Version GJM/5

MET 2

MANUFACTURING ENGINEERING TRIPOS PART IIA

Thursday 27 April 2023 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

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM

CUED approved calculator allowed

Engineering data books

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 material and a processing route are to be selected for the ball bearing race shown in Fig. 1. The race must withstand contact with the hardened steel rolling elements, which transmit the radial loads supported by the bearing.

(a) Explain one technical, one quality, and one economic attribute of the bearing race to be considered when selecting a material and processing route. [15%]

(b) A steel of type BS 503M40 (En12) is proposed for the bearing race. The CCT diagram for this steel is given in Fig. 2. The bearing race is austenitised, quenched in oil and then tempered at 550 °C for 1 hour.

(i) The equivalent diameter of the bearing race is $D_e = 1.6t$ where t is the average thickness of the race (Fig. 1). The target minimum hardness of the race is 325 HV. What is the maximum allowable value of t ? [30%]

(ii) After heat treatment, how might the hardness of the real bearing race vary relative to this target value? [15%]

(c) It is found that the bearing race described in part (b) is susceptible to cracking in service. Two strategies are considered to improve the component life. For each strategy, describe one way it could be implemented, and explain one advantage and one disadvantage.

(i) Strategy 1: increase the hardenability. [20%]

(ii) Strategy 2: use a surface hardening process. [20%]

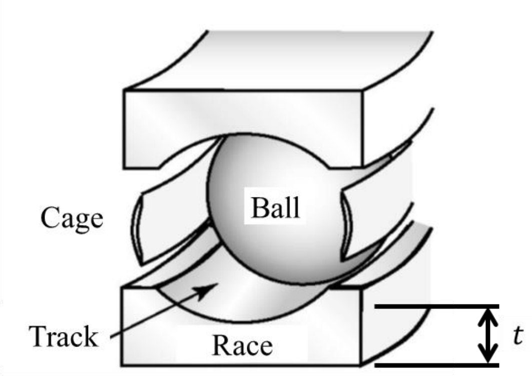

Fig. 1

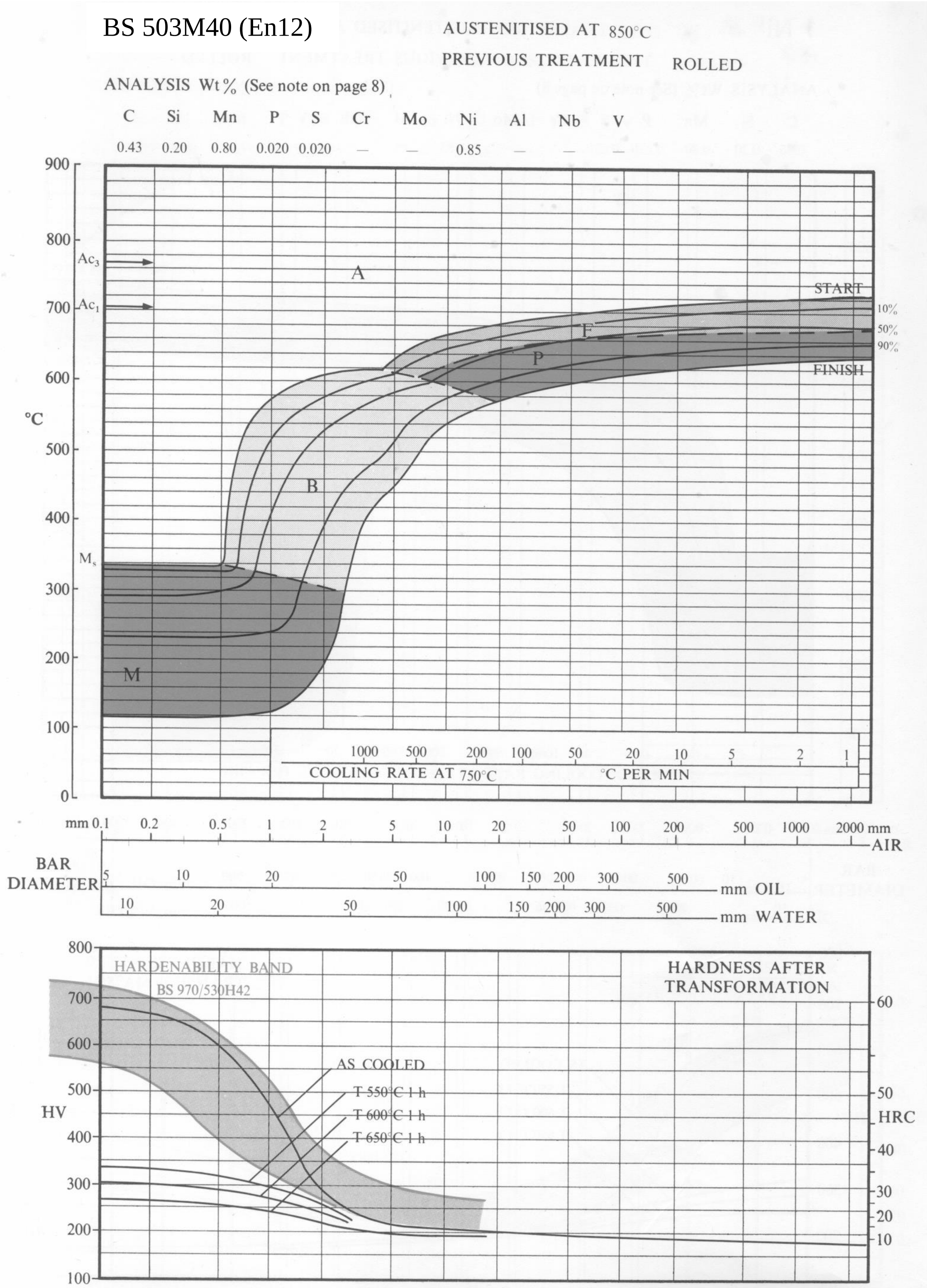

Fig. 2

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2 A circular disc of radius R and thickness h is shaped by hot forging. The forging load F can be modelled using the equilibrium method. The result is:

$$F = 2\pi Y \left(\frac{h}{2\mu}\right)^2 \left[\exp\left(\frac{2\mu R}{h}\right) - 1\right] - 2\pi Y R \left(\frac{h}{2\mu}\right)$$

where Y is the yield strength of the alloy. Coulomb friction with coefficient of friction μ is assumed between the workpiece and the platens.

(a) Sketch how the forging pressure varies across the face of the disc, labelling the key features. Note that a calculation of the forging pressure is not required. [15%]

(b) Show that when the coefficient of friction μ is small:

$$F \approx Y\pi R^2 \left(1 + C\mu\frac{R}{h}\right)$$

where C is a constant. Hence identify the value of C, and discuss why the contribution of friction to the forging load depends on the aspect ratio R/h. [30%]

(c) The disc is manufactured from a heat-treatable aluminium alloy. It is pre-heated, hot forged and then immediately quenched and aged. Discuss the importance of controlling the temperature rise during the pre-heat and forging. [20%]

(d) The forging power P is approximately given by $P \approx Fh\dot{\varepsilon}$, where $\dot{\varepsilon}$ is the strain-rate. Estimate the temperature rise during a 1 ms period of forging for a disc with $R = 10$ mm, $h = 2$ mm, $\dot{\varepsilon} = 10^2$ s^{-1} and $\mu = 0.05$. State any assumptions you make, and explain whether this temperature rise is likely to be spatially uniform. [35%]

The alloy has hot yield strength $Y = 50$ MPa, density $\rho = 2700$ kg m^{-3}, specific heat capacity $c_p = 950$ J kg^{-1} K^{-1} and thermal conductivity $\lambda = 150$ W m^{-1} K^{-1}.

3 A copper pipe of diameter 30 mm, intended to carry hot water at 80 °C, is brazed to a mild steel plate, as shown in Fig. 3(a). After some time in use, cracks are found in the brazed joint, and corrosion of the steel is observed at the point of contact with the pipe.

(a) Discuss the possible causes of these failure mechanisms. [30%]

(b) The following design changes are proposed to solve the problem. In each case, discuss the potential benefits and disadvantages for the life of the joint.

(i) Instead of brazing, the copper pipe is bonded to the mild steel plate using a thin (< 1 mm) layer of epoxy adhesive. [20%]

(ii) The mild steel plate is first galvanised with zinc before the copper pipe is brazed in place. [20%]

(c) The brazed joint is replaced with an injection moulded polyethylene clip, shown in Fig. 3(b), attached to the plate with steel screws (not shown).

(i) Discuss the potential failure mechanisms that might limit the lifetime of the polyethylene clip, and their causes. [15%]

(ii) Discuss whether a thermoset would be a suitable choice for the clip. [15%]

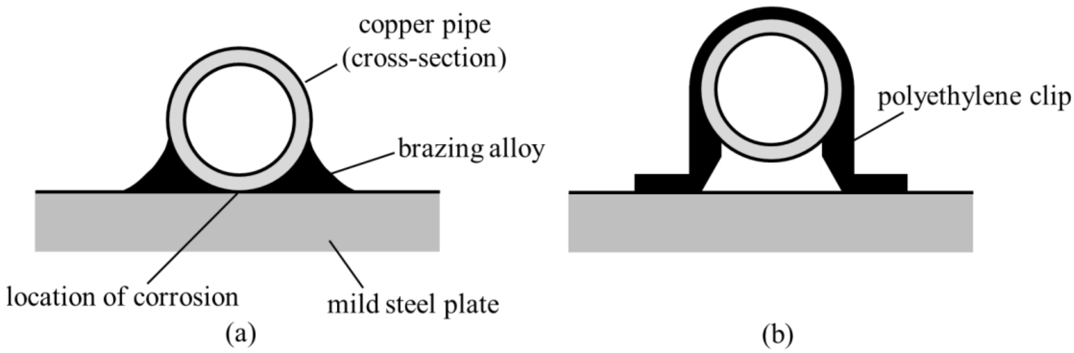

Fig. 3

4 A jeweller wishes to manufacture a set of ten identical beads for a necklace using an alloy of silver (93 wt%) and copper (7 wt%). A drawing of a bead is shown in Fig. 4.

(a) Discuss the suitability of the following two processes for manufacturing the beads, commenting on technical, quality and economic attributes.

(i) Pressure die casting. [20%]

(ii) Investment casting. [20%]

(b) Segregation is observed in the cast beads. Using sketches to support your answer, define what is meant by segregation during solidification of an alloy. Explain why segregation may occur on different length scales, including any influence of mould design. [30%]

(c) Laser Powder Bed Fusion (LPBF) additive manufacturing is considered as an alternative route for producing the beads.

(i) Describe four factors to consider when assessing the suitability of LPBF for this application. [20%]

(ii) What strategies can be used to improve the quality of a bead produced using LPBF? [10%]

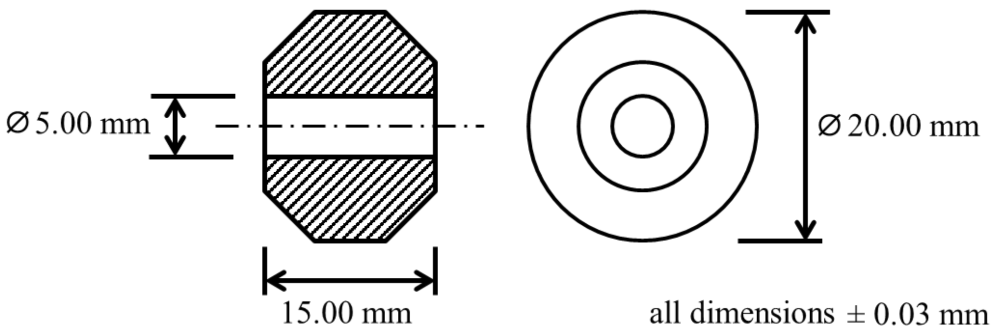

Fig. 4

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