Version NAF/2

EGT3
ENGINEERING TRIPOS PART IIB

Monday 30 April 2018 9.30 to 11.10

Module 4C2

DESIGNING WITH COMPOSITES

Answer not more than ***three*** *questions.*

All questions carry the same number of marks.

The ***approximate*** *percentage of marks allocated to each part of a question is indicated in the right margin.*

Write your candidate number ***not*** *your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Attachment: Module 4C2 Designing with Composites datasheet (6 pages)
Engineering Data Book

10 minutes reading time is allowed for this paper at the start of the exam.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

1 A lightweight composite material comprising continuous Kevlar fibres in an epoxy matrix is used to construct a thin-walled spherical pressure vessel. The elastic constants of the unidirectional Kevlar/epoxy lamina are given in the data sheet. Each lamina has a thickness of 0.25 mm.

(a) Calculate the stiffness matrix $[Q]$ for the lamina in the principal material axes (1, 2). [15%]

(b) The wall of the vessel is to be manufactured from Kevlar/epoxy plies with a stacking sequence of $[(\pm 30/90)]$ which is repeated n times, i.e. $[(\pm 30/90)_{\mathrm{n}}]$. Show that the proposed stacking sequence produces a balanced laminate. Explain the significance of this when the laminate is subjected to in-plane loads or displacements. [30%]

(c) Find the extensional stiffness matrix $[A]$ of the laminate, in terms of n. [25%]

(d) A spherical vessel of diameter 1 m must be designed to carry an internal pressure of 2 MPa in service. Given that the biaxial strain for first failure in the laminate is $\varepsilon_x = \varepsilon_y = 2.3 \times 10^{-3}$, determine the required number of laminae n. [30%]

2 Account for the following observations.

(a) A unidirectional CFRP lamina splits easily along the fibre direction, whereas a quasi-isotropic CFRP laminate is much more resistant to splitting. Make suitable reference to the role of toughness and delamination upon the failure mode. [35%]

(b) The Poisson ratio of long-fibre laminates is sensitive to lay-up. [15%]

(c) Joints are commonly a source of failure in laminated composites, and are challenging to account for in design. [25%]

(d) The transverse tensile strength of a unidirectional CFRP lamina is more sensitive to the presence of porosity in the matrix than is the longitudinal tensile strength. [25%]

3 (a) Consider a unidirectional composite with the following elastic constants: $E_1 = 39$ GPa, $E_2 = 8.3$ GPa, $\nu_{12} = 0.3$, $G_{12} = 4.1$GPa.

(i) Calculate the compliance matrix $[S]$ in the principal material axes (1, 2). [10%]

(ii) Show that the transformed compliance $\bar{S}_{11}$ increases by a factor of about 2 when the composite is loaded at 25° to the fibre axis compared with the on-axis value. What is the maximum value of $\bar{S}_{11}$ that the lamina can exhibit and at what loading angle does this occur? [35%]

(b) Consider a thin-walled cylindrical vessel with closed ends, produced by filament winding.

(i) Describe the process of filament winding with the aid of a sketch. List the main parameters controlling the process. [25%]

(ii) The walls of the vessel may be considered as an angle-ply laminate, aligned at $\pm 60^\circ$ with respect to the longitudinal axis of the vessel. Each ply behaves as a unidirectional lamina with elastic constants shown above which result in the stiffness matrix:

$$[Q] = \begin{bmatrix} 39.76 & 2.54 & 0 \\ 2.54 & 8.46 & 0 \\ 0 & 0 & 4.1 \end{bmatrix} \text{ GPa}$$

Calculate the strain ratio in the axial and hoop directions $\varepsilon_{axial} / \varepsilon_{hoop}$ when the vessel is internally pressurised. [30%]

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4 (a) Explain why an increase in the matrix strength of a unidirectional CFRP lamina leads to an increase in its compressive strength, but to a decrease in its toughness for cracking transverse to the fibre direction. [30%]

(b) An AS/3501 carbon fibre-epoxy $[0/90]_S$ laminate of overall thickness 1 mm (with material properties given on the datasheet) is subjected to tensile stresses σ_1^∞ and σ_2^∞ along the 0^o and 90^o fibre directions, respectively. The stiffness matrix $[Q]$ for a unidirectional lamina of this material, and the laminate extensional matrix $[A]^{-1}$ are as follows:

$$[Q] = \begin{bmatrix} 139 & 2.7 & 0 \\ 2.7 & 9.0 & 0 \\ 0 & 0 & 6.9 \end{bmatrix} \text{GPa}, \quad [A]^{-1} = \begin{bmatrix} 0.0135 & -0.0005 & 0 \\ -0.0005 & 0.0135 & 0 \\ 0 & 0 & 0.145 \end{bmatrix} \frac{1}{\text{GPa mm}}$$

(i) For uniaxial loading $\left(\sigma_1^\infty > 0, \sigma_2^\infty = 0\right)$ calculate the value of σ_1^∞ that gives first ply failure using the maximum strain criterion. [30%]

(ii) If instead, the maximum stress criterion is used, calculate the value of σ_1^∞ that gives first ply failure for uniaxial tension of the laminate. Comment upon this value in relation to that obtained in part (b)(i). [40%]

END OF PAPER