Introduction to Composite Materials and Structures

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Lecture 31
Failure of Unidirectional Composites
*Transverse Compression, Shear, and Out-of-Plane Loading*
Failure Due to Transverse Compression

- A unidirectional lamina, when subjected to compressive load, can fail in various ways. These failure modes are:
  - Matrix shear failure
  - Matrix shear failure accompanied with debonding and/or crushing of fibers

- Figure 31.1 shows how a unidirectional lamina subjected to transverse load may fail in shear, accompanied with debonding of fibers.
Failure Due to Transverse Compression

- It has been experimentally observed that transverse compression strength of a unidirectional lamina is less than its longitudinal compression strength.

- However, if constraints are imposed on the lamina such that the deformation in direction normal to load-fiber axes are prevented, then the transverse compressive strength may be comparable to longitudinal compressive strength.

- This increase in transverse compressive strength is attributable to the fact that due to imposition of such constraints, failure now occurs due to shearing of fibers, which are significantly stronger than matrix and interface. In such a situation, transverse compressive strength should increase with fiber volume fraction, and this has indeed been confirmed by experiments.
Failure Due to Inplane Shear

- Figure 31.2 shows a representation of unidirectional lamina subjected to in-plane shear force.

- As shown in Fig. 31.2, a unidirectional lamina develops high values of *shear-stress concentration* at the fiber-matrix interface, when subjected to in-plane shear forces. This high shear stress concentration can cause shear failure in the matrix, which may be accompanied by fiber-matrix debonding as well.
Failure Due to Inplane Shear

• In general, the failure of a unidirectional lamina due to inplane shear force may occur in three different modes.
  - Failure of matrix due to shear stress.
  - Failure of matrix due to shear stress accompanied with fiber-matrix debonding
  - Fiber-matrix debonding

• The inplane shear strength of a unidirectional lamina, $\tau_{LTU}$ can be expressed as ratio of matrix shear strength, $\tau_{mu}$ and shear strain concentration factor, $k_\tau$, using the following relation:

$$\tau_{LTU} = \frac{\tau_{mu}}{k_\tau}$$

$$k_\tau = \frac{1 - V_f (1 - \frac{G_m}{G_{12f}})}{1 - (\frac{4V_f}{\pi})^{1/2} (1 - \frac{G_m}{G_{12f}})}$$

Eq. 31.1
Failure Due to Out-of-Plane Loading

• A unidirectional lamina may be subjected to out-of-plane loading as well. This loading could be application of either of the following:
  – Tensile or compressive stress in out-of-plane direction, i.e. $\sigma_3$.
  – Shear stress $\tau_{23}$.
  – Shear stress $\tau_{13}$.

• If the material is transversely isotropic in 2-3 plane, and is normally loaded out-of-plane through $\sigma_3$, then, such a loading is equivalent application of inplane load $\sigma_2$.

• Similarly, a unidirectional lamina which is isotropic in 2-3 plane responds to application of out-of-plane shear stress $\tau_{13}$, in ways similar to those when it sees in-plane shear stress $\tau_{12}$.
Failure Due to Out-of-Plane Loading

- Further, a unidirectional lamina which is isotropic in 2-3 plane responds to application of out-of-plane shear stress $\tau_{23}$, in an equivalent way when it is exerted upon by biaxial tension/compression along axes $y$, and $z$, which are at 45° to 2- and 3-axes. This is shown in Fig. 31.3.

Fig. 31.3: Unidirectional composite’s failure mode due to application of pure out-of-plane shear along aligned with 1-2 plane
Failure Due to Out-of-Plane Loading

• For such a biaxial loading, the most probable failure mode would be cracking of matrix in direction normal to y axis. This is shown in Fig. 31.3. The reason for such a failure mode is the fact that the material is significantly weaker in transverse tension, vis-à-vis transverse compression.

• However, the failure strength for such a failure mode may be approximately equal (not exactly equal) that of sample under pure transverse tension. This is because the sample is loaded biaxially, and not uniaxially.
References

