

UNIVERSITY OF GREATER MANCHESTER

**SCHOOL OF ENGINEERING AND BUILT
ENVIRONMENT**

B.ENG (HONS) MECHANICAL ENGINEERING

SEMESTER ONE EXAMINATION 2025/2026

ADVANCED MATERIALS & STRUCTURES

MODULE NO: AME6012

Date: Monday 12th January 2026

Time: 10am – 1pm

INSTRUCTIONS TO CANDIDATES:

There are FIVE questions.

Attempt any FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

Electronic calculators may be used provided that data and program storage memory is cleared prior to the examination.

CANDIDATES REQUIRE:

Formula Sheet (attached).

Q1.

a) A finite element analysis of an aluminium extrusion calculated the following stresses at one of the Gauss points: Direct stresses: $\sigma_x = 160$ MPa tension, $\sigma_y = 85$ MPa tensile and $\sigma_z = 75$ MPa compressive accompanied by two shear stresses: $\tau_{xy} = 45$ MPa and $\tau_{yz} = 55$ MPa. Using this information:

(i) Sketch the elemental cube representing the state of stress at this point. **(3 marks)**

(ii) Show that the characteristic equation representing the state of stress at this point is given as: $\sigma^3 - 170\sigma^2 - 9825\sigma + 1352125 = 0$ and show the largest stress acting at this point is 183 MPa to within $\pm 1\%$. **(7 marks)**

(iii) Calculate direction of the largest stress and show this by a simple sketch. **(3 marks)**

b) If the yield stress of the material is 450 MPa determine the factor of safety (FOS) at this point based upon a suitable yield criteria stating any assumptions you have made assuming the other principal stress at this point are 93 MPa in compression and 79 MPa in tension. **(5 marks)**

c) The component was manufactured by extrusion along the x direction producing a 40% increase in the yield strength in this direction Explain how this would influence the choice of yield criteria and estimate the new FOS based upon a suitable new yield criteria. State your assumptions. **(7 marks)**

(Total 25 marks)

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Q2.

- a) Part of a docks crane is immersed in the water and is fabricated from surface coated high strength steel with the properties given in Table Q2. The supporting leg is subjected to cyclic stresses ranging from 250MPa tensile to 140MPa compressive approximately every 60 minutes for 12 hours per day. The leg however is susceptible to cracks on the outside edge if damaged and therefore is monitored regularly; however, the equipment used can only detect cracks larger than 2mm.

Using the above information and the material data in table Q2, determine the time taken for the crack to grow to 5mm.

(10 marks)

Table Q2	
Yield Strength	790 MPa
Young's Modulus	208 GPa
Poisson's Ratio	0.32
Fracture toughness	88 MPa.m ^{0.5}
Paris coefficients M & C	3.2 & 1.2x10 ⁻¹²
Shape factor Y	1.12

- b) Also estimate how much longer life the leg has under these condition.

(4 marks)

- c) If the material could potentially yield at the crack tip describe briefly how you could approach the crack growth expressions to take aspects of tip plasticity into account and estimate the potential increase in time to failure. State any assumptions you have made.

(7 marks)

- d) Explain briefly why this estimate is conservative and what other factors could be considered to improve the life predictions

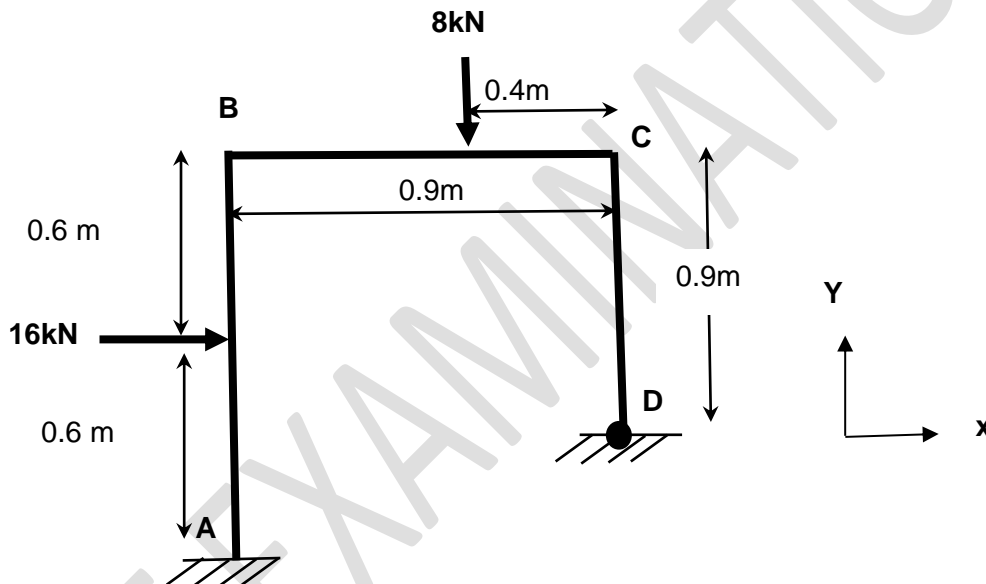
(4 marks)**(Total 25 marks)****PLEASE TURN THE PAGE**

Q3.

- a) Figure Q3 shows schematically a frame representing a ships hoist with a worst case scenario load case consisting of a horizontal load of 16 kN and a vertical load of 8 kN. Joints A, B and D can be assumed to be welded whilst joint D is a safety pin. Use this information to determine a suitable tubular section manufactured from steel with a yield stress of 450 MPa and a factor of safety of 3.

Assume for the analysis the material is rigid-perfectly plastic.

Take Z_p as D^2t where: D is the nominal bore and t the thickness of a tubular section.

(12 marks)**Fig Q3 frame set up**

- b) Based upon your tubing determine a suitable shear pin diameter assume a design shear stress of 250 MPa. State your assumptions.

(9 marks)

- c) Describe and sketch two other material models that could be used in place of the rigid perfectly plastic behaviour stating in each case whether they would produce a higher or lower factor of safety and why this is the case.

(4 marks)**(Total 25 marks)****PLEASE TURN THE PAGE**

Q4.

- a) A high-performance aerospace component with rectangular cross-section is to be manufactured from a 0/90 woven hybrid reinforcement consisting of high modulus Kevlar® fibre and/or carbon fibre with an epoxy matrix with a density of 1.3Tonnes/m³ in the form of a prepreg skin bonded to a 25mm thick ROHACELL® foam core. The foam has a density of 75Kg/m³ and a failure strain of 4%. The component is subject to both flexure and torsion; these loads are shown in **Fig. Q4**. The flexural load could be in the form of low velocity impact in the form of runway debris. Using this information in **Table Q4** determine a suitable layup and wall thickness for the composite and illustrate this by a sketch. Show all your workings and assumptions.

(19 marks)

Fibre Modulus GPa	Fibre Density Kg/m ³	Safe working strain %	Bond strength of skin MPa	Lamina Thickness mm
Carbon 320	1800	0.4	12	0.25
Kevlar 112	1440	0.5	12	0.25

Table Q4

- b) Describe how you would join the ends of the component if was: (i) permanently fixed or (ii) have the ability to be disassembled.

(6 marks)

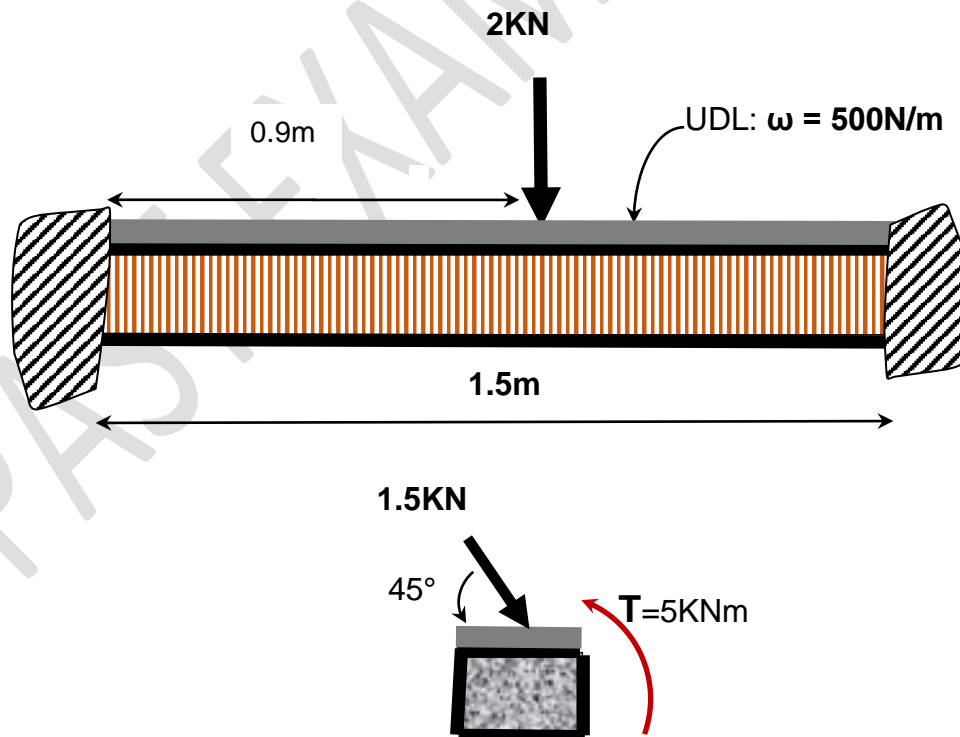


Fig Q4 schematic of the component

(Total 25 marks)

School of Engineering and Built Environment
BEng (Hons) Mechanical Engineering
Semester One Examination 2025/2026
Advanced Materials & Structures
Module No. AME6012

Q5.

a) An aerospace grade titanium alloy link connection is shown in Fig Q5a as well as its S-N curve in Fig Q5c. Take the Young's modulus as 104 GPa and ν as 0.3 for this material. The component is CNC manufactured. It is also expected that the component under its normal usage would be under repeated cyclic loading with a maximum bending moment of 80kNm acting against the thickness dimension with a lower load of 20kNm. A finite element plot of the maximum Principal stress is shown in Fig Q5b. The material has notch sensitivity factor $q = 0.75$, hence, estimate the predicted life of the component under this condition.

(10 marks)

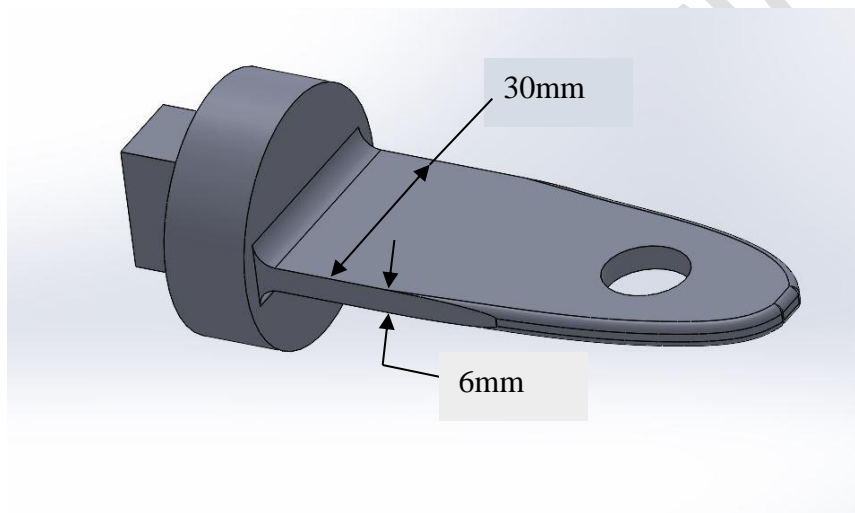


Fig Q5a Schematic of the link

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Question 5 continued

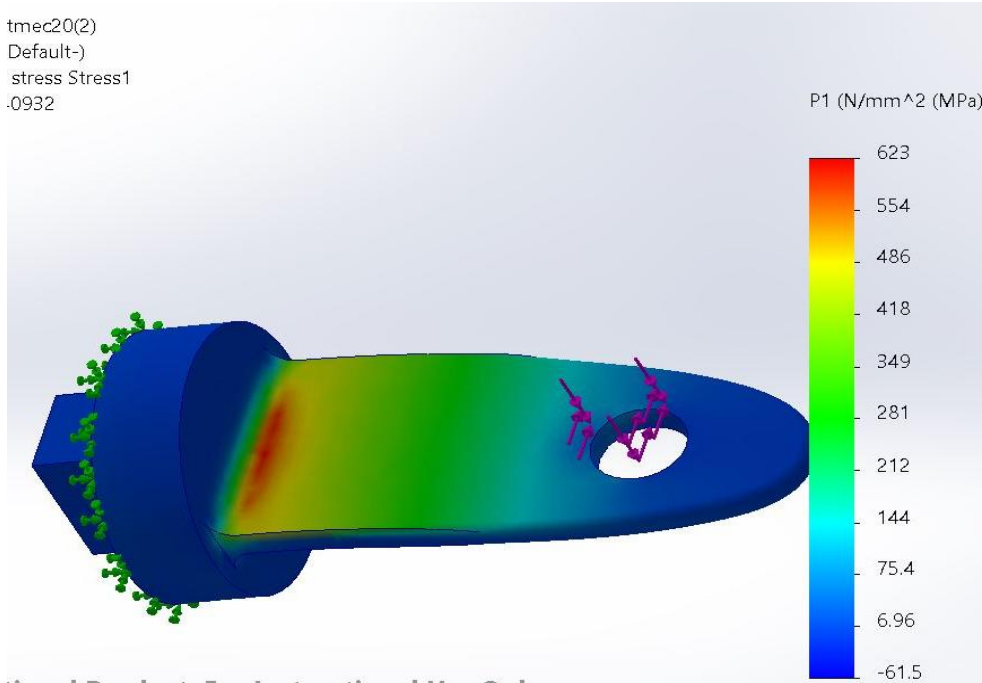


Fig Q5b FEA plot of the Principal stress under an in plane moment of 80KNmm

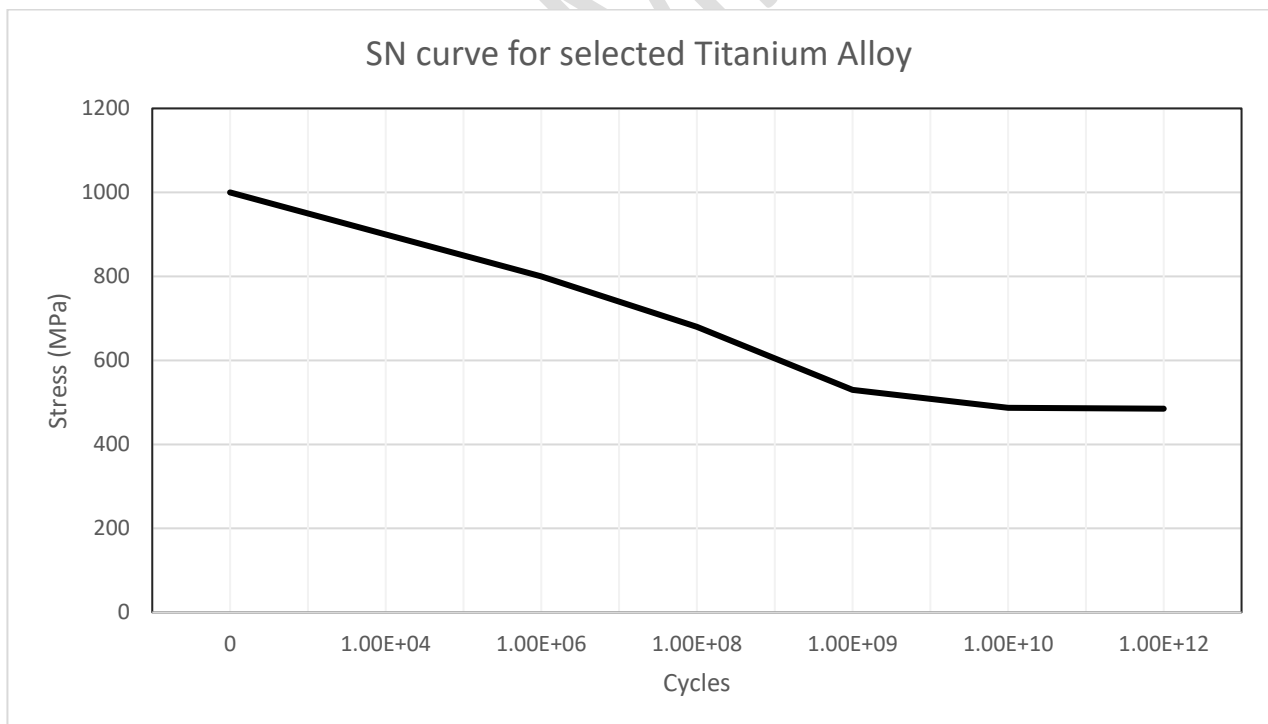


Fig Q5c- S-N Curve for material used, R=-1

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Question 5 continued

- b) Use a suitable mean correction analysis based upon the information given and estimate the change in predicted life of the component

(7 marks)

- c) Further confirmation was achieved using a specialist micro-strain gauge set-up consisting of three gauges in the pattern shown in figure Q5d bonded to the surface at an angle of $\pm 2^\circ$ to the axis of the component. The gauges had a gauge length of 1mm and bonded using a suitable adhesive. The output results under the maximum load condition for the three gauges are given below:

$$\epsilon_0 = 5512 \times 10^{-6} \text{ mm/mm } (0^\circ)$$

$$\epsilon_{45} = 3124 \times 10^{-6} \text{ mm/mm } (45^\circ)$$

$$\epsilon_{90} = -2117 \times 10^{-6} \text{ mm/mm } (90^\circ)$$

Using this data calculate the maximum stress and compare with the predicted stress that was obtained using the finite element method. Explain also why there is a difference between the two results and where the main source of error is likely to occur.

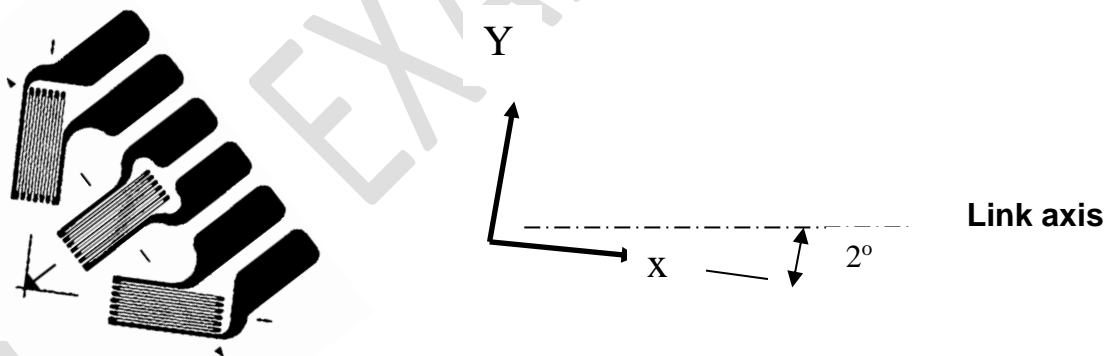
(8 marks)

Fig Q5d Strain Gauge set up

(Total 25 marks)**END OF QUESTIONS****PLEASE TURN THE PGAE FOR FORMULA SHEET**

FORMULA SHEET

Formulae used in Structures and Materials Module

Elasticity – finding the direction vectors

$$\begin{bmatrix} S_x \\ S_y \\ S_z \end{bmatrix} = (\text{Stress Tensor}) \begin{pmatrix} l \\ m \\ n \end{pmatrix}$$

$$k = \frac{1}{\sqrt{a^2 + b^2 + c^2}}$$

Where a, b and c are the co-factors of the eigenvalue stress tensor.

$$\begin{aligned} l &= ak & l &= \cos\alpha, \\ m &= bk & m &= \cos\theta, \\ n &= ck & n &= \cos\varphi. \end{aligned}$$

Principal stresses and Mohr's Circle

$$\tau_{12} = \frac{\sigma_1 - \sigma_2}{2}$$

$$\tau_{13} = \frac{\sigma_1 - \sigma_3}{2}$$

$$\tau_{23} = \frac{\sigma_2 - \sigma_3}{2}$$

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Yield Criterion

Von Mises

$$\sigma_{von\ Mises} = \frac{1}{\sqrt{2}} \left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]^{1/2}$$

Tresca

$$\sigma_3 \geq \sigma_2 \geq \sigma_1$$

$$\sigma_{tresca} = 2 \cdot \tau_{max}$$

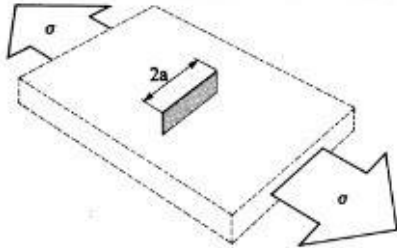
$$\tau_{max} = \max \left(\frac{|\sigma_1 - \sigma_2|}{2}, \frac{|\sigma_1 - \sigma_3|}{2}, \frac{|\sigma_3 - \sigma_2|}{2} \right)$$

$$\frac{\sigma_{von\ Mises}}{\sigma_{Tresca}} = \frac{\sqrt{3}}{2}$$

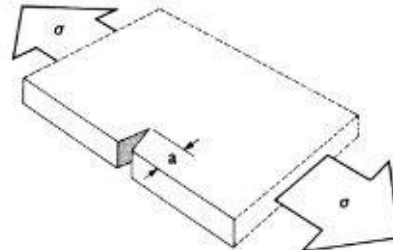
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Fracture mechanics

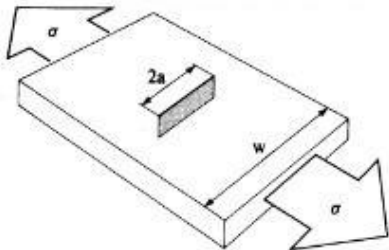
Table: Y values for plates loaded in tension



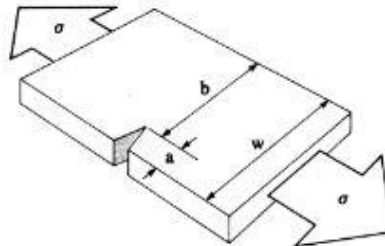
- (1) Through crack of length $2a$ in an *infinite* plate
 $Y = 1$



- (2) Edge crack of length a in an *infinite* plate
 $Y = 1.12$
 Because plane strain and plane stress have identical stress fields, this calibration is also for an edge scratch of depth a on a large body carrying tensile stress σ .

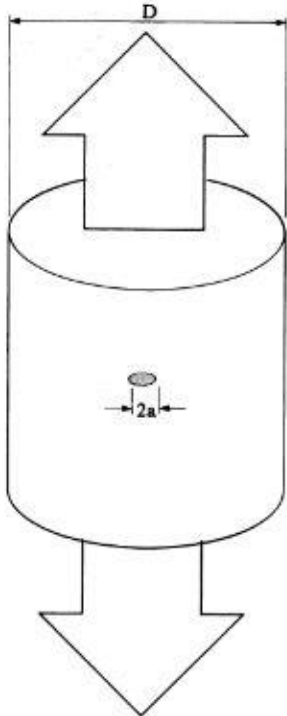


- (3) Through crack of length $2a$ in a plate of width w .
 $Y = \left(\sec \frac{\pi a}{w} \right)^{1/2}, \frac{2a}{w} \leq 0.7$



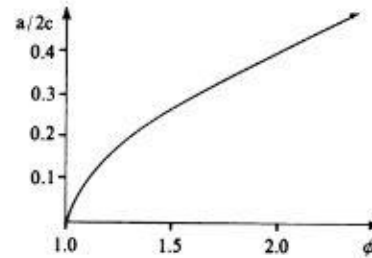
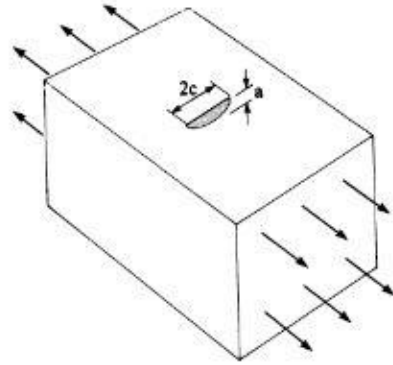
- (4) Edge crack of length a in a plate of width w .
 $Y = 0.265 \left(\frac{b}{w} \right)^4 + \frac{0.875 + 0.265a/w}{(b/w)^{3/2}}$

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(5) Penny-shaped internal crack of radius a .

$$Y = \frac{2}{\pi}, \quad a \ll D$$



(6) Semi-elliptical surface flaw

$$Y = \frac{1.12}{\phi^{1/2}}$$

Life Calculations

$$\frac{da}{dN} = C(\Delta K)^m$$

$$N = \frac{1}{CY^m \sigma_a^m \pi^{\frac{m}{2}} a_0^{\frac{m}{2}}} \int_{a_0}^{a_1} \frac{da}{a^{\frac{m}{2}}}$$

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Composite materials

$$E_{composite} = E_{fibre}V_{fibre} + E_{matrix}(1 - V_{fibre})$$

Fracture Toughness

Table: Fracture toughness of some engineering materials

Material	K_{Ic} (MNm ^{-3/2})	E (GN/m ²)	G_{Ic} (kJ/m ²)
Plain carbon steels	140 - 200	200	100 - 200
High strength steels	30 - 150	200	5 - 110
Low to medium strength steels	10 - 100	200	0.5 - 50
Titanium alloys	30 - 120	120	7 - 120
Aluminium alloys	22 - 33	70	7 - 16
Glass	0.3 - 0.6	70	0.002 - 0.008
Polycrystalline alumina	5	300	0.08
Teak – crack moves across the grain	8	10	6
Concrete	0.4	16	1
PMMA (Perspex)	1.2	4	0.4
Polystyrene	1.7	3	0.01
Polycarbonate (ductile)	1.1	0.02	54
Polycarbonate (brittle)	0.4	0.02	6.7
Epoxy resin	0.8	3	0.2
Fibreglass laminate	10	20	5
Aligned glass fibre composite – crack across fibres	10	35	3
Aligned glass fibre composite – crack down fibres	0.03	10	0.0001
Aligned carbon fibre composite – crack across fibres	20	185	2

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Strain relationships

We know normal strain in any direction (θ) is given by

$$\epsilon_n = \frac{1}{2}(\epsilon_x + \epsilon_y) + \frac{1}{2}(\epsilon_x - \epsilon_y) \cos 2\theta + \frac{\gamma_{xy}}{2} \sin 2\theta$$

where ϵ_x = normal strain at a point in x-direction

ϵ_y = normal strain at a point in y- direction

γ_{xy} = shear strain at a point on x face in y direction

$$\text{2D Strain tensor} = \begin{bmatrix} \epsilon_x & \frac{\gamma_{xy}}{2} \\ \frac{\gamma_{xy}}{2} & \epsilon_y \end{bmatrix}$$

Hooke's Law in 2D

$$\sigma_1 = \frac{E}{(1-\nu^2)}(\epsilon_1 + \nu\epsilon_2)$$

$$\sigma_2 = \frac{E}{(1-\nu^2)}(\epsilon_2 + \nu\epsilon_1)$$

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Related Mathematics

Cubic Equations-General form

$\sigma^3 + F_1 \sigma^2 + F_2 \sigma + F_3 = 0$ where: F_1 , F_2 , & F_3 are constants then the solution has three roots, say a , b & c , giving: $(\sigma-a).(\sigma-b).(\sigma-c) = 0$,

hence,

$$\sigma^3 - \sigma^2 (a+b+c) + \sigma (a+c)b - abc = 0$$

as a general form.

If either a , b or c is known a simple quadratic equation based upon the other two unknowns can be derived and solved.

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Finding determinants using cofactors

Sign of cofactor

$$\begin{bmatrix} + & - & + \\ - & + & - \\ + & - & + \end{bmatrix}$$

$$A = \begin{pmatrix} 2 & 4 & -3 \\ 1 & 0 & 4 \\ 2 & -1 & 2 \end{pmatrix}$$

Find determinants

$$A = \begin{pmatrix} 2 & 4 & -3 \\ 1 & 0 & 4 \\ 2 & -1 & 2 \end{pmatrix}$$

$$2 \begin{vmatrix} 0 & 4 \\ -1 & 2 \end{vmatrix} - 4 \begin{vmatrix} 1 & 4 \\ 2 & 2 \end{vmatrix} - 3 \begin{vmatrix} 1 & 0 \\ 2 & -1 \end{vmatrix}$$

$$2[(0 \times 2) - (-1 \times 4)] - 4[(1 \times 2) - (2 \times 4)] - 3[(1 \times -1) - (0 \times 2)]$$

$$A = \begin{pmatrix} 2 & 4 & -3 \\ 1 & 0 & 4 \\ 2 & -1 & 2 \end{pmatrix}$$

$$8 + 24 + 3 = 35$$

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