Mechanical Testing of Composites and their Constituents

- Tests done to determine intrinsic material properties such as modulus and strength for use in design and analysis (major emphasis here)
- Tests done to determine quality or acceptability of specific components during manufacturing (minor emphasis here)

American Society for Testing and Materials (ASTM) Standards

- ASTM Standards and Literature References for Composite Materials, 1987
- ASTM Vol. 15.03 Space Simulation; Aerospace and Aircraft; Composite Materials, published annually

Direct measurement of fiber longitudinal properties $E_f$ and $S_f^{(+)}$

Indirect measurement of fiber longitudinal properties $E_f$ and $S_f^{(+)}$

Tensile measurement of neat resin properties $E_m$ and $S_m^{(+)}$

Note: Experimental load-deflection curve compared with predicted curve (from finite element model) using $E_{12}$ as a curve-fitting parameter in prediction

Note: strength and modulus values must be corrected to account for the portion of the load carried by resin (use micromechanics equations)
ASTM 618-81 Conditioning Plastics and Electrical Insulating Materials for Testing

Standard Laboratory Atmosphere:
Temperature of 23°C (73.4°F) and relative humidity of 50%

Specimen for measurement of neat resin compressive properties $E_m$ and $S_m^{1/3}$

Neat resin compression specimen support jig

Compression test fixture for neat resin specimen

3 point bending specimen for measurement of flexural properties of neat resin or composite

4 point bending specimen for measurement of flexural properties of neat resin or composite

Bending moment diagram
Composite tensile specimen for measurement of longitudinal properties $E_x$ and $S_{11}$:

![Composite tensile specimen](image1)

Description of specimen from ASTM D3039-76:

![Description of specimen](image2)

Typical stress-strain curves from D3039 specimen:

![Typical stress-strain curves](image3)

End constraints can cause bending of off-axis tensile specimens due to shear coupling:

![End constraints](image4)

Importance of specimen length-to-width ratio:

![Importance of specimen length-to-width ratio](image5)

Difference between $E_x$ and $\overline{E}_{11}$ for graphite/epoxy:

![Difference between $E_x$ and $\overline{E}_{11}$](image6)
Lamina tensile strength can be “backed out” from laminate tensile test data.

Compression test specimen and fixture for ASTM D3410-87 Procedure A (Celanese fixture)

Note: D3410-87 fixtures produce side-loading rather than end-loading as in D695-90.

Exploded view of compression test specimen and fixture for ASTM D3410-87 Procedure A

Compression test specimen and fixture for ASTM D3410-87 Procedure B (IITRI fixture)

Compression test specimen and fixture for ASTM D3410-87 Procedure C (sandwich beam)

Compression after impact (CAI) fixture
Measurement of shear properties $G_{12}, S_{LT}$

- Rail shear test, ASTM D4255-83
- ±45 degree laminate test
- Off-axis tensile test
- Iosipescu shear test, ASTM D5379
- Torsion tube
- Sandwich cross-beam

Rail shear test, ASTM D4255-83 Methods A and B

Shear stress from applied stress:
$$\tau = \frac{P}{W}$$

Shear strain from measured normal strains:
$$\gamma = \varepsilon_x - \varepsilon_y$$

Shear modulus:
$$G_{12} = \frac{P \tau}{2W}$$

Off-axis tensile test for indirect measurement of $G_{12}$

Young’s modulus, $E_x:
$$E_x = \frac{\sigma_x}{\varepsilon_x}$$

When $\sigma_y = 0, \sigma_z = 0$

$$E_x = \frac{\sigma_x}{\varepsilon_x} = \frac{1}{S_{11}} = \frac{1}{S_{11}} \sigma_x$$

or

$$E_x = \frac{1}{E_1} \left[ -\frac{2v_{12}}{E_1} + \frac{1}{G_{12}} \right] \sigma^2 + \frac{1}{E_2} \sigma^4$$

(2.38)
Off-axis tensile test for indirect measurement of $G_{12}$

- Conduct off-axis tensile test to measure $E_\alpha$ at some fiber orientation $\theta$
- Conduct longitudinal tension test to measure $E_1$ and $\nu_{12}$
- Conduct transverse tension test to measure $E_2$
- Use above results in Eq. 2.39 to calculate $G_{12}$

Iosipescu test specimen and fixture for in-plane or through-thickness shear properties

ASTM D2344-76 Short beam shear test for interlaminar strength (parallel fibers only)

Note: not recommended for measurement of design properties, only for quality control and specification
Short beam shear test

- Short beam fails due to interlaminar shear stress
- Long beam fails due to either tensile or compressive normal stress on bottom or top of beam, respectively
- Questions about accuracy of mechanics of materials beam theory equations for stresses in short beams where support effects may not be negligible (Whitney’s theory of elasticity analysis)

Exact stress distributions in short beam shear test specimen from theory of elasticity analysis

Conclusion: Stress distributions from mechanics of materials beam theory are only accurate far away from loads and supports

Single fiber fragmentation specimen for measurement of fiber/matrix interfacial shear strength

Test procedure: Load specimen until fiber starts to break up into fragments, then measure “critical lengths” of fragments, then calculate interfacial shear strength from theory of discontinuous fiber composites developed later in Chap. 6

Microindenter test for fiber/matrix interfacial shear strength

Test procedure: Load end of fiber in compression with microindenter probe until fiber slips with respect to matrix, then use finite element analysis of specimen to estimate fiber/matrix interfacial shear strength

Microbond test for fiber/matrix interfacial shear strength

Problem: Difficult to reproduce the composite resin matrix cure condition in a small droplet.

<table>
<thead>
<tr>
<th>Fiber type</th>
<th>Fragmentation</th>
<th>Microbond</th>
<th>Microindenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2-4</td>
<td>95</td>
<td>39</td>
<td>71</td>
</tr>
<tr>
<td>A1-4</td>
<td>37</td>
<td>23</td>
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<td>13h-500</td>
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<td>37</td>
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<tr>
<td>16h-100</td>
<td>22</td>
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<td>27</td>
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</table>

Source: Fred McDougle et al. [1939]. Reprinted by permission of the Society for the Advancement of Material and Process Engineering.
Exploded view of test fixture for ASTM D2290-76
Split Disk Test for Rings