N.I COLLEGE OF ENGINEERING, KUMARACOIL

PART A (2MARKS) AND PART B (16 MARKS) QUESTIONS WITH ANSWERS

AE1402 COMPOSITE MATERIALS AND STRUCTURES

SEMESTER VII, DEPARTMENT OF AERONAUTICAL ENGINEERING

PART A

Unit1

1. What are the major constituents in composite materials?
   Reinforcing phase
   One in which it is embedded is called the matrix.
   Reinforcing phase - Fibres, particles or flakes.
   Matrix- Materials are generally continuous.

2. Define lamina.
   A lamina (also called a ply or layer) is a single flat layer of unidirectional fibers or woven fibers arranged is a matrix.

3. Define laminate.
   A laminate is a stack of plies of composites. Each layer can be laid at various orientations and can be different material systems.

4. Define Hooke's law.
   Within elastic stress is proportional to strain. (e.g) Spring balance.
5. Write compliance and stiffness matrices for Hooke's law stress-strain relationships at a point in an x-y-z orthogonal system.

$$\begin{bmatrix} \varepsilon x \\ \varepsilon y \\ \varepsilon z \\ \gamma yz \\ \gamma zx \\ \gamma xy \end{bmatrix} = \begin{bmatrix} \frac{1}{E} & -\frac{v}{E} & -\frac{v}{E} & o & o & o \\ -\frac{v}{E} & \frac{1}{E} & -\frac{v}{E} & o & o & o \\ -\frac{v}{E} & -\frac{v}{E} & \frac{1}{E} & o & o & o \\ o & o & o & \frac{1}{G} & o & o \\ o & o & o & o & \frac{1}{G} & o \\ o & o & o & o & o & \frac{1}{G} \end{bmatrix} \begin{bmatrix} \sigma x \\ \sigma y \\ \sigma z \\ \tau yz \\ \tau zx \\ \tau xy \end{bmatrix}$$

6. What are advanced composites?
   Advanced composites are composite materials which are traditionally used in the aerospace industries. These composites have high performance reinforcements of a thin dia. in a matrix material such as epoxy and aiuminium.

7. List down the reinforcement materials and resins used in composite materials.
   <u>Reinforcement materials</u>
   Graphite, Glass, Aramid, Kevlar 49, Boron
   <u>Resins</u>
   Epoxy, aluminium, Polyamide, Nylon, Polyesters, Vinyl esters, Phenolics, Polymides, Polybenzimidazoles, Polyphenylquinoxaline.

8. Why are fiber reinforcements of a thin diameter?
   (i) As the fibers become smaller in diameter , it reduces the chances of an

inherent flaw in the material.
(ii) Fixed fiber volume in a given volume of composite, the area of the fiber-matrix interface is inversely proportional to the diameter of the fiber.
(iii) Ability to bend increases with a decrease in the fiber diameter and is measured as flexibility.

9. What are the aircraft structural components made of composite materials?
Elevator face sheets, Horizontal stabilizer, Wing spoilers, ailerons, rudders, elevators, fairings etc.,
Skin on the horizontal stabilizer box, Under wing fairings, fin, rudder and stabilizer skins, skins on vertical fin box, fin leading edge, wing skins, horizontal and vertical tail boxes ; wing and tail control surfaces etc., Wing skins and sub structure; forward fuselage; horizontal stabilizer flaps; ailerons.

10. Explain the difference between isotropic and anisotropic materials.
Anisotropic materials are the opposite of isotropic materials like steel and aluminium. Anisotropic materials have different properties in different directions. For example, the Young's modulus of a piece of wood is higher (different) in the direction of the grain than in the direction perpendicular to the grain. In comparison, a piece of steel has the same young's modulus in all directions.

11. What are the material constants of an orthotropic materials?
For an orthotropic material, the nine independent elastic constants are E11, E22, E33, G12, G13, G23, ν_{12}, ν_{13}, ν_{22}.
Uni-directionally oriented fiber composites are a special class of orthotropic materials. If the fibers are in the 1-2 plane, elastic properties are equal in the 2-3 directions so that E22=E33, $\nu_{12}=\nu_{13}$ and $G_{12}=G_{13}$. Further more G23 can be expressed in terms of E22 and ν_{12}. Thus the number of independent elastic constants for a unidirectionally oriented fiber composite reduces to 5. Such composites are often called transversely isotropic.

12. What are the properties of matrices? Write down its usage.
Properties
Low viscosity.
High melting point.
Low curing temperature.
Usage:

To transfer stresses between the fibers.
To provide a barrier against an adverse environment.
To protect the surface of the fibers from mechanical abrasion.

13. Define (a) Orthotropic material (b) isotropic material and give the number of elastic constants in macro mechanics.
If a material has three mutually perpendicular planes of material symmetry it is called orthotropic material. Three mutually perpendicular planes of material symmetry also imply that there are three mutually perpendicular planes of material symmetry. Note there are nine independent elastic constants.

If all planes in an orthotropic body are identical, it is an isotropic material. This also implies that there are infinite principal directions. Note that there are two independent constants.

14. What is meant by orthogonally isotropic material? Give an example.
The Q_{16} qnd Q_{26} terms are non-zero when has any value other than 0º or 90º. This indicates the anisotropic behaviour of an orthotropic lamina when its fibers are not oriented along or perpendicular to the reference load direction. The terms Q16 and Q26 are that cause an orthotropic lamina to behave like an anisotropic lamina in a laminate, when is neither 0º nor 90º.(Better 30º and 60º).

15. Define composite materials.
A composite is a structural material which consists of combining two or more constituents. The constituents are combined at a macroscopic level and are not soluble in each other. One constituent is called the reinforcing phase and the one in which it is embedded is called the matrix.

16. What is an isotropic body?
A isotropic material has properties that are the same in all directions. For example the Young's modulus of steel is the same in all directions.

17. Write four applications of composite materials?
Air craft. Space, automotive, sporting goods and marine engineering.

18. Distinguish between long fibers and short fibers.
<u>Long fibers</u>: Easy to orient & process. Impact resistance, low shrinkage, improved surface finish and dimensional stability.
<u>Short fibers</u> : Low cost, Easy to work with matrix. Short fibers have few flaws and therefore have higher strength.

19. What is a particulate composite?
It consists of particles immersed in matrices such as alloys and ceramics. They are usually isotropic since the particles are added randomly.

20. What is an anisotropic material?
At a point in anisotropic material, material properties are different in all directions. The material which has 21 independent elastic constants at a point is called an anisotropic material.

Unit 2

1. What are the assumptions made in the strength of materials approach model?
   (i)The bond between fibers and matrix is perfect.
   (ii) The elastic moduli, diameters and space between fibers are uniform.
   (iii)The fibers are continuous and parallel.
   (iv)The fibers and matrix follow Hooke's law.(linearly elastic)
   (v)The fibers possess uniform strength.
   (vi)The composite is free of voids.

2. Find the in-plane shear modulus of a glass/epoxy lamina with a 70% fiber volume fraction. $G_f = 35.42$ GPa; $G_m = 1.308$ GPa.
   $$\frac{1}{G_{12}} = \frac{0.7}{35.42} + \frac{0.3}{1.308}$$
   $$G_{12} = 4.014GPa$$

3. Define micro mechanics.
   Micro mechanics is the study of composite material behaviour wherein the interaction of the constituent materials is examined on a microscopic scale to determine their effect on the properties of the composite material.

4. Find the transverse Young's modulus of a glass/epoxy lamina with a 70% fiber volume fraction. $E_f = 85$ GPa; $E_m = 3.4$GPa.
   $$\frac{1}{E2} = \frac{Vf}{Ef} + \frac{Vm}{Em}$$
   $$= \frac{0.7}{85} + \frac{0.3}{3.4}$$
   E_2 = 10.37 GPa.

5. Distinguish between natural axis and arbitrary axis.
   The axis parallel to the nominal axis, it is called natural axis or right hand co-ordinate system.
   The axis is some inclining of plane is called arbitrary plane.

6. What is macro mechanics?
   The macro mechanical analysis of a lamina is based on average properties and by considering the lamina to be homogeneous. Methods to find these average properties based on the individual mechanical properties of the fiber and the matrix.

7. Define material axes or local axes.
   The axes in the 1-2 co-ordinate system are called the local axes or the material axes. The direction 1 is parallel to the fibers and the direction 2 is perpendicular to the fibers. Direction 1 is also called the longitudinal direction (L) and the direction 2 is called the transverse direction (T). The axes in the x-y co-ordinate system are called the global axes or the off axes.

8. What is density of composites?
The mass of composite (Wc) is the sum of the mass of the fibers (Wf) and the mass of the matrix (Wm) is
Wc= Wf + Wm
The density of the composite in terms of mass fraction

$$\frac{1}{\rho c} = \frac{Wf}{\rho f} + \frac{Wm}{\rho m}$$

9. What is elasticity approach?
Elasticity accounts for equilibrium of forces, compatibility and Hooke's law relationships in three dimensions, whereas the strength of materials approach may not satisfy compatibility and not account for Hooke's law in three dimensions.

10. What is major poisson's ratio?
The major poisson's ratio is defined as the negative of the ratio of the normal strain in the transverse direction to the normal strain in the longitudinal direction, when a normal load is applied in the longitudinal direction.

11. Write the general characteristics of composite materials.
Low specific gravity.
High strength weight ratio.
High modulus-weight ratio.

12. What is meant by "stiffness".
A measure of modulus
The relationship of load and deformation
The ratio between the applied stress and resulting strain.

13. Write short notes on: Resilience.
A property of a material, which is able to do work against restraining, forces during return from a deformed condition.

14. What are the assumptions made in micro mechanics?
Micro mechanics – The study of composite material behaviour wherein the interaction of the constituent materials is examined in detail as part of the definition of the behaviour of the heterogeneous composite material.
The two basic approaches to the micromechanics of composite materials are
   (i) Mechanics of materials
   (ii) Elasticity
The mechanics of materials (or strength of materials or resistance of materials) approach embodies the usual concept of vastly simplifying assumptions regarding the hypothesized behaviour of the mechanical system. The elasticity approach actually is at least three approaches (i) bounding principles (ii) exact solutions and (iii) approximate solutions. All approaches are characterized by more rigorous satisfaction of physical laws (equilibrium, deformation continuity and compatibility and stress-strain relations) than in mechanics of materials.

15. What is fiber reinforced plastic (FRP)?
A general term for a composite that is reinforced with cloth, mat, strands or any other fiber form.

16. Define the term: constituent.
In general, an element of a larger grouping. In advanced composites, the principal constituents are the fibers and the matrix.

17. What is a homogeneous body?
A homogeneous body has properties that are the same at all points in the body. A steel rod is an example of a homogeneous body. However, if one heats this rod at one end, the temperature at various points on the rod would be different. Since young's modulus of steel varies with temperature, we no longer have a homogeneous body.

18. What is a non homogeneous body?
A non-homogeneous or inhomogeneous body has material properties which are a function of the position on the body.

19. How local and global stresses are related?
The global and local stresses in an angle lamina are related to each other through the angle of the lamina, □

$$\begin{bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{bmatrix} = [T]^{-1} \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_{12} \end{bmatrix}$$

Where [T] is called the transformation matrix and is defined as

$$[T]^{-1} = \begin{bmatrix} c^2 & s^2 & -2sc \\ s^2 & c^2 & 2sc \\ sc & -sc & c^2 - s^2 \end{bmatrix}$$

20. What are the elements of the transformed reduced stiffness matrix ?

$$\bar{Q}_{11} = Q_{11} C^4 + Q_{22} S^4 + 2(Q_{12} + 2Q_{66}) S^2 C^2$$

$$\bar{Q}_{12} = (Q_{11} + Q_{22} - 4Q_{66}) S^2 C^2 + Q_{12}(C^4 + S^4)$$

$$\bar{Q}_{22} = Q_{11} S^4 + Q_{22} C^4 + 2(Q_{12} + 2Q_{66}) S^2 C^2$$

$$\overline{\overline{Q}}_{16} = (Q_{11} - Q_{12} - 2Q_{66})C^3 S - (Q_{22} - Q_{12} - 2Q_{66})S^3 C$$

$$\overline{\overline{Q}}_{26} = (Q_{11} - Q_{12} - 2Q_{66})C S^3 - (Q_{22} - Q_{12} - 2Q_{66})C^3 S$$

$$\overline{\overline{Q}}_{66} = (Q_{11} + Q_{22} - 2Q_{12} - 2Q_{66})S^2 C^2 + Q_{66}(S^4 + C^4)$$

Unit 3

1. Distinguish between symmetric cross ply laminate and symmetric angle ply laminate.
   Symmetric cross ply laminates
   Odd no. of plies
   [0/90/0/90/0]
   Symmetric angle ply laminates
   + □ and – □ directions
   Odd no. of plies
   [-40/40/-40/40/-40]

2. Give an example of a laminate with zero coupling stiffness matrix,
   Symmetric laminates
   A laminate is called symmetric if the material, angle and thickness of plies are the same above and below the mid-plane. A example of symmetric laminates is $[0/30/\overline{60}]_s$ as shown below:
   /0/30/60/30/0/
   For symmetric laminates from the definition of [B] matrix, it can be proved [B]=0. Hence

$$\begin{bmatrix} N_x \\ N_y \\ N_z \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_x^{\circ} \\ \varepsilon_y^{\circ} \\ \varepsilon_z^{\circ} \end{bmatrix}$$

$$\begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{12} & D_{22} & D_{26} \\ D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{bmatrix} \kappa_x \\ \kappa_y \\ \kappa_z \end{bmatrix}$$

3. What are the merits and demerits of Tsai-hill failure theory?
   The variation of strength with angle of lamina orientation is smooth rather than having cusps that are not seen in experimental results.
   The strength continuously decreases as □ grows from 0º rather than the rise in uni-axial strength that is characteristic of both the maximum stress and the max. strain criteria.
   The agreement between the criterion and experiment is even better than that at first glance. The maximum stress and strain criteria are incorrect by100% at 30º.
   Considerable interaction exists between the failure strengths X,Y,S in the Tsai-hill criterion but none exists in the previous criteria where axial, transverse and shear failures are presumed to occur independently.

4. Give examples of anti symmetric angle ply and symmetric cross ply laminates.
   Anti-symmetric angle ply
   [-40/40/-40/40]
   Symmetric cross ply laminate
   [90/0/90/0/90]

5. Define cross ply laminate and angle ply laminate.

   Cross ply laminates

   A laminate is called a cross ply laminate (also called laminates with specially orthotropic layers) if only 0º and 90 º plies were used to make a laminate. An example of a cross ply laminate is a (0/90/90/0/90] laminate.

   Angle ply laminates

   A laminate is called an angle ply laminate if it has plies of same material and thickness, and only oriented at +□ and – □ direction. An example of an angle ply laminate is [-40/40/-40/40].

6. What are the assumptions made in classical small deformation theory for a laminate?

   (i)Each lamina is orthotropic.
   (ii)Each lamina is homogeneous.
   (iii)A line straight and perpendicular to the middle surface remains straight and perpendicular to the middle surface during deformation ($\gamma_{xz} = \gamma_{xz} = 0$)
   (iv)A straight line in the z-direction remains of constant length ($\varepsilon_z = 0$).
   (v)The laminate is thin and is loaded only in its plane. (plane stress) ($\sigma_z = \tau_{xz} = \tau_{xz} = 0$)
   (vi)Displacements are continuous and small throughout the laminate.
   ($|u|$, $|v|$, $|w|$ <<laminate thickness).
   (vii)Each lamina is elastic.
   (viii)No slip occurs between the lamina inter faces.

7. Define inter laminar stresses with causes.

   In classical lamination theory no account is taken of stresses such as σ_{zx}, τ_{zx} and τ_{zy} which are shown on an element of an angle-ply laminate loaded with Nx. These stresses are called inter laminar stresses and exist on surfaces between adjacent layers although they exist within the layers but are usually largest at the layer interfaces.

   Accordingly, classical lamination theory does not include some of the stresses that actually cause failure of a composite laminate.

8. Define: Laminate code.

   A laminate is made of a group of a single layers bonded to each other. Each layer can be identified by its location in the laminate, its material and its angle of orientation with a reference axis. Each lamina is represented by the angle of ply and separated from other plies by a slash sign. The first ply is the top ply of the laminate. Special notations are used for symmetric laminates, laminates with adjacent lamina of same orientation or of opposite angles and hybrid laminates.

9. Define: Quasi-isotropic laminate.

   A laminate approximating isotropy by orientation of plies in several or more directions.

10. What is inter laminar shear?

    A shearing force tending to produce a displacement between two laminae along the plane of their interface.

11. Define the term: Balanced laminate.

A laminate in which all the plies are at angles other than 0º and 90º and occur in ±pairs. The plies are symmetrical about the centre line.

12. What are the equations of [A],[B] and [D] matrices?

$$Aij = \underset{k=1}{\overset{3}{\varepsilon}}\left[\bar{Q}_{ij}\right]_k (h_k - h_{k-1}) \text{, i= 1,2,3; j=1,2,3}$$

$$Bij = \frac{1}{2}\underset{k=1}{\overset{3}{\varepsilon}}\left[\bar{Q}_{ij}\right]_k (h_k^2 - h_{k-1}^2) \text{ i=1,2,3; j=1,2,3}$$

$$Dij = \frac{1}{3}\underset{k=1}{\overset{3}{\varepsilon}}\left[\bar{Q}_{ij}\right]_k (h_k^3 - h_{k-1}^3) \text{ ,i=1,2,3; j=1,2,3}$$

13. What are the transverse equations for laminated plates?

The equilibrium differential equations in terms of the force and moment resultants derived and the transverse loading p(x,y) are

$N_{xx} + N_{yy}=0$

$N_{xy,x}+ N_{y,y}=0$

$M_{x,xx}+2M_{xy,xy}+M_{y,yy}=-p$

Where a comma denotes differentiation of the principal symbol with respect to the principal symbol with respect to the subscript that follows the comma.

14. What is hybrid laminate?

Graphite/Epoxy	0
Boron/Epoxy	45
Boron/Epoxy	– 45
Boron/Epoxy	– 45
Boron/Epoxy	45
Graphite/Epoxy	0

$[0^{Gr}/\pm45^{B}]_s$ denotes the above laminate. It consists of six plies but the 0º plies are made of graphite/epoxy, while the angle plies are made of boron/epoxy.

15. What is maximum strain failure theory?

This theory is based on the Maximum Normal strain theory by St. Venant and the Maximum shear stress theory by Tresca as applied to isotropic materials. The strains applied to a lamina are resolved to strains in the local axes. Failure is predicted in a lamina, if any of the normal or shearing strains in the local axes of a lamina or exceed the corresponding ultimate strains of the unidirectional lamina. Given the strains /stresses in an angle lamina, find the strains in the local axes. A lamina is considered to be failed if

$-(\varepsilon_1^c)_{ult} < \varepsilon_1 < (\varepsilon_1^t)_{ult}$

$-(\varepsilon_2^c)_{ult} < \varepsilon_2 < (\varepsilon_2^c)_{ult}$

or

$-(\gamma_{12})_{ult} < \gamma_{12} < (\gamma_{12})_{ult}$

16. What are the types of hybrid laminates?
Interply hybrid laminates
Intraply hybrid composites
Interply-intraply hybrids
Resin hybrid laminates

17. What is warpage of laminates?
In laminates which are not symmetric, a temperature difference results in out-of-plane deformation. This deformation is also called warpage and is calculated by integrating –displacement equation

$$\kappa_x = -\frac{\partial^2 w}{\partial x^2}$$

$$\kappa y = -\frac{\partial^2 w}{\partial y^2}$$

$$\kappa_{xy} = -2\frac{\partial^2 w}{\partial x \partial y}$$

18. What is maximum stress failure theory?
The stresses acting on a lamina are resolved into the normal and shear stresses in the local axes. Failure is predicted in a lamina, if any of the normal or shear stresses in the local axes of a lamina are equal to or exceed the corresponding ultimate strengths of the unidirectional lamina.
Given the stresses or atrains in the global axes of a lamina, one can find the stresses in the material axes . The lamina is considered to be failed if

$$-(\sigma_1^c)_{ult} < \sigma_1 < (\sigma_1^T)_{ult}$$

$$-(\sigma_2^c)_{ult} < \sigma_2 < (\sigma_2^T)_{ult}$$

or

$$-(\tau_{12})_{ult} < \tau_{12} < (\tau_{12})_{ult}$$

19. What is strength ratio?
The strength ratio is defined as

$$\text{SR}=\frac{\text{Maximum Load Which Can Be Applied}}{\text{Load Applied}}$$

The concept of strength ratio is applicable to any failure theory. If SR>1, then the lamina is safe and the applied stress can be increased by a factor of SR. If SR<1, the lamina is unsafe and the applied stress needs to be reduced by a factor of SR. A value of SR=1 implies the failure load.

20. What is 'failure envelopes'?
A failure envelope is a three dimensional plot of the combinations of the normal and shear stresses which can be applied to an angle lamina just before failure. Since drawing three-dimensional graphs can be time consuming, one may develop failure envelopes for constant shear stress, τ_{xy}, and then use the two normal stresses σ_x and σ_y as the two axes. Then if the applied stress is within the failure envelope, the lamina is safe, otherwise it has failed.

Unit 4

1. List down the materials used for sandwich construction.
   Face material
   Core material
   Wood
   Foam
   Polyvinyl chloride foam(PVC)
   Poystyrene foams
   Polyurethane foams
   Polymethyl methacrylamide foams
   Styrene acrylonitrile (SAN) co-polymer foams

2. List down the advantages using a sandwich construction.
   Stiffness to weight ratio is high.
   Strength to weight ratio is high.
   Honeycomb sandwich panels are also used for energy absorption, air directionanlisation, acoustical and thermal versatility, radio frequency shielding etc.,
   Honeycomb is also used for straightening and directing air flow.

3. What are the three elements in a structural sandwich?
   A pair of thin and strong facing.
   A thick and light weight core to separate the facings and carry loads from one facings to the other and
   An attachment which is capable of transmitting shear and axial loads to and from the core.

4. List down the modes of failure in a sandwich structure.
   Facing failure
   Flexure crushing of core
   Local crushing of core
   General buckling
   Shear crimping
   Face wrinkling
   Intra-cell buckling (dimpling)

5. What are the different failure modes of sandwich construction?
   Facing failure
   Transverse shear failure
   Flexure crushing of core
   Local crushing of core
   General buckling
   Shear crimping
   Face wrinkling
   Intra-cell buckling (dimpling)

6. What is meant by sandwich construction?
   Two relatively thin, parallel sheets of structural material bonded to and separated by a relatively thick, light weight core.

7. Define: Shear crimping.
The column buckling caused by the core having too low a shear modulus.

8. Distinguish between face dimpling and face wrinkling.

Face dimpling	Face wrinkling
The compressive buckling of the facing in between the honeycomb walls caused by thin facings or large cell core.	The local compressive instability of facing; similar to plate buckling on an elastic foundation.

9. What is splicing?
When large core pieces or complex shapes are desired, small pieces can be spliced together with core splicing adhesives.

10. What is bonding pressure?
Adhesives such as the phenolics and some others actually require more than atmospheric pressure in order to prevent excessive porosity. Most of the core materials alone cannot withstand compressive bonding loads exceeding a few atmospheres and consequently are not fit to be used with any adhesive system requiring higher bonding pressures.

11. What is fillet forming?
In order to achieve a good attachment to an open cell core, the adhesive must have a unique combination of surface tension, surface wetting and controlled flow during early stages of cure. Controlled flow prevents the adhesive from flowing down the cell wall and leaving a low strength top skin attachment and an overweight bottom skin attachment.

12. What is adaptability?
In case of contoured parts, the adhesive must also be a good gap-filler without appreciable strength penalty, since tolerance control of details is much more difficult to achieve on contoured parts than on flat panels.

13. What is meant by flexure modulus.
The ratio, within the elastic limit, of the applied stress on a test specimen in flexure to the corresponding strain in the outermost fibers of the specimen.

14. What are the aspects must be considered in designing sandwich structures?
(a)The sandwich is a composite structure.
(b) The material used may be anisotropic
(c) The core has sufficient shear modulus.

15. What is the purpose of the attachment of core with facings?
(a) Act as single unit under deflection.
(b) Prevent separation and relative motion between the components
(c) Have sufficient strength to force failure in either the core or the facings at only the ultimate load.

16. Write short notes on : Polyvinyl chloride
Closed-cell polyvinyl chloride (PVC) foams are one of the most commonly used core materials for the construction of high Performance sandwich structures. Although, they are a chemical hybrid of PVC and polyurethane, they tend to be referred to simply as 'PVC foams'.

17. What is the needs of design guide lines in sandwich construction?
Requirements of thick facings to withstand the tensile, compressive and shear stresses induced by the design loads.
Adequate strength of the core to withstand shear stresses induced by the design loads.
Adequate compressive strength of the core to resist crushing by design loads acting normal to the panel facings or by compressive stresses induced through flexure.
Requirements of thick core having sufficient shear modulus to prevent overall buckling of the sandwich under load.

18. What is the property of toughness?
In the area of sandwich core-to–facing bonds, toughness refers to the resistance shown by the adhesive towards loads, which act to separate the facings from core under either static or dynamic conditions. Greater toughness in the bond line usually equates to greater durability and thus to longer service life.

19. Define: Foam.
The use of foam as a structural core continues to be extensive. Recent developments in the technology of foam injection have increased the use of these materials. The most novel of these methods is the use of a cold-cavity die, in which the foam is injection molded in a single production step. This is one of the core materials.

20. What are the types of honeycomb?
Paper honeycomb
Aluminium honeycomb
Glass fibre reinforced plastic honeycomb
Aramid paper honeycomb
Carbon fibre honeycomb
Kevlar honeycomb
Kevlar paper honeycomb

Unit 5

1. Explain the difference between fibers and whiskers.
   Fiber
   A fiber is characterised geometrically not only by its very high length to diameter ratio but by its near crystal sized diameter.
   Whiskers
   A whisker has essentially the same near-crystal-sized diameter as a fiber but generally is very short and stubby, although the length-to-diameter ratio can be in the hundreds. Thus a whisker is an even more obvious example of the crystal –bulk-material-property-difference paradox.

2. Distinguish between open mould and close mould processes.
   Open mould process: It is done in open structure.
   - Spray lay up
   - Hand lay up
   - Filament winding
   - SMC
   - Expansion tool moulding
   - Contact moulding

   Closed mould processes
   It is done in a closed structure.
   - Compression moulding
   - Vacuum bag
   - Injection moulding
   - Resin transfer

3. What is meant by sizing of glass fibers?
   The filaments are cooled rapidly and coated with a sizing such as starch, gelatine, oil etc. to avoid damage to the fibers. The sizing imparts strand integrity, resin compatibility, adhesion properties, etc. to the final product.

4. What is vacuum bag moulding?
   A process in which a lay-up is cured under pressure by drawing a vacuum in the space between the lay-up and a flexible sheet placed over it and sealed at the edges.

5. Define: Roving.
   Collection of bundles of continuous filaments either as untwisted strands or as twisted yarns.

6. What is pre-preg?
   It is impregnated with resin and partly cured. A combination of mat, fabric or non-woven material with resin advanced to B-stage, ready for curing.

7. What is meant by knitting?
   A method of constructing fabric by interlocking series of loops of one or more yarns.

8. State the process of injection moulding.
   Method of forming a plastic to the designed shape by forcing the heat softened plastic into a relatively cool cavity under pressure.

9. Give brief notes on: filament winding.
   A fabrication process in which continuous filament is treated with resin and wound onto a removable mandrel in a present pattern.

10. State the definition of fiber glass.
    An individual filament made by drawing molten glass. A continuous filament is a glass fiber of great of indefinite length.

11. What is facing failure?
    The sandwich panel failure caused by the facing failing in compression, tension or local buckling.

12. Explain the term: Facing.
    One of the two outer layers, which has been bonded to the core of a sandwich.

13. What is meant by cure?
    To change the properties of a thermosetting resin irreversibly by chemical reaction, i.e., condensation, ring closure, or addition. Cure may be accomplished by addition of curing (cross-linking) agents, with or without catalyst, and with or without heat and pressure.

14. Define the term: Creep.
    The time dependent part of strain resulting from an applied stress. Also referred to as the change in dimension of a material under load over a period of time.

15. What is creel?
    A framework arranged to hold tows, rovings or yarns so that many ends can be withdrawn smoothly and evenly without tangling.

16. What is ‘chopped strands’?
    Short strands cut from continuous filament strands of reinforcing fibetr, not held together by any means.

17. What is the function of caul plate?
    Smooth metal plates, free of surface defects, same size and shape as that of a composite lay-up, used immediately in contact with the lay-up during the curing process to transmit normal pressure and to a smooth surface on the finished laminate.

18. What are the characteristics of carbon fiber?
    Reinforcing fiber known for its light weight, high strength and high stiffness produced by pyrolysis of an organic precursor fiber in an inert atmosphere at temperature above 1000ºC. Can also be graphitised by heat-treating above 2500ºC.

19. What is the function of bleeder cloth?
A material used to allow the escape of gases and excess resin during cure cycle. It is removed after completion of curing cycle.

20. What are the desired properties of the matrix?
Reduced moisture absorption.
Low shrinkage.
Low coefficient of thermal expansion.
Good flow characteristics so that it penetrates the fibre bundles completely and eliminates voids during the compacting/curing process.
Reasonable strength, modulus and elongation (elongation should be greater than fibre).
Must be elastic to transfer load to fibers.

PartB (16 Marks) Questions with keys

Unit 1

1. Obtain an expression for E_1 , E_2, and G_{12} in terms of material properties with respect to principal material directions using mechanics of material approach.
Ans: Refer 'Mechanics of materials approach' by Autar K.Kaw pp 159-173.

2.(a) What are the advantages of composite material? And explain its area of application?
Ans: Refer 'Mechanics of materials approach' by Autar K.Kaw pp 28-45.

(b) Show the reduction of anisotropic material stress-strain equations to those of a monoclinic material stress-strain equations.
Ans: Refer 'Mechanics of materials approach' by Autar K.Kaw pp 75-77.

3. For a graphite/epoxy unidirectional lamina, find the following.
(a) Compliance matrix.
(b) Minor poisons ratio.
(c) Reduced stiffness matrix.
(d) Strains in the 1-2 co-ordinate system if the applied stresses are σ_1=2MPa, σ_2= -3MPa, τ_{12}= 4MPa,
E_1=181GPa, E_2=10.3 GPa, υ_{12}=0.28,G_{12}=7.17 GPa.
Ans:

$$\text{(a) } [S]=\begin{bmatrix} 0.0055 & -0.0015 & 0 \\ -0.0015 & 0.097 & 0 \\ 0 & 0 & 0.1395 \end{bmatrix} \text{x}10^{-9}\,\text{Pa}^{-1}$$

(b) $\upsilon_{21} = 0.01593$

(c) $[Q] = \begin{bmatrix} 181.8 & 2.897 & 0 \\ 2.897 & 10.35 & 0 \\ 0 & 0 & 7.17 \end{bmatrix} x10^9$

(d) $\varepsilon_1 = 15.69 \frac{\mu m}{m}$; $\varepsilon_2 = -294.4 \frac{\mu m}{m}$; $\gamma_{12} = 557.9 \frac{\mu m}{m}$.

4. Explain the Hooke.s law for different materials?
   Ans: Refer ‘Mechanics of materials approach’ by Autar K.Kaw pp 67-69.

5. Explain monoclinic material with compliance and stiffness matrices.
   Ans: Refer ‘Mechanics of materials approach’ by Autar K.Kaw pp 70-72.

Unit 2

1. (a) For glass epoxy laminate $E_f = 85$ Gpa, $E_m = 3.4$ GPa, $\upsilon_m = 0.3$ and $\upsilon_f = 0.25$, find the minor Poisson’s ratio υ_{21} and G_{12} for a fiber volume fraction of 70%.
   Ans; $\upsilon_{21} = 0.23$; $G_{12} = 0.03939$.

   (b) What weight of glass fibers must be added to 1kg of epoxy to produce a composite with a density of 1700 kg/m^3, $\rho_f = 2500$kg/m^3 and $\rho_m = 1200$ kg/m^3.
   Ans: Weight of glass fibers = 1.3007kg.

2.(a) Describe stress strain relations for a lamina of arbitrary orientation.
   Ans: Refer ‘Advanced composite materials’ by Lalit Gupta pp 115-116.

   (b) A graphite/ epoxy cuboid specimen with voids has dimensions a x b x c and its mass is Mc. After putting it in a mixture of sulphuric acid and hydrogen peroxide, the remaining graphite fibers have a mass Mf. From independent tests, the densities of graphite and epoxy are ρ_f and ρ_m, respectively. Find the volume fraction of the voids in terms of a, b, c, Mf,Mc, ρ_f and ρ_m.

   Ans.: $V_v = \frac{v_v}{abc} = 1 - \frac{1}{abc}\left[\frac{M_f}{\rho_f} + \frac{M_c - M_f}{\rho_m}\right]$

3. Explain the elasticity approach to find four elastic moduli.
   Ans: Refer ‘Mechanics of materials approach’ by Autar K.Kaw p180-183.

4. Explain Hooke.s law for a twodimensional unidirectional lamina?
   Ans: Refer ‘Mechanics of materials approach’ by Autar K.Kaw pp 80-82.

5. Find the following for a 60º angle lamina of graphite /epoxy. E_1=181GPa, E_2=10.3GPa, υ_{12}=0.28,G_{12}=7.17 GPa.
   (a) Transformed compliance matrix
   (b) Transformed reduced stiffness matrix
   If the applied stress is σ_x =2 MPa, σ_y =-3MPa, τ_{xy} = 4MPa, also find
   (c) Global strains
   (d) Local strains
   (e) Local stresses

(f) Principal stresses
(g) Maximum shear stress
(h) Principal strains
Ans:

$$\bar{S}_{12} = -0.7878(10^{-11})\frac{1}{Pa}$$

$$\bar{S}_{16} = -0.3234(10^{-10})\frac{1}{Pa}$$

(a) $$\bar{S}_{22} = 0.3475(10^{-10})\frac{1}{Pa}$$

$$\bar{S}_{26} = -0.4696(10^{-10})\frac{1}{Pa}$$

$$\bar{S}_{66} = 0.1141(10^{-9})\frac{1}{Pa}$$

(b) $$\left[\bar{Q}\right] = \begin{bmatrix} 0.2365 & 0.3246 & 0.2005 \\ 0.3246 & 0.1094 & 0.5419 \\ 0.2005 & 0.5419 & 0.3674 \end{bmatrix} x10^{11}\,Pa$$

(c) $$\begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix} = \begin{bmatrix} 0.5534(10^{-4}) \\ -0.3078(10^{-3}) \\ 0.5328(10^{-3}) \end{bmatrix}$$

(d) $$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{bmatrix} = \begin{bmatrix} 0.1367(10^{-4}) \\ -0.2662(10^{-3}) \\ -0.5809(10^{-3}) \end{bmatrix}$$

(e) $$\begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{bmatrix} = \begin{bmatrix} 0.1714(10^{7}) \\ -0.2714(10^{7}) \\ -0.4165(10^{7}) \end{bmatrix} Pa$$

(f) $\sigma_{max,min}$ = 4.217,-5.217 MPa
(g) τ_{max} = 4.717 MPa.
(h) $\varepsilon_{max,\,min}$ = 1.962(10^{-4}), -4.486(10^{-4})

Unit 3

1. Explain Tsai-Hill failure theory used for anisotropic materials.
   Show that for unidirectional lamina the failure theory can be written as $\sigma_1^2 / X^2 - \sigma_1\sigma_2 / X^2 + \sigma_2^2 / Y^2 + \tau_{12}^2 / S^2 = 1$ where σ_1, σ_2, τ_{12} are the stress components with respect to principal material direction and X, Y and Z are failure strengths of the lamina.
   Ans: Refer 'Mechanics of materials approach' by Autar K.Kaw pp 119-122.

2.(a) What are the types of laminates given below? Mention which elements of

[A],[B] and [D] are zero for each of them.

(1) [± 45 / ± 45]
(2) [30 / -45 / -30 / 45]
(3) [0 / 90 / 0 / 90]

Ans: (1) Angle ply laminate
(2) Balanced laminate
(3) Cross ply laminate and also

Refer 'Mechanics of materials approach' by Autar K.Kaw pp 269-271.

(b) Compute [A] matrix for a [0/±45] laminate with the following laminate properties. E_1 =145 GPa, E_2 =10.5 GPa, υ_{12} = 0.28 and G_{12} =7.5 GPa. Thickness of each lamina is 0.25 mm.

$$\text{Ans: } \begin{bmatrix} 6.045X10^6 & 1.728X10^6 & 0 \\ 5.55x10^5 & 2.668x10^7 & 0 \\ 0 & 0 & 2.068x10^7 \end{bmatrix}$$

3. Find the stiffness matrices [A], [B] for a three ply [0/30/-45] graphite epoxy laminate. Assume each lamina has a thickness of 5mm. The properties of graphite/epoxy E_l =181 GPa, E_t =10.3 GPa, υ_{lt} = 0.28 and G_{lt} =7.17 GPa.

$$\text{Ans: } [A] = \begin{bmatrix} 1.739x10^9 & 3.88x10^8 & 5.66x10^7 \\ 3.44x10^8 & 4.53x10^8 & -1.14x10^8 \\ 5.66x10^7 & -1.141x10^8 & 4.525x10^8 \end{bmatrix} \text{ Pa-m.}$$

$$[B] = \begin{bmatrix} -3.128x10^6 & 9.85x10^5 & -1.07x10^6 \\ 9.86x10^5 & 1.157x10^6 & -1.07x10^6 \\ -1.07x10^6 & -1.07x10^6 & 9.85x10^5 \end{bmatrix} \text{ Pa-m.}$$

4. A symmetric angle ply laminate hae the following data: 4 Layers of each 0.5mm thick +45º/-45º/-45º/+45º . E_l =210 GPa, E_t =21 GPa, υ_{it} = 0.3 and G_{it} =7 GPa. Compute the in-plane stiffness matrix of the laminate.
Ans: Refer 'Mechanics of materials approach' by Autar K.Kaw pp 237-23.

5. Derive the governing differential equation for a laminated unidirectional anisotropic plate.
Ans: Refer 'Mechanics of composite materials' by Robert M. Jones pp 290-299.

<u>Unit 4</u>

1(a) What are the materials used for sandwich construction.
Ans: Refer 'Advanced composite materials' by Lalit Gupta pp 68-76.

(b) Write short notes on the failure modes of sandwich panels.
Ans: Refer 'Advanced composite materials' by Lalit Gupta pp 83.

2. (a) Explain basic design concept of sandwich construction.
Ans: Refer 'Advanced composite materials' by Lalit Gupta pp 81-82.

(b) Explain the two methods of honey comb core manufacturing.
Ans: Refer ‘Advanced composite materials’ by Lalit Gupta pp 77-78.

3. Explain the cell configuration in honeycomb cores?
Ans: Refer ‘Advanced composite materials’ by Lalit Gupta pp 78-79.

4. Obtain an expression for the flexural modulus of a
(a) Sandwich plate with different face thickness.
(b) Sandwich plate with different face thickness and material.
Ans:Refer ‘Mechanics of materials approach’ by Autar K.Kaw pp 84-88.

5. Explain the honeycomb processes.
Ans: Refer ‘Advanced composite materials’ by Lalit Gupta pp 81-82.

Unit 5

1. (a) What are the functions and desirable properties of resins?`
Ans: Refer ‘Advanced composite materials’ by Lalit Gupta pp 33-34.

(b) Write short notes on vacuum bag moulding and continuous pultrusion.
Ans: Refer ‘Advanced composite materials’ by Lalit Gupta pp 201-203;215-217.

2. (a) Explain with neat sketches the production of carbon fibers.
Ans: Refer ‘Advanced composite materials’ by Lalit Gupta pp 15-18.

(b) What are the commercial forms of fibers?
Ans: Refer ‘Advanced composite materials’ by Lalit Gupta pp 9-32.

3.(a) Explain open and closed mould processes.
(b) Explain with neat sketches one fabrication process under each method.
Ans: Refer ‘Advanced composite materials’ by Lalit Gupta pp 189-215.

4. Explain any two methods of glass fiber manufacturing with neat sketch.
Ans: Refer ‘Advanced composite materials’ by Lalit Gupta pp 11-14.

5. (a) Explain the applications of resins.
Ans: Refer ‘Advanced composite materials’ by Lalit Gupta pp 43-44.

(b) Write short notes on Netting analysis.
Ans: Refer ‘Mechanics of composite materials’ by Robert M. Jones pp 253-254.