Loughborough University

MATERIALS IN SERVICE
(23MPB313)

Semester 1 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).

Answer ALL THREE questions.

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1. A ceramic nanoparticle reinforced steel matrix composite is to be employed for nuclear applications, such as the first wall and blanket materials.

   (a) Suggest a possible ceramic dispersoid and provide four reasons why your suggestion is suitable for this application. [5]

   (b) Could melt stirring be used to produce the above composite? Justify your answer. [4]

   (c) For the composite, provide a schematic illustration and give full details of:

      (i) the strengthening mechanism. [7]

      (ii) the mechanism that leads to its radiation resistance. [4]

2. (a) Why is initial inspection of a defect/failure needed before any NDT is carried out?
   Hint: In your answer include the types of inspection that could be carried out prior to NDT and what information is needed. [5]

   (b) Several large steel rods are in service in a die casting machine. One of these breaks and is removed from the machine to be inspected.
   The fracture surface is shown in Figure Q2.

      (i) What kind of failure is demonstrated by the rod? Explain your answer. [2]

      (ii) Suggest a suitable NDT technique to test the remaining rods in-service and give the main advantages of your chosen technique for this component. [3]

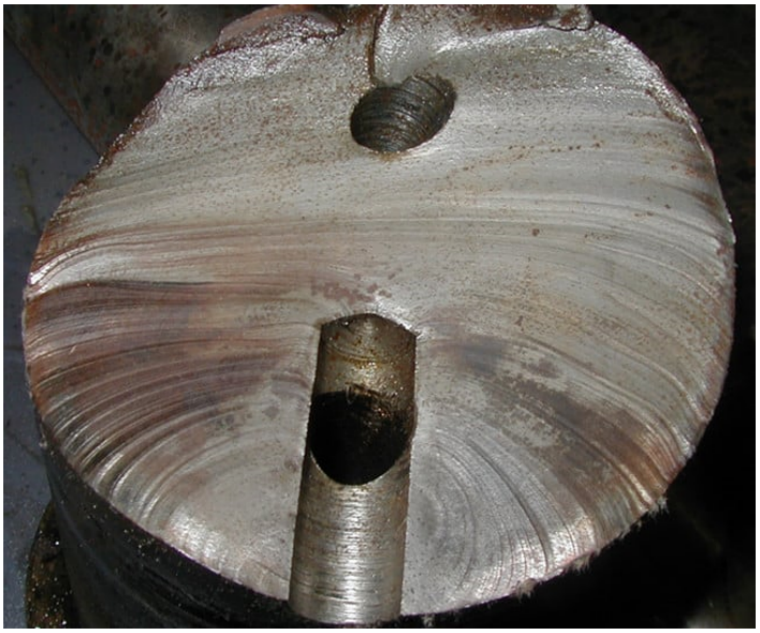

Figure Q2.

(c) It is important to know the Limiting Oxygen Index (LOI) of polymers when choosing suitable materials for a given application. Explain what the LOI of a polymer is. [1]

(d) Given that air contains ∼20.95% oxygen and using Table Q2 below, explain which of these polymers would be classed as:

(i) A flame retardant. [3]

(ii) Self-extinguishing. [2]

Polymer	LOI (%)
Polytetrafluoroethylene (PTFE)	95
Polyvinyl alcohol (PVA)	21.6-22.5
Polymethylmethacrylate (PMMA)	17.3

Table Q2

(e) Stating a specific example, explain why T_g is an important factor to consider when choosing a polymer for a particular application. [2]

(f) Biodegradation of a polymer can be defined by its breakdown into lower molecular weight fragments by the action of naturally occurring organisms. Choose one of the following applications and state whether biodegradation would be an advantage or a disadvantage, explaining your reasoning.

(i) Single use food packaging.

(ii) A wind turbine. [2 for either]

3. (a) Two large brass alloy plates are to be riveted together with mild steel rivets and the assembly exposed to a sea water environment. You are asked to comment on this design and decide that it is not advisable.
From the galvanic series, the electrode potential for the brass alloy is $-0.35\,\text{V}$ and the mild steel is $-0.65\,\text{V}$.

(i) Explain what type of corrosion may be expected and why the design may make the assembly susceptible to failure due to corrosion. [2]

(ii) If the design cannot be changed, explain how the assembly could be protected from corrosion. [2]

(b) A 6000 series Al-Mg-Si alloy is modified with additions of Ni and the resulting microstructure contains Al_3Ni and Mg_2Si second phase particles in the α-Al matrix. Using the electrode potentials in Table Q3, describe how these particles would influence aqueous corrosion. You may assume that any surface passive layer is broken down in regions adjacent to the particles. [4]

Phase	Electrode Potential (V)
α-Al matrix	-0.635
Al_3Ni	-0.479
Mg_2Si	-0.918

Table Q3.

(c) For aqueous corrosion of a metal in sea water, use the Nernst equation given below in Equation 1 to show that regions depleted in oxygen will be anodic relative to the metal exposed to the bulk solution.
The cathode reaction is:

$O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^-$ $(E^0 = 1.228\,\text{V})$.

Take the pH of the sea water to be 7 and the concentration of O_2 to be $4.5\times10^{-4}\,\text{M}$ in the bulk solution and $2.75\times10^{-5}\,\text{M}$ in the depleted region. [7]

(d) Briefly explain the mechanisms that give rise to corrosion in a region that can become depleted in oxygen. [5]

Equations and data:

$$E = E^0 - \frac{2.303RT}{nF}\log Q \qquad \text{(Equation 1)}$$

R is the gas constant $= 8.314\,\text{J mol}^{-1}\,\text{K}^{-1}$. The temperature is 298.15 K. F is the Faraday constant $= 96\,485\,\text{C mol}^{-1}$.
$\text{pOH} = -\log[OH^-]$ and $\text{pOH} = 14 - \text{pH}$