

24MPB313
Materials in Service

Semester 1 2024/25

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).

Answer **ALL** questions.

A list of equations, constants and data tables are included at the end of the paper.

1. To prevent corrosion, a mild steel lamppost is painted in a polymer coating. Over time however, the polymer is seen to have cracked and separated from the steel and corrosion of the steel taking place, see Figure Q1a.

(a) (i) State three factors that may have led to the failure of the polymer coating. [3 marks]

(ii) From consideration of Figure Q1a what two types of corrosion may be occurring on the steel component? [2 marks]

(iii) Choose one of your identified types of corrosion in Q1.a.ii and state why you think this type of corrosion is occurring. Draw a schematic of your selected mechanism. [6 marks]

(iv) From the Figure Q1a, it appears that the lamppost has been painted several times. How should the re-painting have been carried out to improve the corrosion protection? [3 marks]

(b) (i) Explain what is meant by the Limiting Oxygen Index (LOI) and how this should be used to select polymers for certain applications. [2 marks]

(ii) Give two examples of factors that may affect the LOI value for a given polymer. [2 marks]

(iii) Why might LOI need to be considered in the polymer selection process for a street lamppost? [2 marks]

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Q1 Continued/...



Figure Q1a

2. Aluminium and nickel are used extensively in the aerospace sector. Two 2 mm thick aluminium sheets are riveted together with nickel rivets.

(a) For this configuration answer the following:

(i) If galvanic corrosion were to occur which element would act as the anode and which as the cathode? [1 mark]

(ii) Write out the reaction in both a balanced chemical equation and in cell notation. [2 marks]

(iii) Calculate the standard cell potential and state if there would be any corrosion. [2 marks]

(iv) Calculate the cell potential and determine if corrosion would be spontaneous. [2 marks]

(v) Discuss if this is a good joining strategy in terms of the materials chosen and suggest a strategy for mitigating any galvanic corrosion. [3 marks]

(b) Nickel components were found to fatigue. Draw a schematic of a S-N curve you would expect for nickel and explain how this can be used in designing the life of a component. [5 marks]

(c) Tensile tests are carried out on the aluminium sheets used on the aircraft in Q2a. The samples are machined out of the sheet with a sample width of 20 mm and the gauge length 100 mm. From the data in Table Q2c and showing all working calculate:

(i) The yield stress [2 marks]

(ii) The yield strain [1 mark]

(iii) The Young's modulus [1 mark]

(iv) Percent Elongation [1 mark]

Table Q2c

Load at Yield	8870 N
Sample length at Yield	100.36 mm
Final sample length	106.8 mm

3. You are part of a small team who live and work on a remote communications satellite station situated between Earth and the new scientific settlements on Mars. You are fully self-sufficient, but the station was built 50 years ago, and some equipment is aging. One area of concern is the power plant.

(a) Draw a labelled schematic of a nuclear power system to produce electricity. [6 marks]

(b) The current operating temperature of the plant is 475°C , and it is decided to reduce the operating temperature by 100°C to extend the life of components. Assuming room temperature is 25°C , calculate the theoretical reduction in efficiency. [3 marks]

(c) What could be done to reduce the efficiency loss calculated in Q3b? [1 mark]

(d) Inspection on the steel steam tubes show several issues including numerous cracks at the welded joints. A schematic of a welded joint taken out of service is shown in Figure Q3d. You need to test other joints to see if any of the defects in the schematic are present in the components in-situ. Discuss what NDT test methods you could use to look for each of the defects labelled 1-5 in Figure Q3d and what issues you could encounter.

[10 marks]

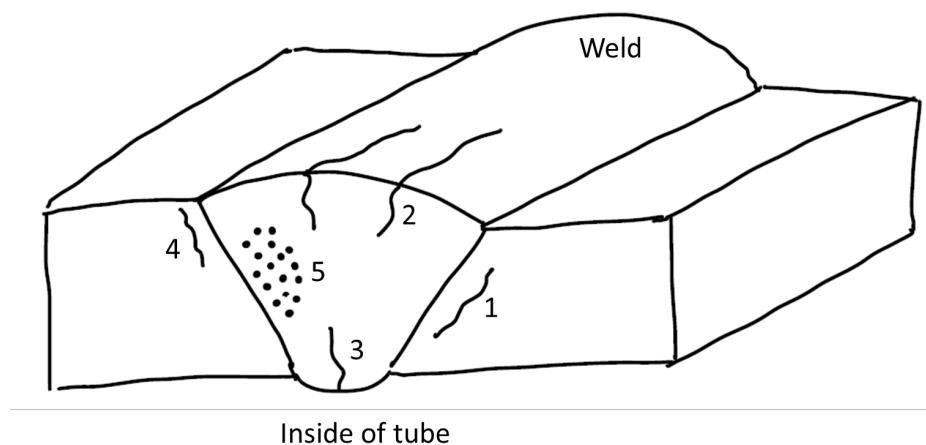


Figure Q3d

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Dr RL Higginson

Standard Data

Table MPB313 (a): Standard electrode potentials for a selection of elements

Element	Electrode	Electrode Potential (V)
Lithium	Li^+, Li	-2.959
Rubidium	Rb^+, Rb	-2.925
Potassium	K^+, K	-2.924
Calcium	$\text{Ca}^{2+}, \text{Ca}$	-2.763
Sodium	Na^+, Na	-2.714
Magnesium	$\text{Mg}^{2+}, \text{Mg}$	-2.37
Beryllium	$\text{Be}^{2+}, \text{Be}$	-1.85
Aluminium	$\text{Al}^{3+}, \text{Al}$	-1.69
Titanium	$\text{Ti}^{2+}, \text{Ti}$	-1.63
Chromium	$\text{Cr}^{2+}, \text{Cr}$	-0.91
Zinc	$\text{Zn}^{2+}, \text{Zn}$	-0.761
Chromium	$\text{Cr}^{3+}, \text{Cr}$	-0.74
Iron	$\text{Fe}^{2+}, \text{Fe}$	-0.44
Cadmium	$\text{Cd}^{2+}, \text{Cd}$	-0.42
Nickel	$\text{Ni}^{2+}, \text{Ni}$	-0.23
Tin	$\text{Sn}^{2+}, \text{Sn}$	-0.14
Lead	$\text{Pb}^{2+}, \text{Pb}$	-0.13
Iron	$\text{Fe}^{3+}, \text{Fe}$	-0.045
Hydrogen	H^+, H_2	0.00
Copper	$\text{Cu}^{2+}, \text{Cu}$	0.337
Copper	Cu^+, Cu	0.522
Silver	Ag^+, Ag	0.797
Mercury	$\text{Hg}^{2+}, \text{Hg}$	0.798
Platinum	$\text{Pt}^{2+}, \text{Pt}$	1.20
Gold	$\text{Au}^{3+}, \text{Au}$	1.50

Table MPB313 (b): Limiting Oxygen Index of a selection of polymeric materials

Polymer	LOI
Polytetrafluoroethylene (PTFE)	95.0
Polyvinylidene chloride	60.0
Polyvinyl chloride (rigid) (PVC)	45-49
Silicone rubber	30.0
Polyphenylene oxide	28-29
Polycarbonate	26-28
Nylon	23-26
Polyvinyl fluoride	22.6
Polyethylene Tetra phthalate	22-26
Polyvinyl alcohol	21.6-22.5
Phenolic resin	21.0
Epoxy resin	19.8
Polyester resin	18.9
ABS co-polymer	18.3-18.8
Polystyrene	17.6-18.3
Polypropylene	17.5-18.0
Polymethyl methacrylate	17.3
Natural rubber	17.2
Polyurethane foam	16.5

Constants

F = Faraday Constant = 96485 C mol^{-1}

R = gas constant = $8.314 \text{ J mol}^{-1} \text{ K}$

List of equations

Mechanical Testing

Engineering Stress $\sigma = \frac{F}{A_0}$

Engineering Strain $\varepsilon = \frac{l-l_0}{l_0}$

Young's Modulus (E) $\sigma = E\varepsilon$

Proof Strain $\% \varepsilon = \frac{l-l_0}{l_0} \times 100$

Percent Elongation $\%EL = \frac{l_f-l_0}{l_0}$

Percent reduction in area $\%RA = \frac{A_f-A_0}{A_0}$

Resilience $U = \int_0^{\varepsilon_y} \sigma d\varepsilon = \frac{\sigma_y^2}{2E}$

Shear Stress $\tau = \frac{16T}{\pi d^3}$

Shear Strain $\gamma = \frac{r\theta}{L}$

Shear Modulus, G, $\tau = G\gamma$

Poisson's ratio $\nu = -\frac{\varepsilon_x}{\varepsilon_z} = -\frac{\varepsilon_y}{\varepsilon_z}$

$E = 2G(1+\nu)$

Three-point bend rectangular cross section $\sigma_{fs} = \frac{3F_f L}{2bd^2}$

Three-point bend circular cross section $\sigma_{fs} = \frac{F_f L}{\pi r^3}$

$$\text{Strain rate } \dot{\varepsilon} = \frac{d\varepsilon}{dt} = \dot{\varepsilon} = A_2 \sigma^n \exp\left(-\frac{Q_c}{RT}\right)$$

Corrosion

$$\Delta G_{\text{cell}} = -nFE_{\text{cell}}$$

$$E_{\text{cell}} = E_{\text{cathode}} - E_{\text{anode}}$$

$$E = E^{\circ} - \frac{RT}{nF} \ln Q$$

Other

$$\eta = 1 - \frac{T_C}{T_H}$$