

**UNIVERSITY OF GREATER MANCHESTER**  
**WESTERN INTERNATIONAL COLLEGE, RAS AL**  
**KHAIMAH**  
**BENG(HONS) MECHANICAL ENGINEERING**  
**SEMESTER ONE EXAMINATION 2025/2026**  
**ADVANCED MATERIALS & STRUCTURES**  
**MODULE NO: AME6012**

Date: Tuesday, 20<sup>th</sup> January 2026

Duration: 10:00am – 1:00pm

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**INSTRUCTIONS TO CANDIDATES:**

There are **FIVE (5)** questions on this paper.

Answer any **FOUR (4)** questions only. All questions carry equal marks.

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

**CANDIDATES REQUIRE:**

Formula Sheet (attached)

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**Q1a.**

Critically evaluate scattered-light photoelasticity (SLP) with phase-stepping for thick components. Explain the stress–optic law, optical setup calibration, slice reconstruction and practical sources of error. Give two industrial applications and include clear, labeled sketches to support your explanation. (12 Marks)

**Q1b.**

A stress state at a point in a gearbox carrier (MPa) is represented by:

$$\sigma = \begin{bmatrix} 85 & -25 & 12 \\ -25 & -30 & -18 \\ 12 & -18 & 45 \end{bmatrix}$$

- i) Draw a properly labeled infinitesimal cube, showing the sense of all normal and shear components acting on each face. (3 marks)
- ii) Using  $|\sigma - \lambda \mathbf{I}| = 0$ , determine the eigenvalues and hence the principal stresses, stating tension or compression. (5 marks)
- iii) Determine the principal directions (unit eigenvectors) using cofactors/eigenvector relations and indicate them on a neat sketch. Comment on orthogonality checks. (5 marks)

**(Total: 25 Marks)**

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**Q2a.**

Classify composites by reinforcement type and architecture. Critically appraise at least four continuous fibre systems in terms of stiffness, strength, density, temperature resistance and durability.

(10 Marks)

**Q2b.**

A Unidirectional (UD) carbon/epoxy composite has 55 vol% carbon fibres ( $E_f = 230$  GPa) and 45 vol% epoxy ( $E_m = 3.2$  GPa).

i) Determine the longitudinal modulus  $E_L$  (iso-strain rule of mixtures). (3 marks)

ii) The component has cross-sectional area  $A = 240$  mm<sup>2</sup> and is subjected to a longitudinal stress  $\sigma_L = 60$  MPa. Compute the load carried by each phase (fibre and matrix). (7 Marks)

(iii) Calculate the strain in the fibre and matrix under applied stress and comment on compatibility. (5 Marks)

**(Total: 25 Marks)**

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**Q3a.**

A steel detail experiences the following repeating spectrum block of  $1.00 \times 10^5$  cycles. Using Miner's cumulative damage hypothesis; determine: (i) the damage per block, (ii) the number of blocks to failure, and (iii) the expected total life (cycles).

**Table 1: Stress & number of cycles**

Stress Amplitude $\sigma_a$ (MPa)	Cycles per block $n_i$	Fatigue life at $\sigma_a$ $N_{fi}$ (cycles)
380	8000	60000
320	12000	220000
270	20000	700000
240	30000	2000000
210	30000	15000000

State any assumptions on mean stress and loading sequence.

(13 Marks)

**Q3b.**

Using the Griffith–Irwin energy approach, explain the role of energy release rate  $G$  and its relationship to stress intensity factor  $K$  in plane stress and plane strain. Justify the three fracture modes (I/II/III) with clear, labeled sketches, and comment on R-curves and thickness effects on apparent toughness.

(12 Marks)

**(Total: 25 Marks)**

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**Q4.**

The thin-walled, multi-cell extruded aluminium member (length 3 m) of Figure Q5 is subject to torque  $T$  about its axis. Wall thicknesses and panel lengths are:

- Thicknesses:  $t_1 = 0.012$  m,  $t_2 = 0.009$  m,  $t_3 = 0.005$  m
- Panel lengths:  $AB = AG = 0.22$  m,  $BC = GF = 0.42$  m,  $BG = CF = CD = DE = EF = 0.32$  m
- Shear modulus:  $G = 27$  GPa

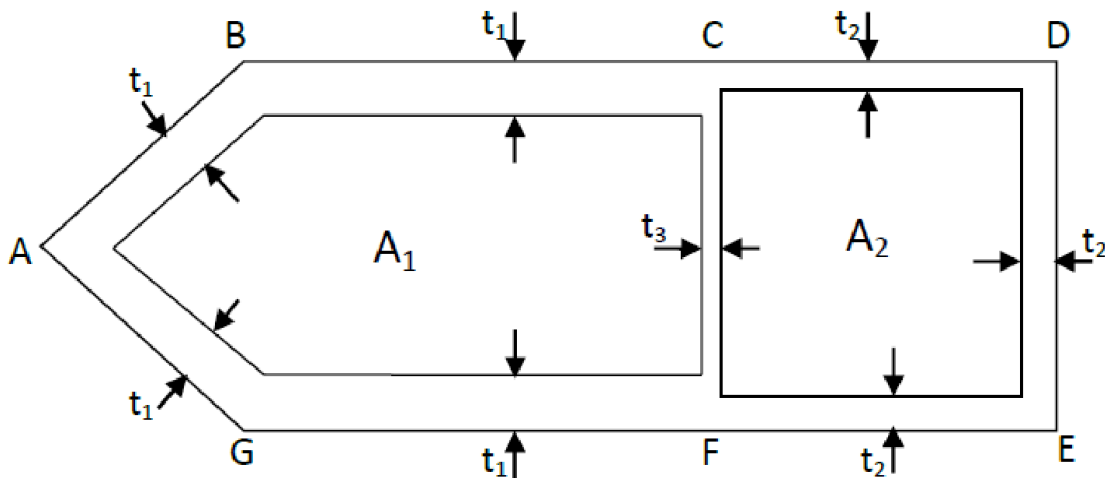


Figure: Cross section of extruded aluminium member

- Determine the maximum torque  $T_{\max}$  permitted by an allowable shear stress of 55 MPa. (8 marks)
- For  $T_{\max}$ , evaluate the shear stress in each wall; indicate magnitude and sense (sketch the shear-flow distribution). (4 marks)
- Under  $T_{\max}$ , determine the angle of twist over the 3 m length. (3 marks)

**Q4. Continues over the page**

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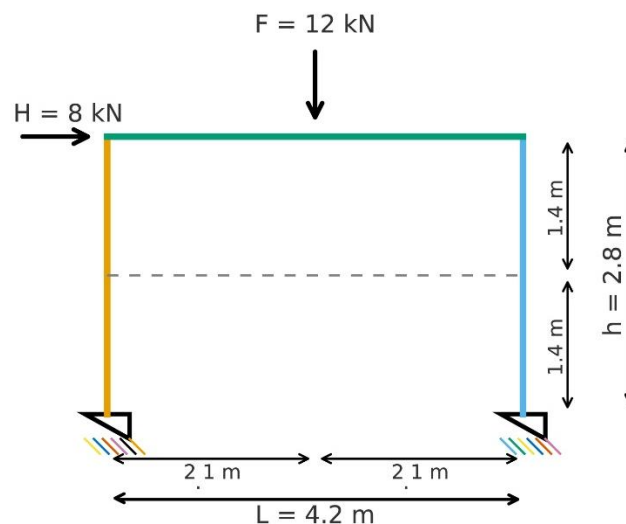
**Q4. Continued...**

d) A redesign removes panel BG (converting the left-hand cell into an open section). For this modified section, determine the new maximum shear stress under the same torque as in part (a) and the percentage increase in angle of twist. State assumptions regarding warping restraint and compatibility. (10 marks)

**(Total: 25 Marks)**

**Q5.**

The portal frame shown in Figure has fixed bases, column height  $h = 2.8$  m, beam span  $L = 4.2$  m, a vertical mid-span load  $F = 12$  kN, and a top-level horizontal load  $H = 8$  kN acting to the right at the left column head. The yield stress of the steel is  $\sigma_y = 140$  MPa.



**Figure:** Portal frame with forces

**Q5. Continues over the page**

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**Q5. Continued...**

- a) Define and discuss plastic hinges in structural analysis and how they are used to identify collapse mechanisms in portal frames. (5 marks)
- b) Describe the calculation of plastic modulus  $Z_p$  for a frame member and explain its significance in estimating plastic moment capacity  $M_p = \sigma_y Z_p$  and collapse load. (5 marks)
- c) For the frame in Figure, identify and illustrate all plausible collapse mechanisms (sway, beam, combined). (5 marks)
- d) Using upper-bound plastic analysis, determine the required plastic moment capacities at the critical hinge locations and hence the required section plastic modulus  $Z_p$  at those sections for  $\sigma_y = 140$  MPa. State assumptions on hinge locations and yield lines. (5 marks)
- e) For a rectangular hollow section (RHS) beam, outer depth  $D = 160$  mm, outer width  $B = 80$  mm, choose a wall thickness  $t$  to satisfy the likeliest failure mode from part (c). Provide a sketch with dimensions and show checks against the required  $Z_p$ . (5 marks)

**(Total: 25 Marks)**

-----END OF QUESTIONS-----

**Please turn the page for the formula sheet**

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## FORMULA SHEET

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### STRESS & STRAIN IN 3D

#### Stress Tensor

$$\sigma = \begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{xy} & \sigma_y & \tau_{yz} \\ \tau_{xz} & \tau_{yz} & \sigma_z \end{bmatrix}$$

#### Stress Invariants

$$I_1 = \sigma_x + \sigma_y + \sigma_z$$

$$I_2 = \sigma_x\sigma_y + \sigma_y\sigma_z + \sigma_z\sigma_x - (\tau_{xy}^2 + \tau_{yz}^2 + \tau_{xz}^2)$$

$$I_3 = \sigma_x\sigma_y\sigma_z + 2\tau_{xy}\tau_{yz}\tau_{xz} - \sigma_x\tau_{yz}^2 - \sigma_y\tau_{xz}^2 - \sigma_z\tau_{xy}^2$$

#### Principal Stresses

$$\det(\sigma - \lambda I) = 0$$

$$\lambda^3 - I_1\lambda^2 + I_2\lambda - I_3 = 0$$

#### Principal Directions

$$(\sigma - \sigma_i I)v_i = 0$$

$$e_i = \frac{v}{\sqrt{l^2 + m^2 + n^2}}$$

#### Yield Criteria

##### Von Mises

$$\sigma_{vm} = \sqrt{\frac{1}{2}[(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2] + 3(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{xz}^2)}$$

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**Tresca**

$$\sigma_{\text{Tresca}} = \max(|\sigma_1 - \sigma_2|, |\sigma_2 - \sigma_3|, |\sigma_1 - \sigma_3|)$$

**THIN-WALLED MULTI-CELL TORSION****Shear Flow & Stress**

$$q = \tau t, \tau = \frac{q}{t}$$

**Single Closed Cell**

$$T = 2Aq, q = \frac{T}{2A}$$

$$J = \frac{4A^2}{\oint ds/t}$$

$$T = GJ\theta', \theta = \theta' L$$

**Multi-Cell Sections**

$$T = 2 \sum_{i=1}^n A_i q_i$$

$$\theta' = \frac{1}{2A_i} \oint_{\text{cell } i} \frac{q(s)}{G t(s)} ds$$

$$q_{\text{wall}} = q_i - q_j$$

**Open Thin-Walled Sections**

$$J_{\text{open}} = \sum_i \frac{t_i l_i^3}{3}$$

$$\tau_i(s) = \frac{T s_i}{J_{\text{open}} t_i}$$

$$\theta'_{\text{open}} = \frac{T}{G J_{\text{open}}}$$

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$$\% \text{increase} = \frac{\theta_{\text{open}} - \theta_{\text{closed}}}{\theta_{\text{closed}}} \times 100\%$$

## FRACTURE MECHANICS

### Stress Intensity Factor

$$K_I = Y \sigma \sqrt{\pi a}$$

### Geometry Factor $Y$ for Common Cracks

#### Through crack of total length $2a$ in an infinite plate

$$Y = 1$$

#### Edge crack of length $a$ in an infinite plate

$$Y = 1.12$$

#### Through crack of length $2a$ in a finite-width plate $w$

$$Y = \sec \left( \frac{\pi a}{w} \right)^{1/2} \text{ valid for } \frac{2a}{w} \leq 0.7$$

#### Edge crack of length $a$ in a plate of width $w$

$$Y = 0.265 \left( \frac{b}{w} \right)^4 + \frac{0.875 + 0.265(a/w)}{(b/w)^{3/2}}$$

where  $b = w - a$ .

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### **GRIFFITH-IRWIN ENERGY APPROACH**

#### **Energy Release Rate**

$$G = \frac{d\Pi}{dA}$$

#### **Griffith Criterion**

$$G = 2\gamma_s$$

#### **Relationship Between $G$ and $K$**

##### **Plane Stress**

$$G = \frac{K^2}{E}$$

##### **Plane Strain**

$$G = \frac{K^2}{E'} = \frac{K^2}{E/(1-\nu^2)}$$

#### **Critical Conditions**

$$G = G_c, K = K_c$$

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### FATIGUE — MINER'S RULE

$$D_i = \frac{n_i}{N_{fi}}$$

$$D_{\text{block}} = \sum_i \frac{n_i}{N_{fi}}$$

$$\sum_i \frac{n_i}{N_{fi}} = 1$$

$$N_{\text{blocks}} = \frac{1}{D_{\text{block}}}$$

$$N_{\text{total}} = N_{\text{blocks}} n_{\text{block}}$$

### COMPOSITE MATERIALS

$$V_f = \frac{A_f}{A_c}, V_m = 1 - V_f$$

$$E_c = V_f E_f + V_m E_m$$

$$\sigma_c = V_f \sigma_f + V_m \sigma_m$$

$$\varepsilon_c = \varepsilon_f = \varepsilon_m$$

$$\sigma_f = E_f \varepsilon_c, \sigma_m = E_m \varepsilon_c$$

$$F_f = \sigma_f A_f, F_m = \sigma_m A_m$$

### PLASTIC ANALYSIS — HINGES

$$M_p = \sigma_y Z_p$$

$$Z_p = \sum A_i y_i$$

$$\sum P_i \Delta_i = \sum M_{p,j} \theta_j$$

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### Portal Frame Mechanisms

$$H_c = \frac{4M_p}{h}$$

$$F_c = \frac{4M_p}{L}$$

$$H\Delta + F\delta = \sum M_p \theta$$

### RHS Plastic Modulus

$$b = B - 2t, d = D - 2t$$

$$Z_{p,RHS} = \frac{BD^2 - bd^2}{4}$$

$$Z_{p,req} = \frac{M_{p,req}}{\sigma_y}$$

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### PHOTOELASTICITY — STRESS-OPTIC LAW

$$\Delta n = C(\sigma_1 - \sigma_2)$$

$$\delta = \frac{2\pi}{\lambda} \Delta n t$$

$$\delta = \frac{2\pi}{\lambda} Ct(\sigma_1 - \sigma_2)$$


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**REFER TO TABLE BELOW (Dimensions and Properties)**

DIMENSIONS AND PROPERTIES

Designation		Mass per Metre kg	Area of Section A cm <sup>2</sup>	Ratios for Local Buckling		Second Moment of Area		Radius of Gyration		Elastic Modulus		Plastic Modulus		Torsional Constants		Surface Area per Metre m <sup>2</sup>
Size	Thickness			d/t	b/t	Axis x-x cm <sup>4</sup>	Axis y-y cm <sup>4</sup>	Axis x-x cm	Axis y-y cm	Axis x-x cm <sup>3</sup>	Axis y-y cm <sup>3</sup>	Axis x-x cm <sup>3</sup>	Axis y-y cm <sup>3</sup>	J cm <sup>4</sup>	C cm <sup>3</sup>	
D mm	B mm															
50x30	2.5	2.89	3.68	17.0	9.00	11.8	5.22	1.79	1.19	4.73	3.48	5.92	4.11	11.7	5.73	0.154
	3.0	3.41	4.34	13.7	7.00	13.6	5.94	1.77	1.17	5.43	3.90	6.88	4.76	13.5	6.51	0.152
	3.2	3.61	4.60	12.6	6.38	14.2	6.20	1.76	1.16	5.68	4.13	7.25	5.00	14.2	6.80	0.152
	4.0	4.39	5.59	9.50	4.50	16.5	7.08	1.72	1.13	6.60	4.72	8.59	5.88	16.6	7.77	0.150
	5.0	5.28	6.73	7.00	3.00	18.7	7.89	1.67	1.08	7.49	5.26	10.0	6.80	19.0	8.67	0.147
60x40	2.5	3.68	4.68	21.0	13.0	22.8	12.1	2.21	1.60	7.61	6.03	9.32	7.02	25.1	9.73	0.194
	3.0	4.35	5.54	17.0	10.3	26.5	13.9	2.18	1.58	8.82	6.95	10.9	8.19	29.2	11.2	0.192
	3.2	4.62	5.88	15.8	9.50	27.8	14.8	2.18	1.57	9.27	7.29	11.5	8.64	30.8	11.7	0.192
	4.0	5.64	7.19	12.0	7.00	32.8	17.0	2.14	1.54	10.9	8.52	13.8	10.3	36.7	13.7	0.190
	5.0	6.85	8.73	9.00	5.00	38.1	19.5	2.09	1.50	12.7	9.77	16.4	12.2	43.0	15.7	0.187
	6.3	8.31	10.6	6.52	3.35	43.4	21.9	2.02	1.44	14.5	11.0	19.2	14.2	49.5	17.6	0.184
80x40	3.0	5.29	6.74	23.7	10.3	54.2	18.0	2.84	1.63	13.6	9.00	17.1	10.4	43.8	15.3	0.232
	3.2	5.62	7.16	22.0	9.50	57.2	18.9	2.83	1.63	14.3	9.46	18.0	11.0	46.2	16.1	0.232
	4.0	6.90	8.79	17.0	7.00	68.2	22.2	2.79	1.59	17.1	11.1	21.8	13.2	55.2	18.9	0.230
	5.0	8.42	10.7	13.0	5.00	80.3	25.7	2.74	1.55	20.1	12.9	26.1	15.7	65.1	21.9	0.227
	6.3	10.3	13.1	9.70	3.35	93.3	29.2	2.67	1.49	23.3	14.6	31.1	18.4	75.6	24.8	0.224
	8.0	12.5	16.0	7.00	2.00	106	32.1	2.58	1.42	26.5	16.1	36.5	21.2	85.8	27.4	0.219
90x50	3.0	6.24	7.94	27.0	13.7	84.4	33.5	3.26	2.06	18.8	13.4	23.2	15.3	76.5	22.4	0.272
	3.6	7.40	9.42	22.0	10.9	98.3	38.7	3.23	2.03	21.8	15.5	27.2	18.0	89.4	25.9	0.271
	5.0	9.99	12.7	15.0	7.00	127	49.2	3.16	1.97	28.3	19.7	36.0	23.5	116	32.9	0.267
	6.3	12.3	15.6	11.3	4.94	150	57.0	3.10	1.91	33.3	22.8	43.2	26.0	138	38.1	0.264
	8.0	15.0	19.2	8.25	3.25	174	64.6	3.01	1.84	38.6	25.8	51.4	32.9	160	43.2	0.259
100x50	3.0	6.71	8.54	30.3	13.7	110	36.8	3.58	2.08	21.9	14.7	27.3	16.8	88.4	25.0	0.292
	3.2	7.13	9.08	28.3	12.6	116	38.8	3.57	2.07	23.2	15.5	28.9	17.7	93.4	26.4	0.292
	4.0	8.78	11.2	22.0	9.50	140	46.2	3.53	2.03	27.9	18.5	35.2	21.5	113	31.4	0.290
	5.0	10.8	13.7	17.0	7.00	167	54.3	3.48	1.99	33.3	21.7	42.8	25.8	135	36.9	0.287
	6.3	13.3	16.9	12.9	4.94	197	63.0	3.42	1.93	39.4	25.2	51.3	30.8	160	42.9	0.284
	8.0	16.3	20.8	9.50	3.25	230	71.7	3.33	1.86	46.0	28.7	61.4	36.3	186	48.9	0.279
100x60	3.0	7.18	9.14	30.3	17.0	124	55.7	3.68	2.47	24.7	18.8	30.2	21.2	121	30.7	0.312
	3.6	8.53	10.9	24.8	13.7	145	64.8	3.65	2.44	28.9	21.6	35.6	24.9	142	35.6	0.311
	5.0	11.6	14.7	17.0	9.00	189	83.6	3.58	2.38	37.8	27.9	47.4	32.9	188	45.9	0.307
	6.3	14.2	18.1	12.9	6.52	225	96.1	3.52	2.33	45.0	32.7	57.3	39.5	224	53.8	0.304
	8.0	17.5	22.4	9.50	4.50	264	113	3.44	2.25	52.8	37.8	68.7	47.1	265	62.2	0.299
120x60	3.6	9.68	12.3	30.3	13.7	227	76.3	4.30	2.49	37.9	25.4	47.2	28.9	183	43.3	0.351
	5.0	13.1	16.7	21.0	9.00	299	96.8	4.23	2.43	49.9	32.9	63.1	38.4	242	56.0	0.347
	6.3	16.2	20.7	18.0	6.52	358	116	4.16	2.37	59.7	38.8	76.7	46.3	290	65.9	0.344
	8.0	20.1	25.8	12.0	4.50	425	135	4.08	2.30	70.8	45.0	92.7	55.4	344	76.6	0.339
120x80	5.0	14.7	18.7	21.0	13.0	365	193	4.42	3.21	60.9	48.2	74.6	56.1	401	77.9	0.387
	6.3	18.2	23.2	16.0	9.70	440	230	4.36	3.15	73.3	57.6	91.0	68.2	487	92.9	0.384
	8.0	22.6	28.8	12.0	7.00	525	273	4.27	3.08	87.5	68.1	111	82.6	587	110	0.379
	10.0	27.4	34.9	9.00	5.00	609	313	4.18	2.99	102	78.1	131	97.3	688	126	0.374
150x100	4.0	15.1	19.2	34.5	22.0	607	324	5.63	4.11	81.0	64.8	97.4	73.6	660	105	0.490
	5.0	18.6	23.7	27.0	17.0	739	392	5.58	4.07	98.5	78.5	119	90.1	807	127	0.487
	6.3	23.1	29.5	20.8	12.9	898	474	5.52	4.01	120	94.8	147	110	986	153	0.484
	8.0	28.9	36.8	15.8	9.50	1067	569	5.44	3.94	145	114	180	135	1203	183	0.479
	10.0	35.3	44.9	12.0	7.00	1292	665	5.34	3.85	171	133	216	161	1432	214	0.474
	12.5	42.8	54.8	9.00	5.00	1488	783	5.22	3.74	198	153	256	190	1679	246	0.468

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