COURSE CONTENT

UNIT-V

Introduction to Composite Materials
A composite material is formed by combining two or more materials with different properties to achieve superior performance. The main constituents are:

- **Fiber (Reinforcement):** Provides strength and stiffness
- **Matrix:** Binds fibers and transfers load

Micromechanics studies how these constituents interact at a microscopic level.

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2. Volume Fractions and Their Importance
Volume fraction is a key parameter:

Vf = Volume of fiber / Total volume
Vm = Volume of matrix / Total volume

Important relation:
Vf + Vm = 1

Higher Vf → higher strength and stiffness (generally)

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3. Density of Composites

ρc = Vf ρf + Vm ρm

Additional Points:

- Lightweight composites are achieved using low-density fibers (e.g., carbon fiber)
- Density affects strength-to-weight ratio

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4. Elastic Properties of Composites

4.1 Longitudinal Modulus (Iso-strain condition)
Assumption: Fiber and matrix undergo same strain

Ec = Ef Vf + Em Vm

Used for loading parallel to fibers

4.2 Transverse Modulus (Iso-stress condition)

Assumption: Fiber and matrix carry same stress

$1/E_c = V_f/E_f + V_m/E_m$

Used for loading perpendicular to fibers

4.3 Shear Modulus

$1/G_c = V_f/G_f + V_m/G_m$

4.4 Poisson's Ratio

$\nu_c = V_f \nu_f + V_m \nu_m$

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5. Advanced Micromechanical Models

5.1 Halpin–Tsai Equations

$E_c = E_m [(1 + \xi\eta V_f) / (1 - \eta V_f)]$

Where:
$\eta = (E_f/E_m - 1) / (E_f/E_m + \xi)$
ξ depends on fiber geometry (typically 1–2 for circular fibers)

Advantages:

- Accounts for fiber shape
- More accurate than rule of mixtures

5.2 Limitations of Simple Models

- Assume perfect bonding

- Ignore voids and defects
- Not accurate for high temperature or damage conditions

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6. Stress Analysis in Composites

6.1 Longitudinal Stress

$\sigma c = \sigma f\ Vf + \sigma m\ Vm$

6.2 Transverse Stress

- Non-uniform distribution
- Higher stress concentration in matrix

6.3 Stress Concentration Effects

- Occur near fiber ends and discontinuities
- Can lead to crack initiation

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7. Transverse Stresses and Failure Mechanisms

Causes:

- Load perpendicular to fibers
- Thermal mismatch
- Manufacturing defects

Failure modes:

- Matrix cracking
- Fiber pull-out
- Delamination

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8. Thermal Properties of Composites

8.1 Coefficient of Thermal Expansion (CTE)

Longitudinal CTE:
$\alpha_c \approx \alpha_f V_f + \alpha_m V_m$

Transverse CTE:
More complex and matrix-dominated

8.2 Thermal Conductivity

- High along fiber direction
- Low across fibers

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9. Hydrothermal Effects

Hydrothermal = Temperature + Moisture effects

Causes:

- Absorption of moisture by matrix
- Temperature variation

Effects:

- Swelling of matrix
- Reduction in stiffness
- Degradation of interface

Engineering Importance:

- Critical in marine and aerospace structures

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10. Load Transfer Mechanism

Shear Lag Theory (Concept):

- Load transfer occurs through shear stress at fiber-matrix interface

Stages:

1. Load applied to composite

2. Matrix deforms
3. Shear stress develops at interface
4. Load transferred to fibers

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11. Critical Fiber Length

Minimum fiber length required for effective load transfer:

$$L_c = (\sigma_f \times d) / (2\tau)$$

Where:
σ_f = fiber strength
d = fiber diameter
τ = shear stress at interface

If fiber length < Lc → inefficient reinforcement

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12. Interface and Bonding

Types of bonding:

- Mechanical bonding
- Chemical bonding
- Physical bonding

Strong interface → better load transfer
Weak interface → debonding and failure

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13. Types of Fiber Arrangements

- Continuous fibers
- Short fibers
- Random orientation
- Woven fibers

Effect:

- Directional properties (anisotropy)

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14. Advantages of Composite Materials

- High strength-to-weight ratio
- Corrosion resistance
- Tailorable properties
- High fatigue resistance

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15. Limitations of Composites

- High cost
- Complex manufacturing
- Difficult repair
- Sensitivity to temperature and moisture

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16. Applications

- Aerospace (aircraft wings, fuselage)
- Automotive (body panels, drive shafts)
- Marine (boat hulls)
- Civil engineering (bridges, reinforcement)

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17. Design Considerations

- Fiber orientation
- Volume fraction
- Environmental conditions
- Type of loading

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18. Summary

- Micromechanics helps predict composite behavior
- Rule of mixtures is simple but approximate
- Halpin–Tsai gives improved predictions
- Thermal and hydrothermal effects are critical
- Load transfer efficiency determines performance

COURSE CONTENT