UNIVERSITI
TEKNOLOGI
PETRONAS

FINAL EXAMINATION
MAY 2024 SEMESTER

COURSE	**:**	**BBM5123 – ENGINEERING MATERIALS FUNDAMENTALS AND SELECTION**
DATE	**:**	**4 AUGUST 2024 (SUNDAY)**
TIME	**:**	**2:30 PM – 5:30 PM (3 HOURS)**

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

Note :

i. There are **NINE (9)** printed pages in this **double-sided** Question Booklet including the cover page and appendices.

1. Consider a cylindrical Liquified Natural Gas (LNG) tank made of a high-strength steel alloy, as illustrated in **FIGURE Q1**. The internal pressure of the tank is 12 MPa, which induces hoop (σ_h) and longitudinal (σ_l) stresses in the wall of the tank. The tank has an inner radius of 0.5 meters and a wall thickness of 0.05 meters. During an inspection, a semi-elliptical surface crack was detected on the inner surface of the tank. The length of elliptical crack was 0.01 meters, and the fracture toughness of steel is 30 MPa $\sqrt{m}$. The dimensionless constant Y is 1.2.

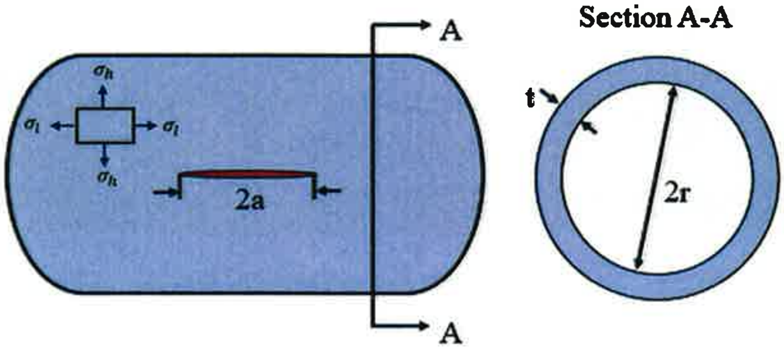


FIGURE Q1

a. Assess whether the crack will propagate in tank under these operating conditions. Justify your answer.

[7 marks]

b. Estimate the critical internal pressure that the tank can sustain without failure.

[6 marks]

c. Comment on the significance of fracture toughness, critical crack length and internal pressure in the context of LNG tank safety and inspection practices. Justify your answer.

[12 marks]

2. The turbine blade was manufactured using a steel alloy by conventional casting technique and has been used for three years without any inspection to observe its condition. The safe lifetime of the blade can be estimated by using the Larson-Miller parameter diagram as shown in **FIGURE Q2** and is defined by $P(Larsen - Miller) = T(20 + \log t_r)$.

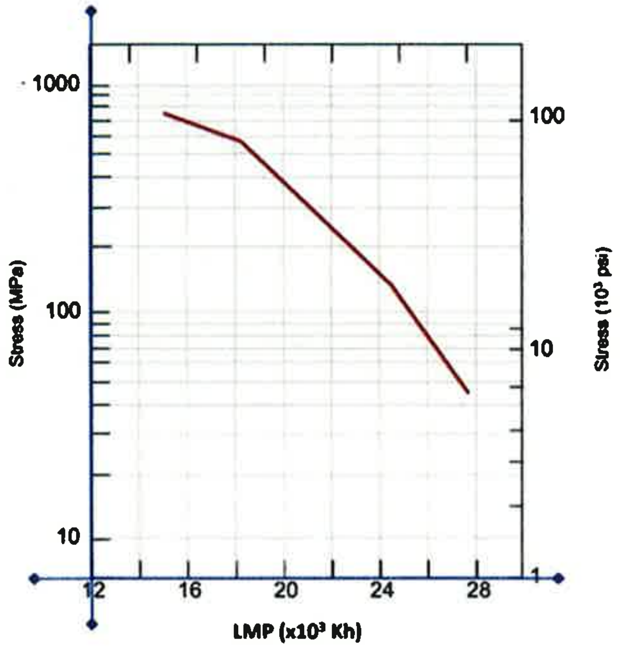


FIGURE Q2

a. Determine the time to rupture (in hours) of the blade if it was designed to operate at the constant stress level and temperature of 80 MPa and 700°C, respectively. Discuss the significance of the calculated creep rupture time for the turbine blade and its implications for material selection and design. Justify your answer.

[15 marks]

b. Propose suitable methods to mitigate the creep behaviour of turbine blade. Discuss the effectiveness of these methods, considering cost, complexity, and long-term sustainability. Justify your answer.

[10 marks]

3. a. A chemical processing plant uses stainless steel tanks to store acidic solutions. Over time, corrosion is observed around the gaskets and flanges as shown in **FIGURE Q3a**.

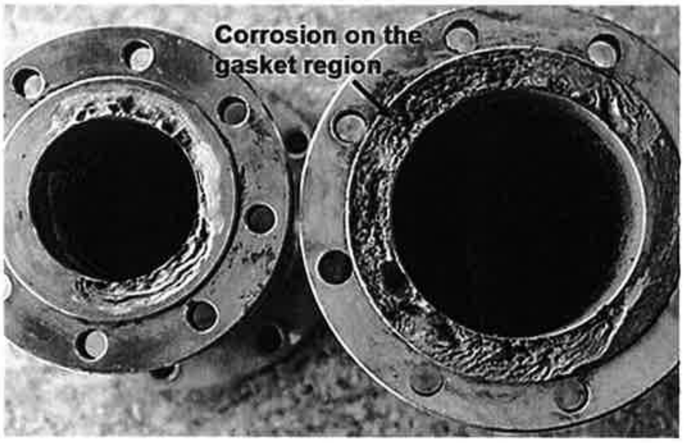


FIGURE Q3a

i. Identify the form of corrosion and discuss how the design of gaskets and flanges could influence the corrosion issue.

[6 marks]

ii. Suggest **TWO (2)** suitable corrosion prevention techniques for this type of corrosion. Justify your answer.

[6 marks]

b. Propose a suitable ceramic material for turbine blade applications and discuss the mechanisms leading to its structural failure.

[5 marks]

c. Polymer-based splint casting (as shown in **FIGURE Q3b**) involves utilizing properties like heating, softening, molding, cooling, and solidification. Select a suitable polymer for the splint casting process and design. Justify the softening and molding mechanisms employed in splint casting.

[8 marks]

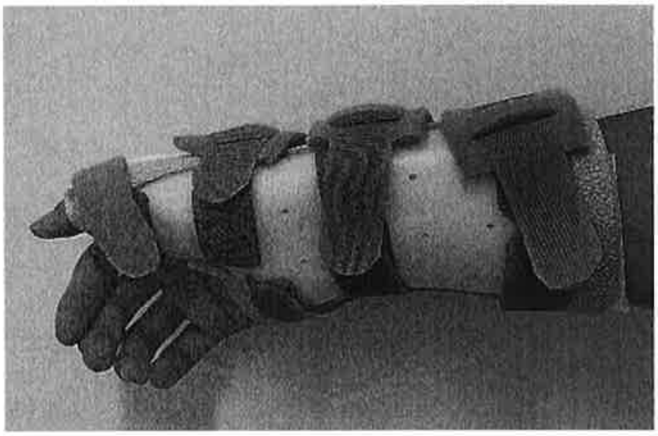


FIGURE Q3b

4. As a design engineer at a pressure vessel manufacturing company TESRO, Malaysia. You are tasked to design a safe pressure vessel to ensure it leaks before it fractures. This allows for the detection of the leak and the subsequent release of pressure. To achieve this, the vessel must be designed to withstand a crack with a length equal to the thickness *t* of the pressure vessel wall without failing due to rapid fracture. The safe pressure *P* is then determined based on this design criterion.

$$P \leq \frac{4}{\pi}\,\frac{1}{R}\left(\frac{K^2{}_{1c}}{\sigma_f}\right)$$

where σ_f is the elastic limit, K_{1c} is the fracture toughness, R is the vessel radius. The pressure M is maximized by choosing the material with the greatest value of

$$M = \frac{K^2{}_{1c}}{\sigma_y}$$

where σ_y represents the yield strength of the material, which is the stress at which a material begins to deform plastically.

a. Clarify the comprehensive material selection process for designing a secure pressure vessel, specifying your assumptions and providing justification for each decision.

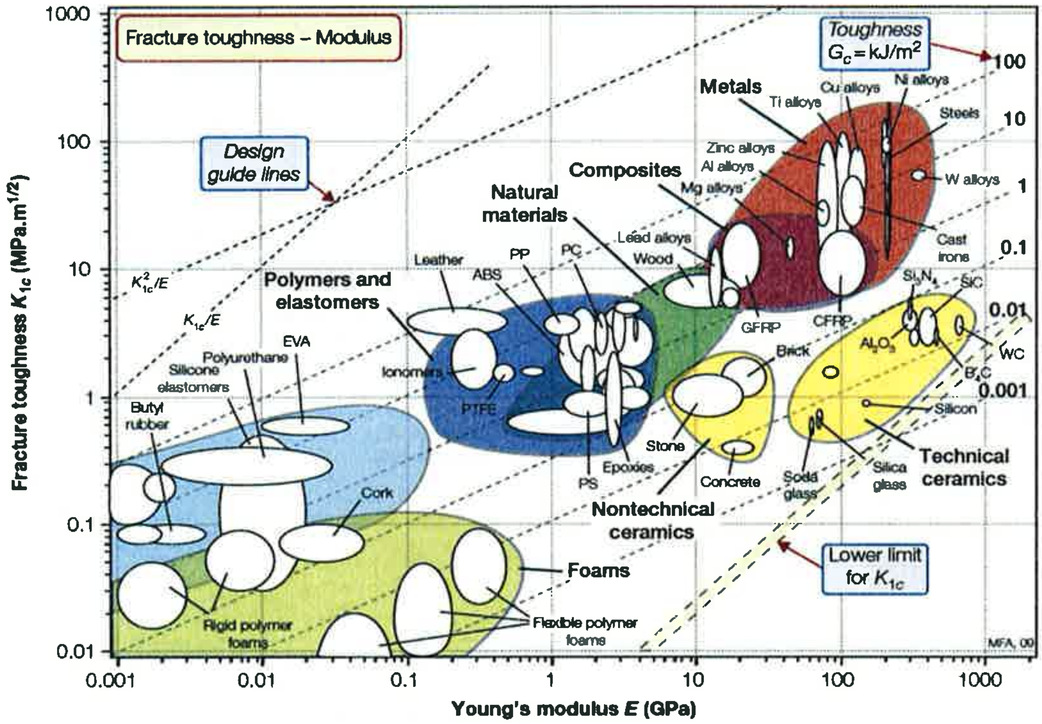
[15 marks]

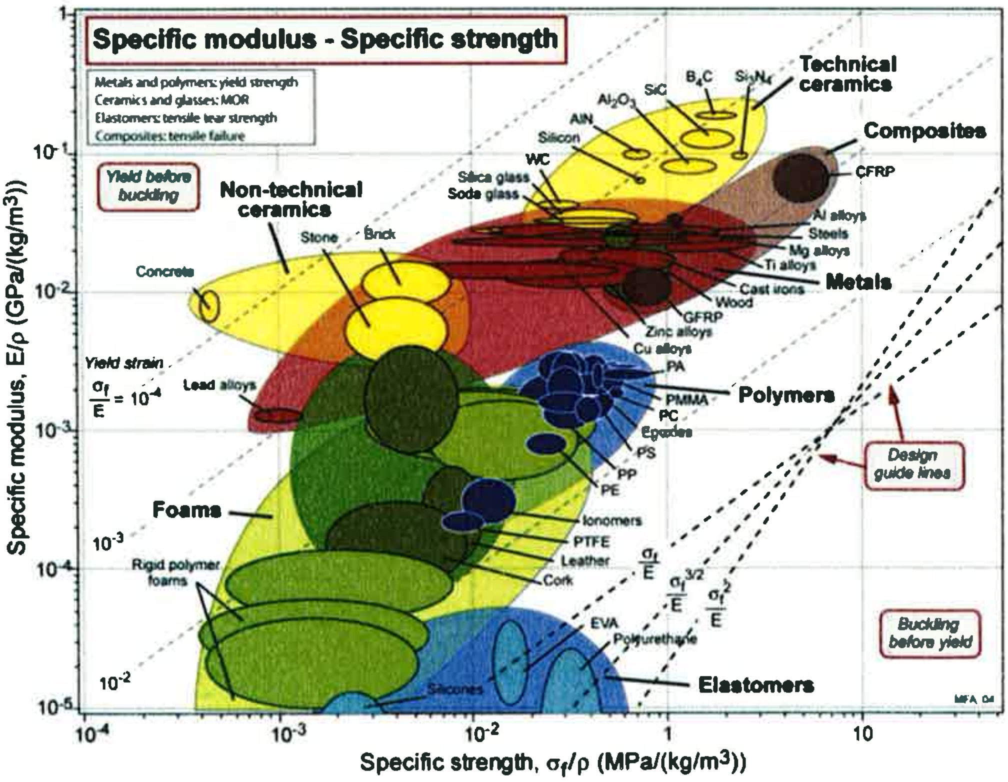
b. Propose **FOUR (4)** suitable material (s) that have particularly high values of *M* for the design of a safe pressure vessel using the appropriate Ashby Charts given in **APPENDIX A**. Justify your choices of materials.

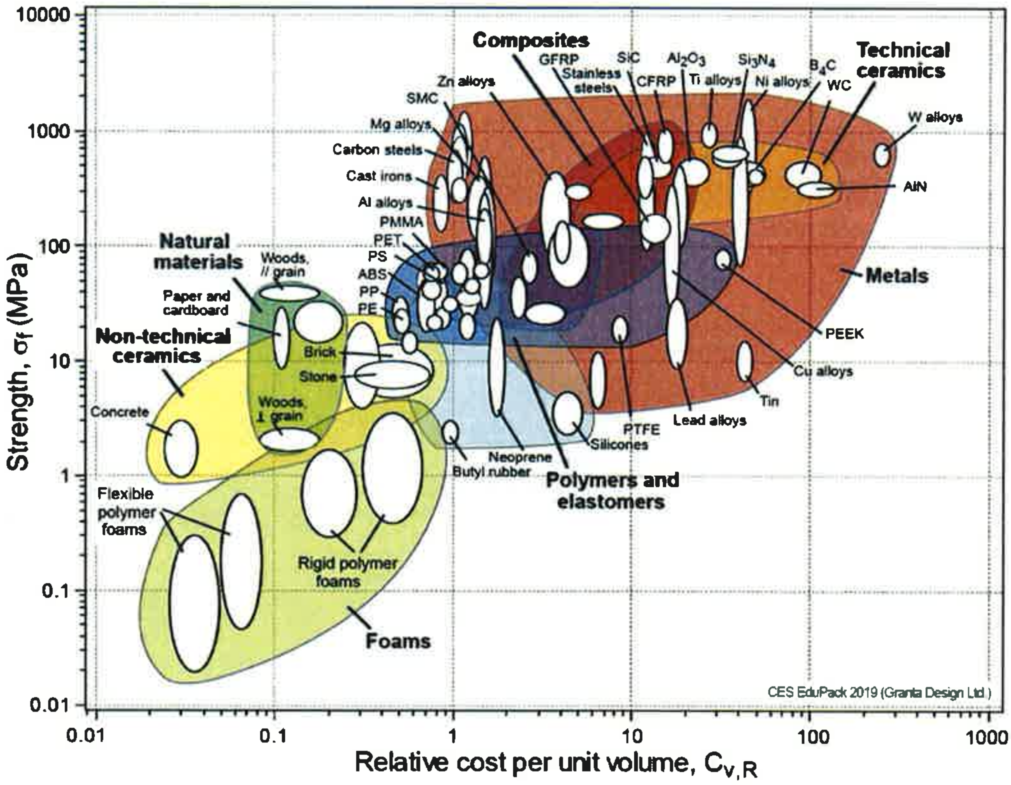
[10 marks]

- END OF PAPER -

APPENDIX A


Fracture toughness – Modulus
Toughness G_c = kJ/m²
Design guide lines
Metals
Composites
Natural materials
Polymers and elastomers
Technical ceramics
Nontechnical ceramics
Foams
Lower limit for K_{1c}
Fracture toughness K_{1c} (MPa.m^1/2)
Young's modulus E (GPa)


Specific modulus - Specific strength
Metals and polymers: yield strength
Ceramics and glasses: MOR
Elastomers: tensile tear strength
Composites: tensile failure
Yield before buckling
Technical ceramics
Composites
Non-technical ceramics
Metals
Polymers
Foams
Elastomers
Design guide lines
Buckling before yield
Specific modulus, E/ρ (GPa/(kg/m³))
Specific strength, σ_f/ρ (MPa/(kg/m³))



Equations and properties

$$HB = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$$

$$\begin{Bmatrix} HRA \\ HRC \\ HDR \end{Bmatrix} = 100 - 500t$$

$$HV = \frac{1.854P}{L^2}$$

$$\begin{Bmatrix} HRB \\ HRF \\ HDG \end{Bmatrix} = 130 - 500t$$

$$HK = \frac{14.2P}{L^2}$$

$$u_r = \frac{1}{2}\sigma_{pl}\varepsilon_{pl} = \frac{{\sigma_{pl}}^2}{2E}$$

$$FS = \frac{3FL}{2bd^2}$$

$$FS = \frac{FL}{\pi R^3}$$

$$FM = \frac{FL^3}{4bd^3\delta}$$

$$FM = \frac{FL^3}{12\pi R^4\delta}$$

$$u_t \approx \frac{\sigma_{YS} + \sigma_u}{2}\varepsilon_f$$ for ductile materials

$$\sigma = \frac{F}{A}$$

$$u_t \approx \frac{2}{3}\sigma_u\varepsilon_u$$ for brittle materials

$$\sigma = E\varepsilon$$

$$v = -\frac{\varepsilon_y}{\varepsilon_x}$$

$$N = \frac{\sigma_{max}}{\sigma_{allowable}}$$

$$\sigma_h = \frac{p\,r}{t} \qquad \sigma_l = \frac{p\,r}{2t}$$

$\sigma_c = \dfrac{K_{Ic}}{Y\sqrt{\pi a}}$	Design (or critical) stress
$a_c = \dfrac{1}{\pi}\left(\dfrac{K_{Ic}}{\sigma Y}\right)^2$	Maximum allowable flaw size
$\sigma_m = \dfrac{\sigma_{\max} + \sigma_{\min}}{2}$	Mean stress (fatigue tests)
$\sigma_r = \sigma_{\max} - \sigma_{\min}$	Range of stress (fatigue tests)
$\sigma_a = \dfrac{\sigma_{\max} - \sigma_{\min}}{2}$	Stress amplitude (fatigue tests)
$R = \dfrac{\sigma_{\min}}{\sigma_{\max}}$	Stress ratio (fatigue tests)
$\sigma = \alpha_l E \Delta T$	Thermal stress
$\dot{\epsilon}_s = K_1 \sigma^n$	Steady-state creep rate (constant temperature)
$\dot{\epsilon}_s = K_2 \sigma^n \exp\left(-\dfrac{Q_c}{RT}\right)$	Steady-state creep rate
$T(C + \log t_r)$	Larson–Miller parameter