Version JHD/Final with numeric answers

EGT1
ENGINEERING TRIPOS PART IB

Monday 14 June 2021 13.30 to 15.40

Paper 3

MATERIALS

*This is an **open-book** exam.*

*Answer not more than **four** questions, which may be taken from either section.*

All questions carry the same number of marks.

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

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

STATIONERY REQUIREMENTS
Write on single-sided paper.

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
You have access to the Engineering Data Book, online or as your hard copy.

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

The time allowed for scanning/uploading answers is 20 minutes.

Your script is to be uploaded as a single consolidated pdf containing all answers to both sections.

SECTION A

1 (a) (i) Explain why oxygen is not required for iron to corrode in an acidic environment. [3]

(ii) What might explain why a structure composed of mild steel panels with stainless steel bolts experiences rapid corrosion at the fixings if placed in contact with seawater? [2]

(iii) Identify two methods for preventing corrosion and comment on the cost and durability of each approach. [4]

(b) (i) Explain why the rate at which a corrosion reaction proceeds is largely independent of the magnitude of the free energy of the reaction. [2]

(ii) Three common ways in which mass changes with time in corrosion are: linear mass gain, linear mass loss and parabolic mass gain. Explain how these arise. [3]

(c) A chrome coating of 1 m^2 area was used to protect the wall of a furnace operating at 700 °C. After one year in service it was found to have gained 5 g in mass through the formation of Cr_2O_3. The change in mass in the corrosion process can be modelled as $\Delta m = \sqrt{tk}$ where Δm is change in mass per square metre, k is a rate constant in $kg^2\ m^{-4}\ s^{-1}$ and t is time in seconds. The density of chromium is 7150 kg m^{-3}. The atomic weight of O is 16 g·mol^{-1} and that of Cr is 52 g·mol^{-1}.

(i) Calculate the value of k. [5]

(ii) Determine what thickness of chromium metal would have been converted to oxide after two years of operation. [6]

2 (a) The phase diagram of the Fe-C system is given in the materials data book.

(i) Identify the temperature and composition of any eutectic, eutectoid, peritectic or peritectoid points. [4]

(ii) Identify the proportions and compositions of the equilibrium phases expected to be present in a 3 wt.% C cast iron at 1000 °C and at room temperature (20 °C). Would the phases expected in a real sample of cast iron be different? [4]

(b) (i) For the cases of a 0.4 wt.% C steel and a 0.9 wt.% C steel use labelled microstructure sketches to explain how the microstructure evolves on slow cooling from 1000 °C to room temperature. [8]

(ii) Sketch and label the microstructure expected at room temperature if a 0.4 wt.% C steel is quenched faster than its critical cooling rate from 1000 °C to room temperature. What differences might be expected as the carbon concentration is increased. [4]

(iii) Consider the BS503M40 steel whose TTT diagram is given in the materials databook. Sketch and label the microstructure you would expect to see if the steel was rapidly quenched to 450 °C and then held at that temperature for 10 minutes before slow cooling to room temperature. [5]

3 (a) (i) Using sketches of free energy versus composition explain why, when combined, some materials mix thoroughly while others split into two phases. [4]

(ii) For the case of the lead-tin system, whose phase diagram is given in the materials databook, sketch how the free energies of the α, β and liquid phases vary with composition at 327, 250 and 150 °C. [6]

(b) A common type of hand-warmer, shown shortly after activation in Fig. 1, contains sodium acetate and a small metal disk inside a plastic bag. Initially the contents of the warmer are in the form of a transparent viscous liquid. When the metal disc is flexed it clicks, and the warmer's contents progressively solidify. During this process the hand-warmer emits heat. The hand-warmer is recharged by heating in boiling water and then being slowly cooled, after which it can be reused.

(i) Explain why flexing the disc initiates solidification, and why the solidification releases heat. What might affect the rate of heat release? [5]

(ii) Why does the reaction, once initiated, proceed to full solidification? [3]

(iii) Explain why the warmer must be thoroughly heated in order to be succesfully recharged. [4]

(iv) The manufacturer receives complaints that a batch of hand-warmers spontaneously solidify on cooling without being triggered with the metal disc. Suggest possible causes for the observed defect. [3]

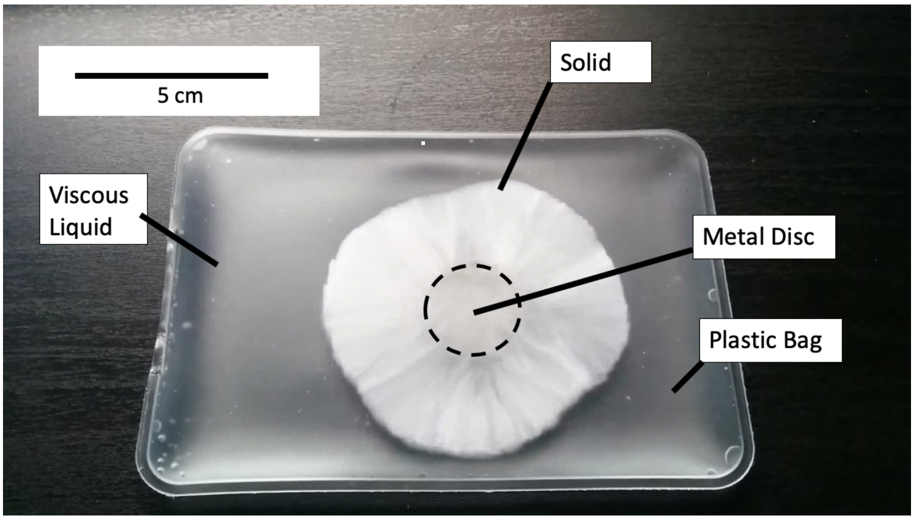

Fig. 1

SECTION B

4 Figure 2 shows the stress-state on an element of a bar of width $2w$ and thickness $2h$ being forged between two parallel dies. The forging operation imposes a pressure $p(x)$ and the horizontal stress $\sigma_x(x)$ is assumed uniform through the bar thickness. The magnitude of the friction stress between the die and bar is given by $|\tau| = m\sigma_Y/2$ where σ_Y is the yield strength of the bar and m a constant with range $0 \leq m \leq 1$. You may assume $w \gg h$ and that the out of plane length of the bar is large compared to w and h.

(a) Considering equilibrium, derive an equation for σ_x in terms of m, σ_Y and h. Include a clear step by step explanation of your method. Outline any assumptions made and comment on their validity. [6]

(b) Using your result in (a), derive an expression for $p(x)$ in terms of the bar geometry, σ_Y and m. Sketch how $p(x)$ varies with m. Include a clear step by step explanation of your method. Outline any assumptions made and comment on their validity. [8]

(c) What is the total forging force, F, per unit depth if $w = 6h$, $m = 0.1$, $\sigma_Y = 200$ MPa and $h = 100$ mm? [5]

(d) Discuss the validity of this analysis for the forging of annealed Cu. [6]

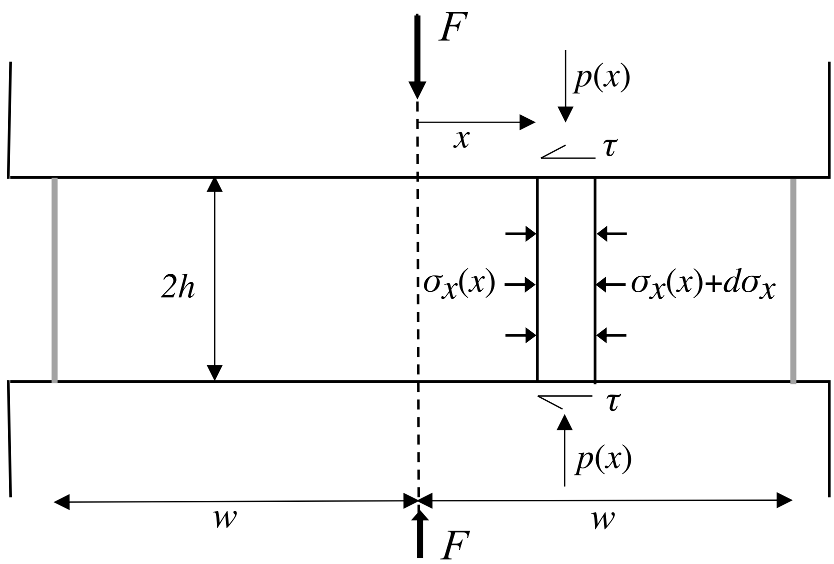

Fig. 2

5 (a) Discuss the role of diffusion in the creep of metal alloys. [5]

(b) Turbine blades for jet engines are manufactured from Ni-based superalloys. How is their composition and processing tailored to reduce

(i) diffusional creep, [3]

(ii) power law creep? [3]

(c) The nominal strain rate for creep of a metal alloy is given by $\dot{\varepsilon} = \dot{\varepsilon}_0 \, (\sigma/\sigma_0)^n$, where n is a dimensionless constant, $\dot{\varepsilon}_0$ and σ_0 are reference strain rate and stress, respectively, while σ is the applied nominal stress.

(i) A cylindrical bar of length L made from this alloy is freely suspended vertically from one end at time $t = 0$. The bar creeps under its own weight. Determine an expression for the extension rate $\mathrm{d}L/\mathrm{d}t$ of the bar at time $t = 0$ in terms of the metal alloy density ρ, acceleration due to gravity g and the material creep constants . [9]

(ii) If σ is the true stress rather than the nominal stress, briefly discuss (without further calculation) why the elongation rate calculated in (c)(i) might cease to be valid for longer times [5]

6 (a) Explain the following observations:

(i) The Young's modulus of an elastomer decreases from 3 GPa at −200 °C to 3 MPa at room temperature whereas the Young's modulus of a thermoset is approximately 10 GPa at both temperatures. [6]

(ii) A bar of cold-drawn Cu has a yield strength of 250 MPa. The bar is annealed at 600 °C for 5 mins and the yield strength of the bar reduces to 50 MPa. [6]

(b) The Al alloy skin of a supersonic aircraft is deliberately "under-aged". What is meant by this term and why is this important for its long-term performance? [8]

(c) A batch of Al-alloy rivets was inadvertently "over-aged". What steps could be taken to salvage this batch of rivets? [5]

END OF PAPER

Numerical Answers

Q1 c i) 7.93 x10^{-13} $kg^2m^{-4}s^{-2}$ ii) 2.13 μm

Q4 c) F= 13.8 h