Composite Structure Engineering Safety Awareness Course

Module: Composite Materials Test Methods

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Composite Materials Test Methods

AGENDA

- Constituent and Prepreg Test Methods
- Physical Test Methods for Composites
- Mechanical Test Methods for Composites
- Adhesives Testing
- Test Methods for Sandwich Composites
- Non-Destructive Testing
Constituent Test Methods

♦ Fibers: CMH-17 Vol. 1, Chapter 3
  - Physical testing – Density, Thermal Properties
  - Mechanical testing – Tension

♦ Matrix: CMH-17 Vol. 1, Chapter 4
  - Thermal/Physical testing – Density, Electrical Resistivity, Coefficient of Thermal Expansion
  - Mechanical testing – Tension, Compression, Shear
Fiber Characterization Testing: Examples

Physical Testing: For constituent content

(CMH-17 Vol. 1, Sections 3.3, 3.4)
- Fiber diameter
- Fiber density – ASTM D 3800, liquid displacement

Mechanical Testing

(CMH-17 Vol. 1, Section 3.5)
- Tensile properties
  - Single fiber tests  ASTM D 3379
  - Tow tests  ASTM D 4018
Matrix Characterization Testing: Examples

- **Thermal Analysis** (CMH-17 Vol. 1, Section 4.5)
  - Glass Transition Temperature, Tg
  - Thermal expansion properties

- **Physical Testing** (CMH-17 Vol. 1, Section 4.5)
  - Matrix density – ASTM D 792 or D 1505

- **Mechanical Testing** (CMH-17 Vol. 1, Section 4.6)
  - Tensile properties - ASTM D 638
  - Compression, shear, flexure
Prepreg Test Methods

- CMH-17 Vol. 1, Chapter 5
- Focus on properties and characteristics of uncured prepreg
  - Fiber and resin content
    - Resin extraction, ASTM C 613
  - Resin flow, gel time
  - Surface tack, drape
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Physical Test Methods for Composites

CMH-17 Vol. 1, Chapter 6

- Density - ASTM D 792
- Constituent content (fiber, matrix, voids)
  - Matrix digestion ASTM D 3171
  - Ignition loss   ASTM D 2584
  - Image analysis
- Flammability
- Thermal cycling/microcracking
- EMI shielding effectiveness
**T_g Determination: Thermoset Composites**

**CMH-17 Vol. 1, Section 6.6.3**

Glass Transition Temperature, $T_g$: A temperature-induced change in the matrix material from the glassy to the rubbery state during heating... A change in matrix stiffness of two or three orders of magnitude occurs during the glass transition

- **Dynamic Mechanical Analysis (DMA)**
  - Most common method
  - Forced oscillation measurement
- **ThermoMechanical Analysis (TMA)**
  - Measure changes in thermal expansion
- **Differential Scanning Calorimetry (DSC)**
  - Measure change in heat capacity associated with $T_g$
  - Well suited for neat resin specimens, more difficult with composites
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- Physical Test Methods for Composites
- **Mechanical Test Methods for Composites** *(CMH-17 Vol. 1, Chapter 6)*
- Adhesives Testing
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Unique Aspects of Testing Composite Materials

- Orthotropy: different stiffnesses and strengths in different directions.
- Minimum thickness flat plates for testing
- Properties not always the same in tension and compression
Elastic Material Properties

• Isotropic Materials (metals, plastics, ceramics, etc.)
  \[ E, \nu, G \]
  But only two are independent:

• Composite Lamina (layer, ply)
  \[ E_1, E_2, E_3 \]
  \[ \nu_{12}, \nu_{13}, \nu_{23} \]
  \[ G_{12}, G_{13}, G_{23} \]

Transverse Isotropy:
  \[ E_2 = E_3 \]
  \[ G_{12} = G_{13} \]
  \[ \nu_{12} = \nu_{13} \]
  \[ G_{23} = \frac{E_2}{2(1 + \nu_{23})} \]
Strength Properties of a Composite Material (Lamina)

- 3 Axial Tensile Strengths
  \( S_1^+, S_2^+, S_3^+ \)
- 3 Axial Compressive Strengths
  \( S_1^-, S_2^-, S_3^- \)
- 3 Shear Strengths
  \( S_{12}, S_{13}, S_{23} \)

Transverse Isotropy: \( S_2 = S_3 \), \( S_{12} = S_{13} \)
Tension Test For Flat Specimens
ASTM D 3039

- Straight-sided specimens
- 0.5 in. wide, ~ 8 in. long
- Adhesively bonded tabs
- Strain gages (or extensometer) to measure axial and transverse strain (for $E$, $\nu_{12}$)
- Requires valid gage section failure
Tabbing of Composite Tension Specimens: Design Variables

Tab Material
- G10 or G11 glass/epoxy circuit board material

Tab Geometric Design
- 0.04-0.08 in. thickness
- Between 5° and 30° taper angle

Adhesive Selection
- High strength
- Thick bondline (0.010 to 0.050 in.)

Categories of Compression Testing

Shear loading methods
- IITRI compression test (ASTM D 3410)

End loading methods
- Modified ASTM D 695

Combined loading methods
- Combined Loading Compression (CLC), ASTM D 6641
Common Compression Test Methods

**Shear loading**
ASTM D 3410
- 5.5 in. long specimen
- 0.5 in. gage length
- Versatile
- Heavy and expensive

**End loading**
Modified ASTM D 695
- 3.18 in. long specimen
- 0.188 in. gage length
- Separate tests for modulus (untabbed) and strength (tabbed)

**Combined loading**
ASTM D 6641
- 5.5 in. long specimen
- 0.5 in. gage length
- Adjustable loading ratio via bolt torque
Shear Testing – Flat Composite Plates

**In-plane shear testing:**

Stiffness: $G_{12}$  
Strength: $S_{12}$

**Out-of-plane (interlaminar) shear testing**

Stiffness: $G_{13}$, $G_{23}$  
Strength: $S_{13}$, $S_{23}$
Common Test Methods: In-Plane Shear

Iosipescu Shear
ASTM D 5379
- 3 x 0.75 in. specimen
- Edge loaded

V-Notched Rail Shear
ASTM D 7078
- 3 x 2.2 in. specimen
- Face loaded
- Recommended by CMH-17

±45 Tension Shear
ASTM D 3518
- Combined stress state (not pure shear)
- Easy to perform
Common Test Methods:

Out-Of-Plane (Interlaminar) Shear

Short Beam Shear
ASTM D 2344
• Shear strength only
• Combined stress state
• Small specimen
• Simple and affordable test

Iosipescu Shear
ASTM D 5379
• 3 x 0.75 in. specimen
• Edge loaded
• Modulus and strength
Other Composite Material Test Methods

- **“Notched” Laminate Testing**
  CMH-17 Vol. 1, Section 7.4

- **Bearing Testing**
  CMH-17 Vol. 1, Section 7.5

- **Compression After Impact Testing**
  CMH-17 Vol. 1, Section 7.7

- **Fracture Mechanics Testing**
  CMH-17 Vol. 1, Section 6.8.6
“Notched” Laminate Testing

- Laminate test, does not yield a material property
- “Notch” = hole
- Tested in tension or compression with or without a fastener (“open” or “filled”)
  - Open-hole tension
  - Filled-hole tension
  - Open-hole compression
  - Filled-hole compression
- Used to provide design values
  - Mechanically fastened joints
  - Effects of manufacturing anomalies and small damage areas
- Governed by ASTM standards (D 5766, D 6484)
Example Notched Laminate Testing: Open Hole Compression Testing

ASTM D 6484

- 12" long x 1.5" wide specimen
- 0.25" diameter center hole
- Face supported
- Clamped in hydraulic grips or end loaded
- Staggered V-shaped joints in both sides of the fixture
- Guide plates to maintain alignment.
Bearing Testing

- Laminate test
- Utilizes specified bolted joint configuration
  - Single shear
    - One bolt
    - Two bolt
  - Double shear
- Used to compare materials and provide design values
  - Not meant to be representative of actual joint designs
  - Yield and ultimate bearing strength
  - Governed by ASTM D 5961
Compression Strength After Impact (CSAI)

ASTM D 7136 - Damage Resistance
ASTM D 7137 - Damage Tolerance
• 4 in. x 6 in. specimen

NASA CAI Test
• 5 in. x 10 in. specimen
Fracture Mechanics Testing

- Determine propagation characteristics of existing cracks/delaminations
- Considers three modes of crack growth
  - Mode I – opening or extension
  - Mode II – shear
  - Mode III – tearing or twist
Fracture Mechanics Test Methods

**Mode I:** ASTM D 5528

*Double cantilever beam flexure test (tension)*

**Mode II:** Currently no ASTM standard

*End-notched flexure test (shear)*
Fracture Mechanics Test Methods

**Mixed Mode (Mode I & II)**
Mixed Mode Bending (MMB) Test, ASTM D 6671

![Diagram of test setup](image)

**Mode I**

**Mode II**
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**Adhesives Testing** *(CMH-17 Vol. 1, Section 7.6)*

- Test Methods for Sandwich Composites
- Non-Destructive Testing
Categories of Adhesives Testing

Adhesive characterization testing
- Typically tensile and shear testing
- Provides adhesive stiffness and strength data
  - Ultimate strength, initial tangent modulus
  - Stress versus strain curves
- Used for design & analysis, comparisons

Bonded joint characterization testing
- Representative of actual joint to be used
- Typically do not follow standardized test methods
Adhesive Characterization: Examples of Shear Test Methods

ASTM D 5656
Thick Adherend Specimen

ASTM D 5379
Iosipescu Shear Specimen

Bonded Joint Characterization Testing
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Test Methods for Sandwich Composites (CMH-17 Vol. 1, Section 6.8)

- Non-Destructive Testing
Mechanical Test Methods for Sandwich Composites

- Flatwise Tension   ASTM C 297
- Flatwise Compression  ASTM C 365
- Sandwich Panel Shear   ASTM C 273
- Sandwich Panel Flexure   ASTM C 393
- Climbing Drum Peel   ASTM D 1781
- Fracture Mechanics Testing
Sandwich Panel Shear Test
ASTM C 273

Tension Loading

Compression Loading
Other Sandwich Panel Tests

Climbing Drum Peel
ASTM D 1781

Mode I Fracture Mechanics: Single Cantilever Beam
(Proposed ASTM standard)
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Why Non-Destructive Testing?

*Also referred to as Non-Destructive Inspection (NDI) & Non-Destructive Evaluation (NDE)*

- Find defects/anomalies that may affect composite performance:
  - Inhomogeneities within the materials
  - Fiber breakage
  - Resin micro-cracking
  - Voids and porosity
  - Delaminations
  - Cure deficiencies
NDT vs. “Destructive” Testing

Non-Destructive Testing (NDT) locates potential problem areas

Destructive (mechanical) testing...
- Required to define problem extent
- Aided and minimized by analysis
- Often both destructive testing and analysis are required
Typical NDT Techniques For Composites

- Visual Inspection
- Tap Testing
- Ultrasonic Methods
- X-Ray
- Thermography
- Shearography
Visual Inspection

- Easiest system to use (eye, microscope)
- Can visually detect...
  - Surface damage (ex: abrasions, cuts, dents)
  - Blisters, bubbles on surface
  - Porosity, delaminations (inspection of edges)
- First line of investigation
Tap Testing

- Follow-on to visual inspection
- Based on ability to 'hear' sound differences
- Effective in mapping delamination areas
- Used extensively because of ease and cost
- Computer-aided/electronic tap testers available for commercial usage

http://www.asi-nde.com
Ultrasonic Test Methods

*Used to monitor for delaminations, voids/porosity, fiber/matrix damage*

**Through-transmission**
- Requires access to both sides of composite structure

**Pulse echo**
- Requires access from only one side of composite structure
- More applicable to field inspections
X-Ray Inspection

- Detects density changes
- Well suited for bonded interfaces
- Can locate delaminations, voids, porosity, moisture, inclusions
- Technique in use many years (rocket motors, nozzles)
Thermography

- Uses heat transfer --- not sound waves
- Requires infrared video camera
- Measures effects from thermal changes
- Useful for locating delaminations and contamination (moisture, solvents)
- Potential field usage
References:
Composite Materials Test Methods

- CMH-17, Composite Materials Handbook, Volume 1
- ASTM Annual Book of ASTM Standards, Volume 15.03, Space Simulation; Aerospace and Aircraft; Composite Materials