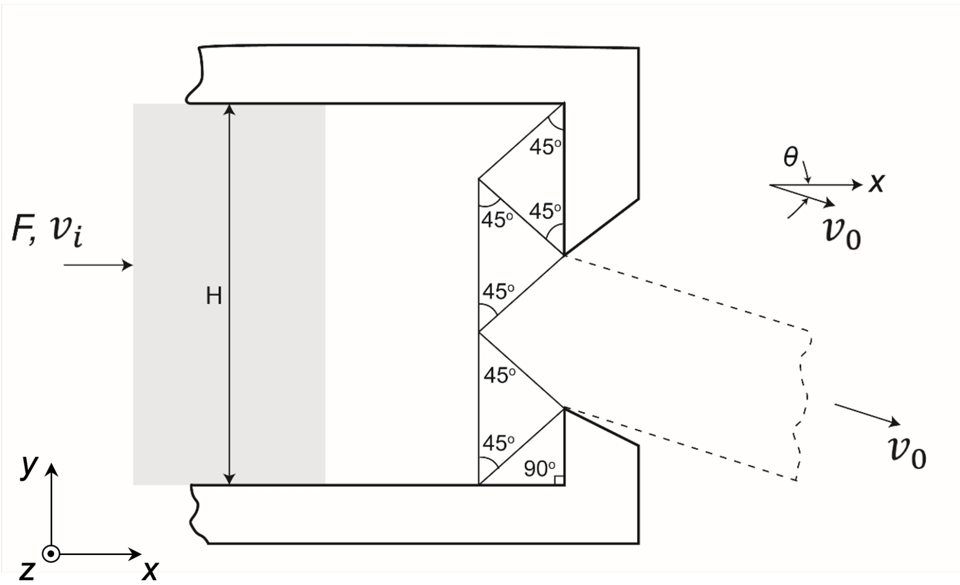

Fig. 1

 (TURN OVER

2 (a) A series of dumbbells, shown in Fig. 2a, is to be manufactured from cast iron. To minimise production time, the manufacturer considers re-designing the product as half dumbbells, shown schematically in Fig. 2b, and then welding the two halves together.

(i) Using Chvorinov's rule, $t_s = C\,(V/A)^2$, compute the difference in solidification time t_s, between the two designs. Use $C = 0.24\ min/cm^2$ for cast iron. [20%]

(ii) Interpret the result obtained in (i) based on the volume to area ratio. [10%]

(iii) Discuss whether making half dumbbells and welding them together is a sensible approach if the objective is to minimise production time. [30%]

(iv) Would casting of the half dumbbells in the orientation shown in Fig. 2b or upside down affect the formation of defects? If so, which ones and how? [10%]

(v) Do you expect the welding to compromise the quality of the product in any way? Justify your answer. [10%]

(b) As an alternative route, the manufacturer considers buying cast iron billets and using machining to produce the dumbbells (Fig. 2a). Comment on the technical, quality, and economic aspects of this manufacturing route compared to casting. [20%]

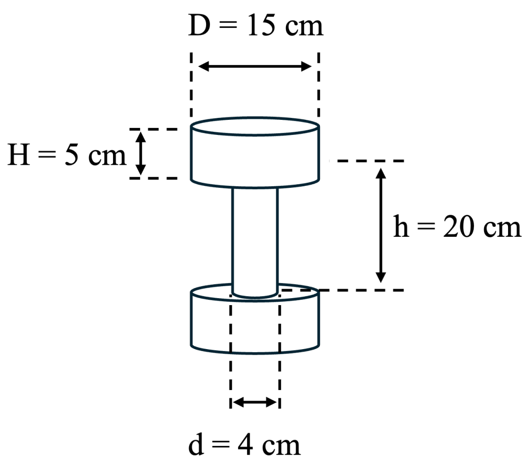

Fig. 2a

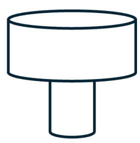

Fig. 2b

3 (a) Failure in engineering materials has a wide range of causes. Design against failure is an important step in manufacturing processes. For each of the following situations, identify what features could lead (or have led) to failure and suggest a suitable mitigation strategy.

(i) Gears with residual stresses on the surface. [15%]

(ii) "Liberty Ships" during World War II failed catastrophically breaking into half in cold ocean waters. [15%]

(iii) Cyclic loading of metal surfaces rolling against each other. [15%]

(iv) The use of sodium lubricants in nuclear reactors. [15%]

(b) You are part of an engineering team tasked with designing a lightweight, durable dashboard support structure for an electric vehicle. The structure must:

- Withstand moderate mechanical loads and vibrations.
- Be cost-effective to manufacture in high volumes.
- Allow for complex geometries to integrate multiple mounting points for electronic components.

Given the options of short-fibre and long-fibre composites:

(i) What would be your choice of fibre composite? Your answer should consider implications on mechanical properties, manufacturing feasibility, and cost. [30%]

(ii) Would your choice change if the application were for producing support structures for the vehicle's chassis? Justify your answer. [10%]

4 (a) To manufacture a landing gear component for an aircraft, an aerospace company opted for Laser Powder Bed Fusion (L-PBF) technology as an alternative route to conventional casting and welding. The as-built part, inclusive of support structures, is shown in Fig. 3a. Note that the original design for conventional manufacturing (not shown here) consisted of multiple sub-components that had to be joined together. Based on this information, discuss two possible reasons why the aerospace company decided to use L-PBF for producing the landing gear. [20%]

(b) An alternative additive technology that was considered for the manufacture of this part was laser directed energy deposition (L-DED).

(i) With reference to Fig. 3a, what advantage would you expect L-DED to bring over L-PBF for the manufacture of this part? [10%]

(ii) The higher throughput of L-DED over L-PBF allows faster production times of metal parts. What is a disadvantage of high-throughput additive manufacturing techniques? [10%]

(iii) Explain why L-DED technology induces lower cooling rates compared to LPBF, and briefly discuss the implications on part microstructure and properties. [30%]

(c) Assume that the part in Fig. 3a was made of steel and recall that laser-based additive manufacture (such as L-PBF and L-DED) can be thought of a series of multiple welding operations.

(i) What microstructure would you expect to find in the as-built part? An indicative CCT diagram for steel welding is shown in Fig. 3b. [20%]

(ii) Briefly explain why, in general, it is challenging to predict the as-built microstructure of metal parts produced by laser-based additive technologies (including L-PBF and L-DED). [10%]

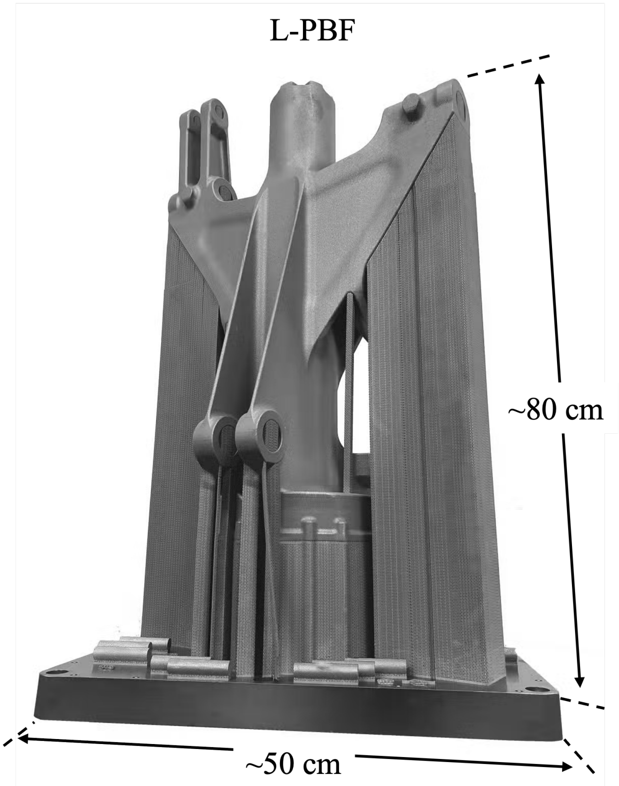

Photo credit: SLM Solutions

Fig. 3a

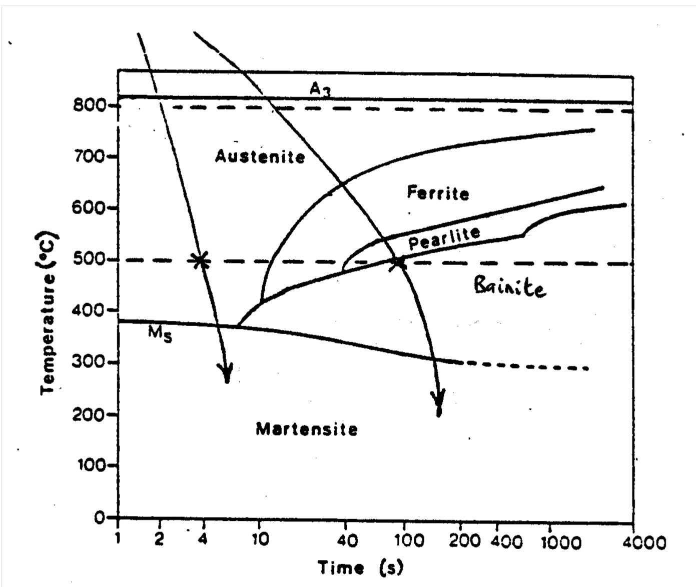

Fig. 3b

END OF PAPER