Question 1

(a) Use your knowledge of metals processing to explain how a metallic body panel for use as an aircraft skin is made. Your answer should explain why casting is not a suitable manufacturing route. [11 marks]

(b) Explain why it is desirable to use small-diameter rolls for the production of sheet metals? [6 marks]

(c) If a steel plate were to be rolled and reduced in thickness from 0.40m to 0.35m in a single pass, what would be the maximum roll radius if the forming pressure were to be kept below 400 MPa? Assume the yield stress of the steel sheet is 200 MPa and the following equation applies:

\[ p_{\text{max}} = \sigma_y \left( 1 + \frac{w}{2d} \right) \]

where:
- \( p_{\text{max}} \) = maximum forming pressure,
- \( \sigma_y \) = yield stress of the steel,
- \( w \) = width of section under forming pressure and
- \( d \) = final thickness. [5 marks]

(d) A design requirement for the roll mill will be to ensure that the rollers exhibit a minimum deflection. How might this requirement be satisfied in practice if small diameter and hence flexible rolls are to be used? [3 marks]

Question 2

(a) Sketch typical stress-strain curves for each of the following materials:
- (i) metals,
- (ii) ceramics,
- (iii) polymers,
- (iv) elastomers. [4 \( \times \) 2 marks = 8 marks]

(b) Using key features of these stress-strain curves, contrast the relative mechanical properties of each type of material, making specific reference to their elastic modulus, strength, processing requirements and the operating environments that they can withstand. [9 marks]

(c) Discuss with examples the importance of these properties in determining end use for two engineering applications of each material. [8 marks]
Question 3

Thrust deflectors and reversers on aircraft engines are controlled by hydraulic actuators. The forces required to reverse thrust can be large, so the actuators (of which each engine may have four) are heavy. One of the heavier parts is the piston rod, identified in Figure Q6. It carries axial compressive loads only, and is designed as a hollow tube, to save weight. The cross section is chosen to carry the loads without compressive failure or buckling.

![Figure Q6. A piston rod](image)

The main objective is to minimise the weight. The length $L$ and the outer radius $R$ are specified. The piston rod must transmit a maximum axial force $F$, it must not fail by yielding in compression or by elastic buckling and it should operate at a temperature up to $300^\circ$C. The piston rod as a thin-walled tube of wall thickness $t$.

(a) Derive the equation for the mass of the rod. [2 marks]

(b) What is the failure criterion for a yield failure? [2 marks]

(c) By eliminating the wall thickness from your equations, calculate the mass of the piston rod and derive the material performance index $M_1$ for this minimum mass constraint. [4 marks]

(d) Buckling occurs when an axially-loaded strut is compressed by force $F = \pi^2 E I / L^2$ where $I$ is given by $I = \pi R^4 t$ for a cylinder. Calculate an alternative material performance index $M_2$ for a minimum mass strut that will not buckle under load. [4 marks]

(e) Draw lines on the appropriate graphs that are attached to the examination paper using both derived performance indices $M_1$ and $M_2$ and use the lines to identify the most suitable materials. (Ensure that you attach the annotated graphs you have used to your answer booklet.) [6 marks]

(f) Create a table for the four selected materials; include the values of the performance indices and comments on their suitability. [7 marks]
Question 4

(a) What is meant by the yield strength of a material?  [4 marks]

(b) Some ductile metals have the yield behaviour defined using a 0.1% proof yield stress. Using a sketch of the stress versus strain behaviour, define the 0.1% proof yield stress.  [4 marks]

(c) Describe the mechanisms that allow a metal to yield. Explain why the crystal structure of a metal is important in determining its ability to yield.  [11 marks]

(d) Identify three ways in which a metal can be strengthened and explain how the increase in strength is achieved in each case.  [6 marks]

Question 5

(a) What is meant by the term fatigue when applied to the failure of engineering materials?  [4 marks]

(b) Identify the key variables in fatigue loading that control the number of cycles before failure for a component.  [4 marks]

(c) Use a diagram showing the relationship between the stress range and the number of cycles to failure to define Basquin’s law and to illustrate the difference between high and low cycle fatigue. What relationship can be used to characterise low cycle fatigue when Basquin’s law does not apply?  [8 marks]

(d) A thick cast iron plate with an inherent crack 10mm long is subjected to tensile stresses that fluctuate from zero to 15MPa. Under these conditions, the crack will grow such that the increase in crack length per cycle, da/dN is given by 

\[ A\sigma^4\pi^2a^{-2} \]

where

\[ a = \text{crack length} \]
\[ N = \text{number of cycles} \]
\[ A = \text{constant} = 2.1 \times 10^{-32} \text{m(Nm}^{3/2})^{-4} \]

Calculate the number of cycles to failure.  [9 marks]
Question 6

(a) Identify five different favourable material properties of ceramics and briefly explain why each makes the selection of a ceramic preferable for a particular modern engineering application. [5 marks]

(b) Ceramics are commonly divided up into the following three groups:

   engineering ceramics,
   electrical ceramics, and
   bioceramics.

Identify specific ceramics that fit into each group and the types of application for which each can be used. [6 marks]

(c) A typical ceramic processing route involves: powder formation, powder compaction and a final sintering procedure. Explain why it is important to have a range of small particle sizes prior to compaction in order to ensure reliable final sintered components. [8 marks]

(d) Discuss the types of transport mechanisms that are present for vapour phase sintering, and for solid state sintering. Identify the driving energy for both and describe the change in volume of the sintered product caused by each process. [6 marks]
Information Sheet 2 (To be handed in with the exam script)