[ESS12]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

B.ENG (HONS) MECHANICAL ENGINEERING

SEMESTER ONE EXAMINATION 2019-20

ADVANCED MATERIALS & STRUCTURES

MODULE NO: AME6012

Date: Monday 13th January 2020 **Time: 10:00am - 1:00pm**

INSTRUCTIONS TO CANDIDATES:

- **There are SIX questions.**
- **Answer 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).**

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Q1.

a) A theme park ride structure under the "worst case scenario" is subjected to the following direct stresses in the x, y and z directions: 95 MPa, 120 MPa in tension and 165 MPa in compression respectively. Due to difference riding conditions there are also possibilities of two shear stresses present, one related to xz with a value of 65 MPa and another related to yz with a value of 55 MPa.

(i) Draw the elemental cube showing the stresses acting.

(4 marks)

(ii) Using this information given above show that the largest stress is 190 MPa in compression.

(8 marks)

(iii) Determine the angles relative to xyz co-ordinates this stress acts and make a sketch showing the direction of this stress.

(7 Marks)

(b) If the yield strength of the material in tension is 385 MPa and the material can be approximated by the von Mises yield criterion determine the factor of safety associated with this point in the structure assuming the other two principal stresses are 135 and 104 MPa in tension.

(6 marks)

Total 25 Marks

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Q2.

a) A high-pressure steel container 30mm thick is under cyclic loading every 20 minutes for eight hours per day and six days per week. The container can be susceptible to internal cracks and is therefore inspected every three month. The equipment however is limited to measuring cracks of greater than 2 mm. The steel has the following properties shown in table Q2 below:

Yield Strength	1150 MPa
Fracture toughness	90 MPa.m$^{0.5}$
Paris coefficients M & C	3.0 & 12x10^{-12}
Shape factor Y	1.2

Table Q2

If under load at the point of inspection the container is subjected to an alternating stress of 300 MPa (tension) to 100MPa (compression) during each cycle determine the time taken for the crack to reach 6 mm.

(12 Marks)

b) Determine also the time taken to reach the critical crack length and explain briefly why this is a conservative estimate using the LEFM method.

(10 Marks)

(c) Sketch also the graph of fatigue-crack growth rates da/dN, as a function of the applied stress-intensity range K in metallic materials, identifying the key elements of the graph

(3 marks)
Total 25 Marks
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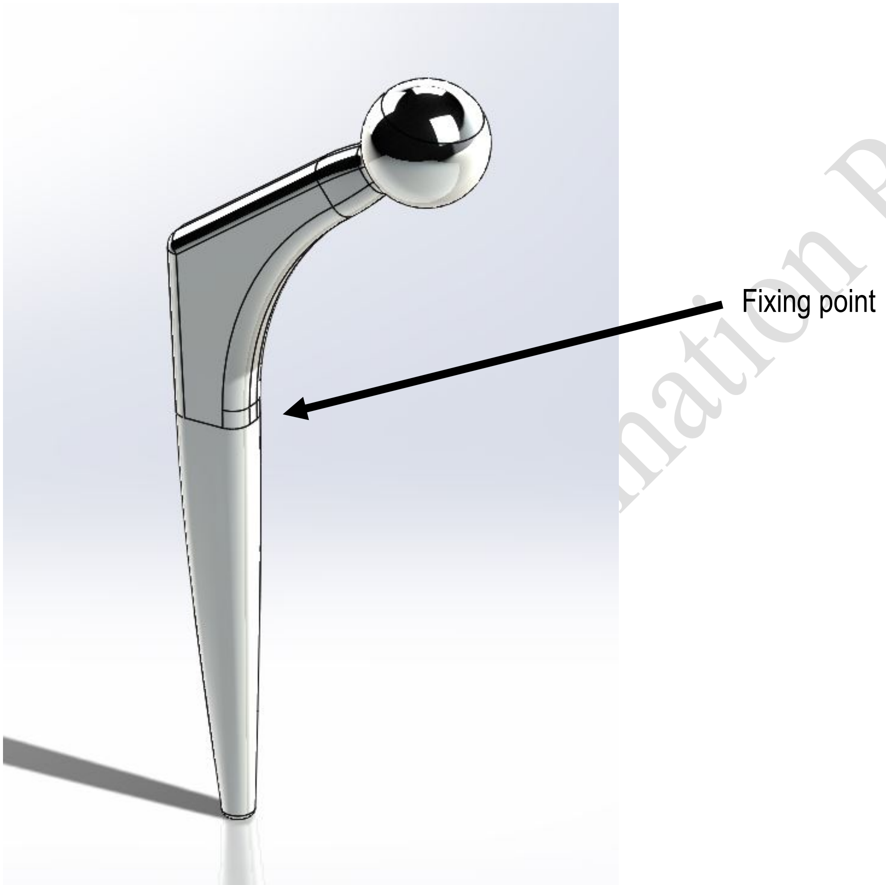
Q3.

a) A hip implant is manufactured from CoCr Mo with a Young's modulus of 104 GPa and a Poisson's ratio of 0.28 is to be tested for future use.
It is also expected that the component under its normal usage would be under repeated cyclic loading. For the shape shown in Fig Q3a the section modulus (Z_{zz}) is 120 mm^3 and cross-sectional area (A_{zz}) is 60mm^2 at the position it is fixed. Using this information determine for a maximum bending moment (M_{zz}) of 36Nm and compressive force of 800N: (i) the induced stress and (ii) the predicted life of the component under this condition along with a lower load of 20Nm for everyday activities.

(10 marks)



<u>Fig Q3a Schematic of the implant</u>

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Q3 continued…

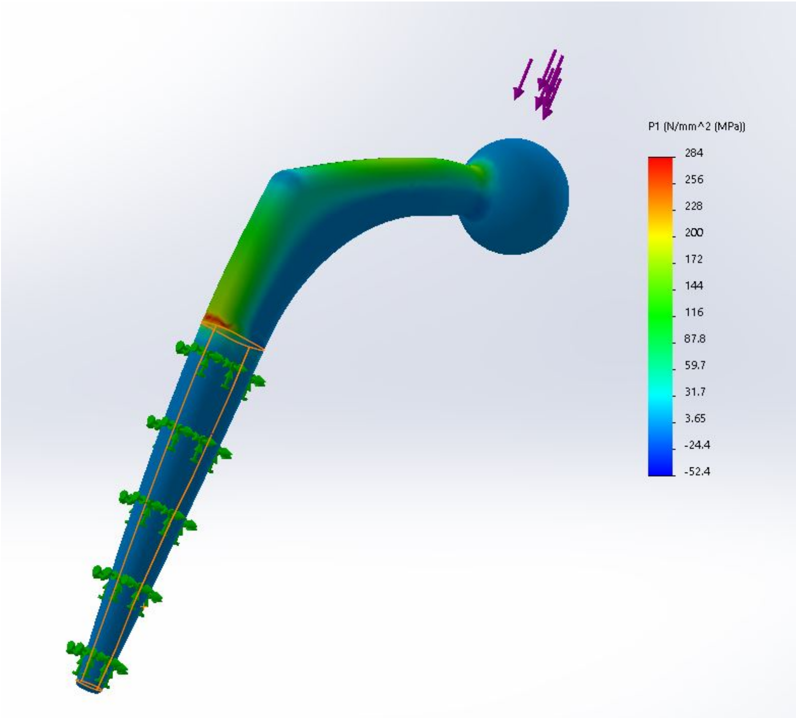

Fig Q3b FEA plot of the Principal stress under an inplane moment of 36Nm

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Q3 continued…

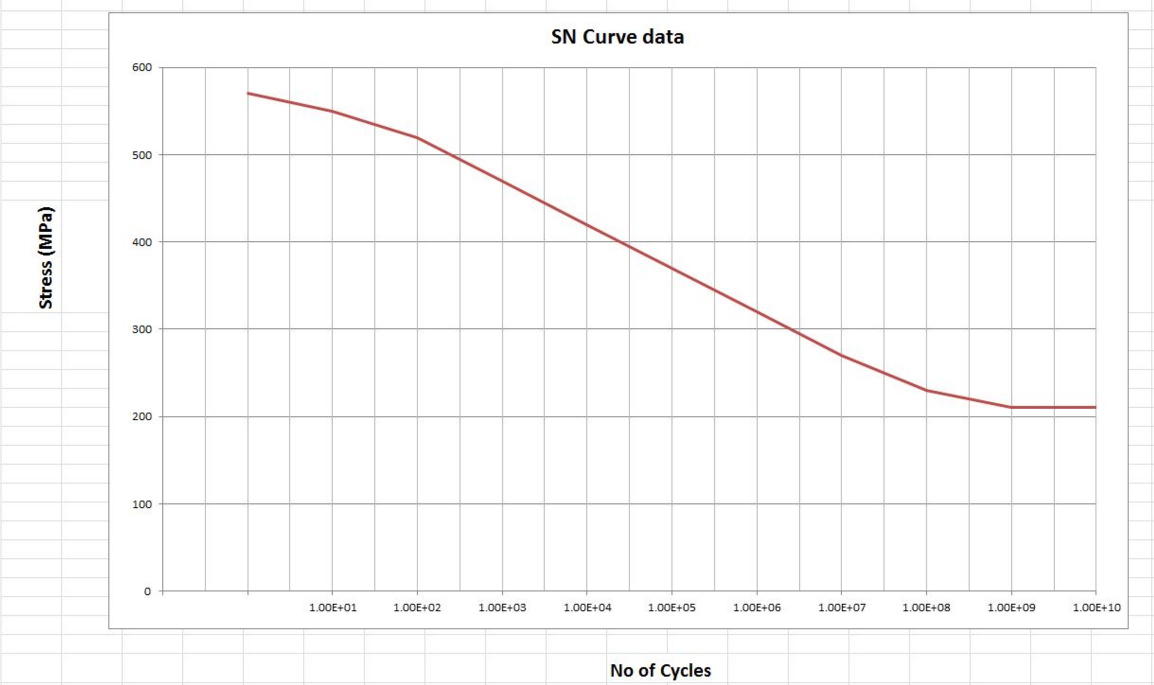

Fig Q3c- S-N Curve for CoCrMo material used.

b) In order to verify the behaviour both finite element analysis and strain gauge techniques were used to evaluate the design. The output from the finite element model is shown in figure Q3b indicating the principal stress values at the position of interest.

Further confirmation was achieved using a strain gauge rosette consisting of three gauges in the pattern shown in figure Q3d bonded to the surface in the region of the fillet at an angle of 5° to the bending axis. The gauges have a gauge length of 3mm and bonded using an epoxy adhesive. The output results under the maximum load condition for the three gauges are given below:

$\varepsilon_x = 2774 \times 10^{-6}$ mm/mm (0°)

$\varepsilon_{xy} = 1006 \times 10^{-6}$ mm/mm (45°) (45°)

$\varepsilon_y = -1236 \times 10^{-6}$ mm/mm (90°) (90°)

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Q3 continued….

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

(15 Marks)

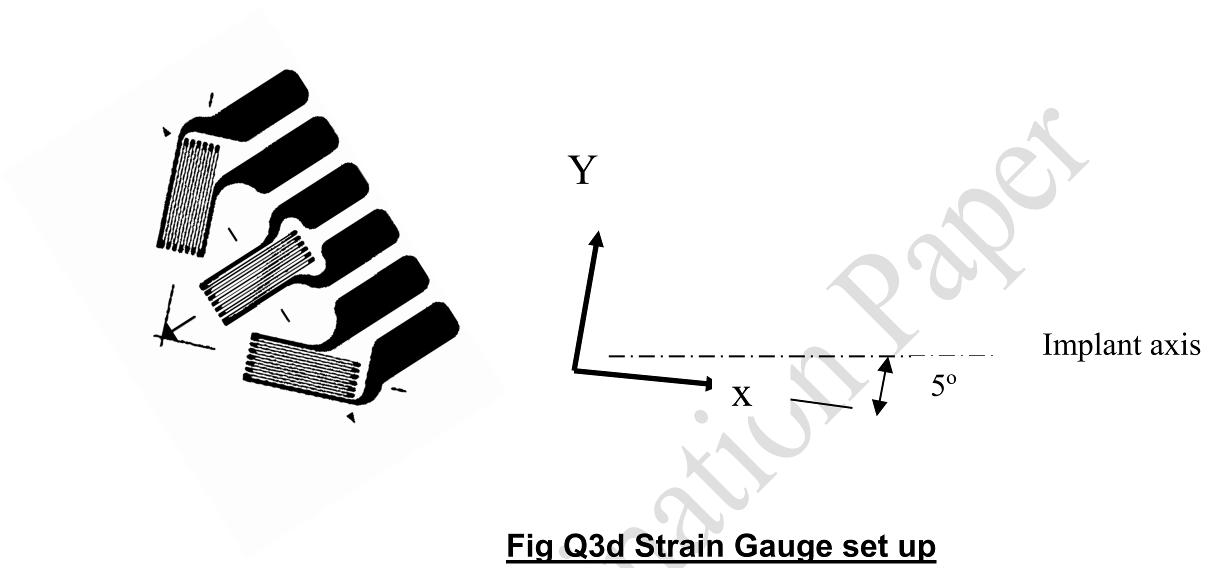

Fig Q3d Strain Gauge set up

Total 25 Mark

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Q4.

(a) An 80 mm wide hollow section beam for a minesweeper is fabricated from glass-reinforced vinylester as shown in fig Q4. The section is used is 3m in length and assumed to be simply supported at each end. The beam needs to support a UDL of 4 KN/m. If the beam is designed to not to exceed the maximum design strain in each material, determine the factor of safety for the beam.

(17 Marks)

(b) Sketch the stress distribution through the depth of the beam and indicate the salient values.

(5 Marks)

(c) Comment also on the efficiency of the design.

(3 Marks)

Assume for the materials used the following values

Material	Efficiency factor (%)	Design Strain (%)	Volume fraction (%)	Reinforcement modulus (GPa)	Matrix modulus (GPa)
UD	90	0.3	55	70	3
CSM	25	0.3	25	70	3
Gel Coat	N/A	0.4	N/A	N/A	3

Table Q4 Material Properties

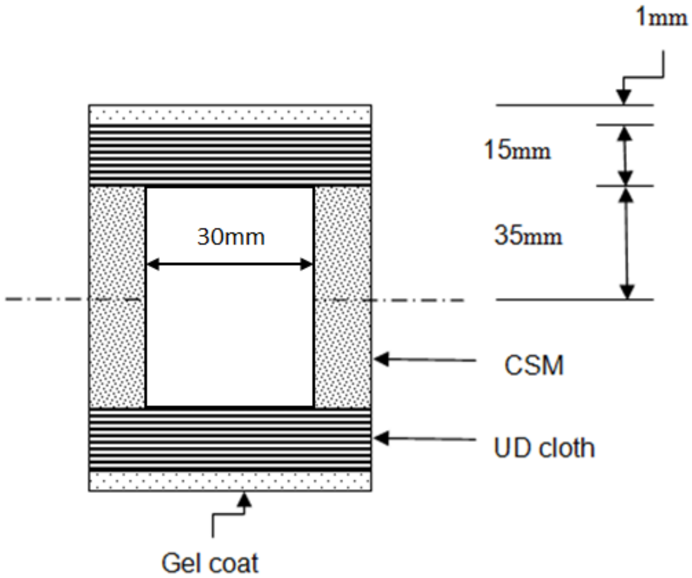

Fig. Q4 Beam Cross-Section

Total 25 Marks
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Q5.

(a) Part of a play area frame is manufactured from galvanised steel tubing and is shown below in Fig Q5.Using this information and assuming the material is idealised as rigid-perfectly plastic with a factor safety of 2 determine a suitable tubular section.

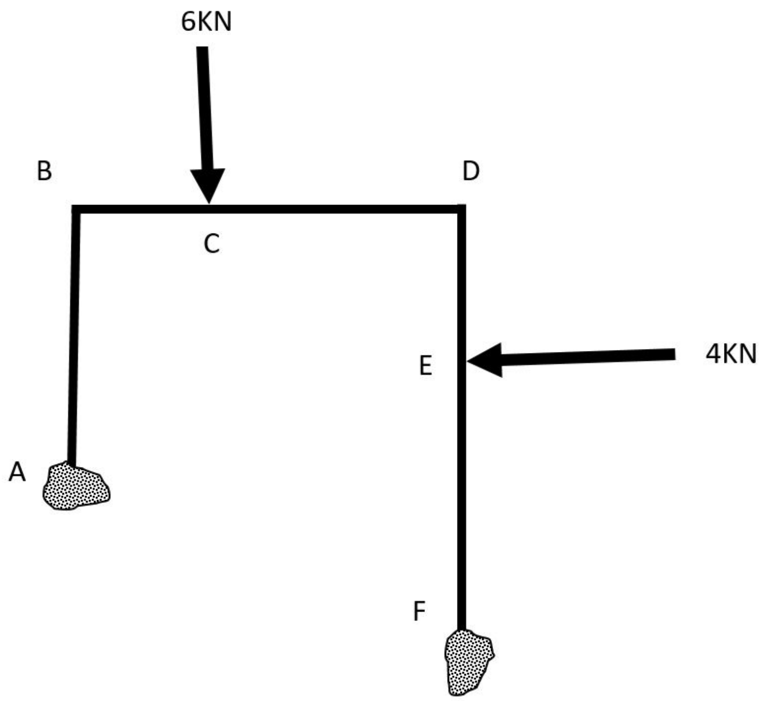
Take Z_p as $4D^2t$ where: D is the nominal bore and t the thickness of a tubular section.

Assume the yield stress for the material is 420 MPa.

(15 Marks)

(b) After the initial design a change is proposed: at position A the leg is now pinned not welded due to a safety requirement, determine the new factor of safety.

(10 Marks)



Member	AB	BC	CD	DE	EF
Length (m)	1.5	0.6	1.2	1.0	1.5

<u>Fig Q5 frame set up</u>

Total 25 Marks

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Q6.

a) A high performance vehicle has an internal front beam member that has the potential to be fabricated from a carbon fibre reinforced (V_{F}=67%) polymer composite (CFRC) square tubular section with an aluminium foam core with a relative density of 0.5. The beam is 2.5m long and is limited to a core thickness of 30 mm. The proposed maximum working loads are given in figure Q6. Using the above information and that in table Q6, design a suitable lay-up for the skins. Also, make a simple sketch of your lay-up.

(20 marks)

b) Estimate the percentage weight saving if the skins had been manufactured from an aluminium alloy skin with a design stress of 200 MPa, an elastic modulus of 69 GPa and a relative density of 2.68.

(5 marks)

Table Q6

Carbon Fibre – Design Properties					
Elastic Modulus E (GPa)	Design Strain (%)	In plane Shear Strength (MPa)	Inter-laminar Shear Strength (MPa)	Relative Density	Laminate Surface Bond Strength (MPa)
330	0.4	45	18	1.68	15

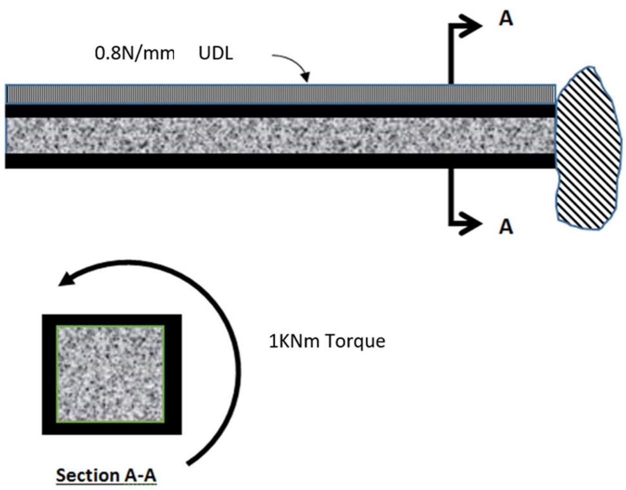

Fig Q6 schematic of the beam

Total 25 Marks

END OF QUESTIONS

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FORMULA SHEET

Formulae used in Structures and Materials Module

Elasticity – finding the direction vectors

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

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

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

$$l = ak \qquad l = \cos\alpha,$$
$$m = bk \qquad m = \cos\theta,$$
$$n = ck \qquad n = \cos\varphi.$$

Principal stresses and Mohr's Circle

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

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

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

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

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

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

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

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

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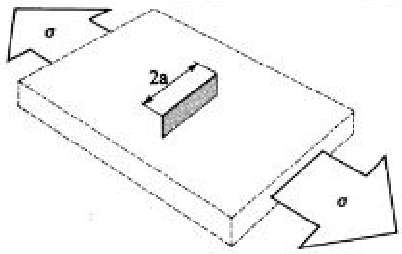
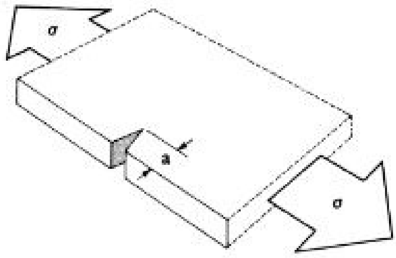
Fracture mechanics

Table: Y values for plates loaded in tension



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

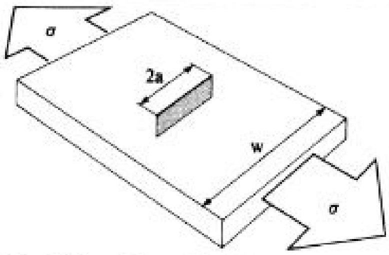
$Y = 1$



(2) Edge crack of length a in an *infinite* plate

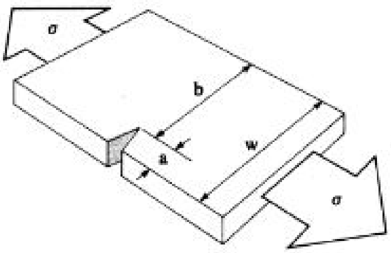
$Y = 1.12$

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.

$$Y = \left(\sec\frac{\pi a}{w}\right)^{1/2}, \quad \frac{2a}{w} \le 0.7$$



(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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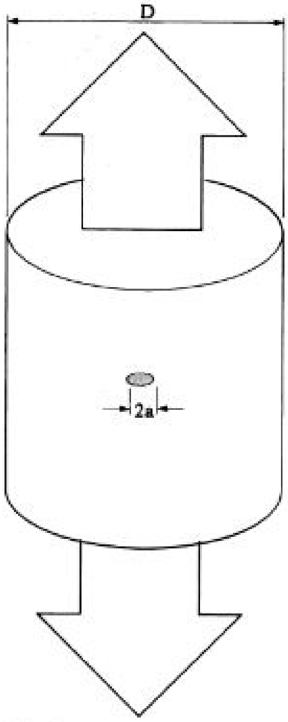
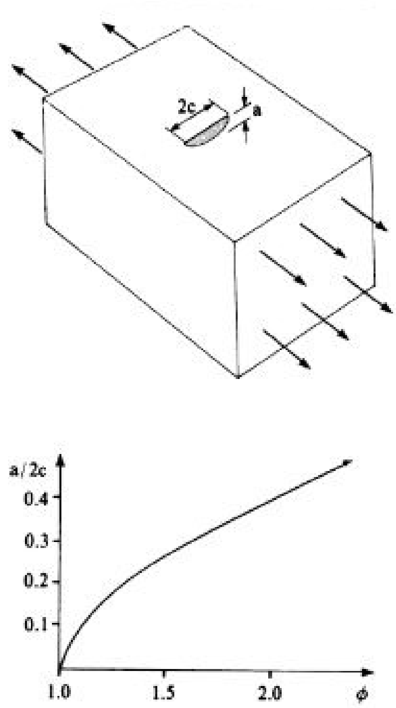


(5) Penny-shaped internal crack of radius a.

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



(6) Semi-elliptical surface flaw

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

Life Calculations

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

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

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)	$\mathcal{G}_{IC}$ (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

$$\varepsilon_n = \frac{1}{2}(\varepsilon_x + \varepsilon_y) + \frac{1}{2}(\varepsilon_x - \varepsilon_y)\cos 2\theta + \frac{\gamma_{xy}}{2}\sin 2\theta$$

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

Hooke's Law in 2D

$$\sigma_1 = \frac{E}{(1-\upsilon^2)}(\varepsilon_1 + \upsilon\varepsilon_2)$$

$$\sigma_2 = \frac{E}{(1-\upsilon^2)}(\varepsilon_2 + \upsilon\varepsilon_1)$$

$$\frac{d}{dr}\left[\frac{1}{r}\frac{d}{dr}\left(r\frac{dw}{dr}\right)\right] = -\frac{Q_r}{D}$$

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Hooke's law is expressed in terms of w, as follows

$$\sigma_r = \frac{E}{1-\upsilon^2}\left(\varepsilon_r + \upsilon\varepsilon_\theta\right) = -\frac{Ez}{1-\upsilon^2}\left(\frac{d^2w}{dr^2} + \frac{\upsilon}{r}\frac{dw}{dr}\right)$$

$$\sigma_\theta = \frac{E}{1-\upsilon^2}\left(\varepsilon_\theta + \upsilon\varepsilon_r\right) = -\frac{Ez}{1-\upsilon^2}\left(\frac{1}{r}\frac{dw}{dr} + \upsilon\frac{d^2w}{dr^2}\right)$$

Bending moment and shear force

$$M_r = -D\left(\frac{d^2w}{dr^2} + \frac{\upsilon}{r}\frac{dw}{dr}\right), D = \frac{Et^3}{12\left(1-\upsilon^2\right)}$$

$$M_\theta = -D\left(\frac{1}{r}\frac{dw}{dr} + \upsilon\frac{d^2w}{dr^2}\right)$$

$$Q_r = -\frac{1}{2\pi r}\int_0^{2\pi}\int_b^r qrdrd\theta = -\frac{1}{r}\int_b^r qrdr$$

Governing equation

$$\boxed{\nabla^4 w = \left(\frac{d^2}{dr^2} + \frac{1}{r}\frac{d}{dr}\right)\left(\frac{d^2}{dr^2} + \frac{1}{r}\frac{d}{dr}\right)w = \frac{q}{D}}$$

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 derived and solved.

Position of the Maximum moment of a propped cantilever length L is given by:

$(\sqrt{2}-1)\,L$ from the prop end

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Finding determinants using cofactors

Sign of cofactor

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

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

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

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

Find determinants

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

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

$$8+24+3=35$$

END OF FORMULA SHEET

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