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

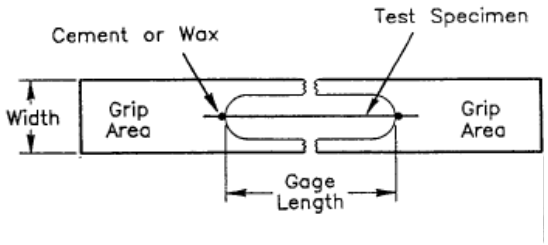
  (CMH-17 Vol. 1, Sections 3.3, 3.4)

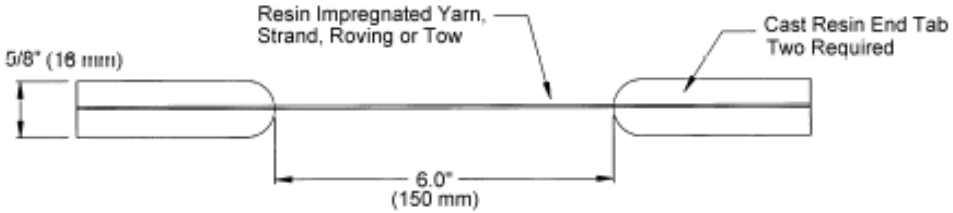
  - Fiber diameter
  - Fiber density – ASTM D 3800, liquid displacement

- Mechanical Testing

  (CMH-17 Vol. 1, Section 3.5)

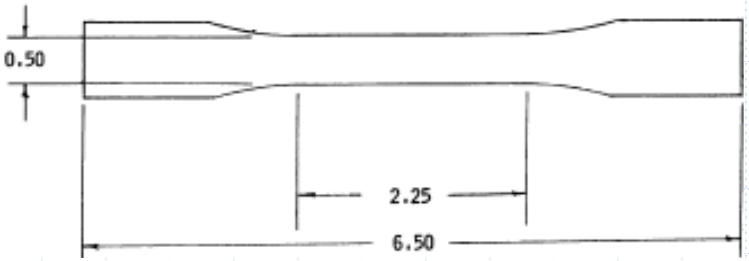
  - Tensile properties
    - Single fiber tests ASTM D 3379
    - Tow tests ASTM D 4018





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

Composite Materials Test Methods

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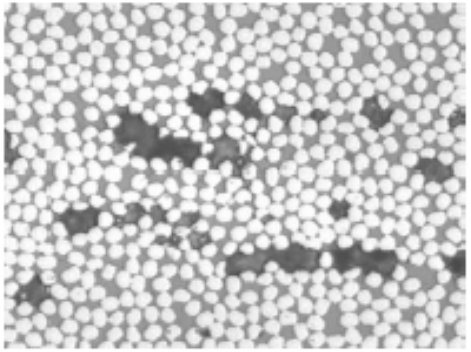
- Non-Destructive Testing

Physical Test Methods for Composites

CMH-17 Vol. 1, Chapter 6

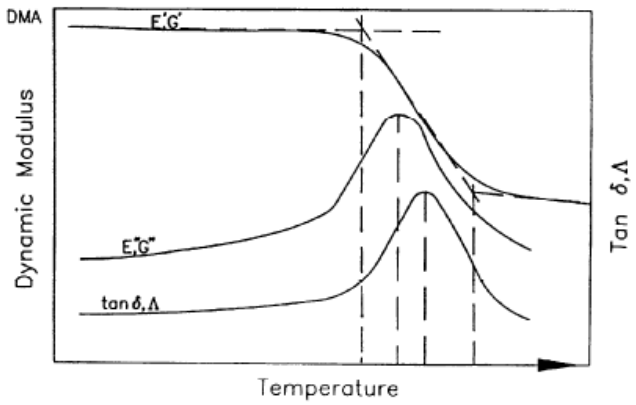
- Density - ASTM D 792
- Constituent content (fiber, matrix, voids)
  - Matrix digestion ASTM D 3171
  - Ignition loss ASTM D 2584
  - Image analysis
- Flammability
- Thermal cycling/microcracking
- EMI shielding effectiveness



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

Composite Materials Test Methods

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- Constituent and Prepreg Test Methods
- Physical Test Methods for Composites
- **Mechanical Test Methods for Composites** (CMH-17 Vol. 1, Chapter 6)
- Adhesives Testing
- Test Methods for Sandwich Composites
- Non-Destructive Testing

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, ν, G

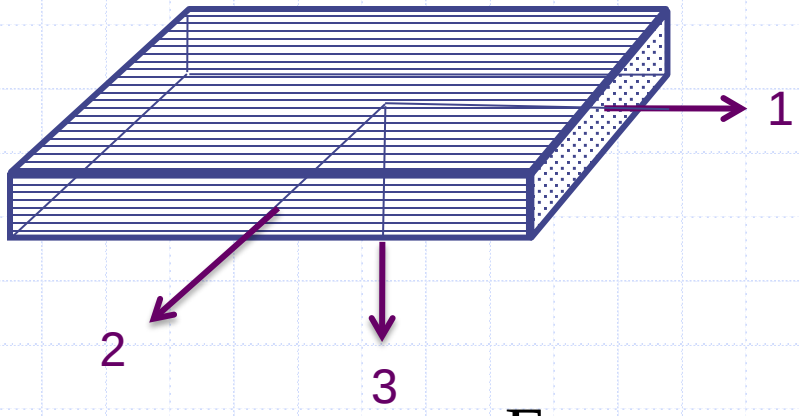
  But only two are independent: $G = \dfrac{E}{2(1+\nu)}$

- Composite Lamina (layer, ply)

  E_1 , E_2 , E_3

  ν_{12} , ν_{13}, ν_{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

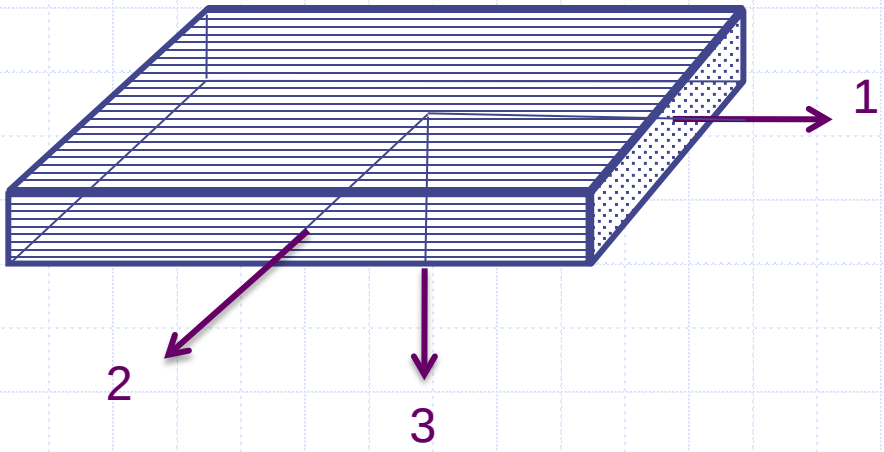
  S_1^+ , S_2^+ , S_3^+

- 3 Axial Compressive Strengths

  S_1^- , S_2^- , S_3^-

- 3 Shear Strengths

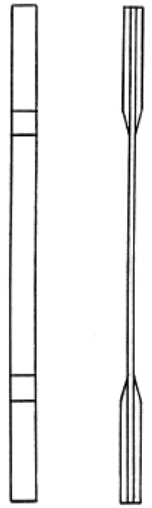
  S_{12} , S_{13} , S_{23}

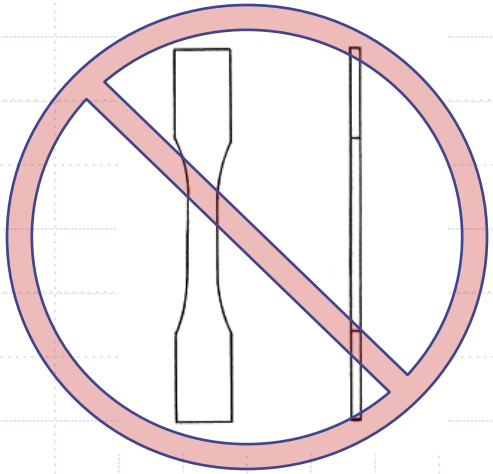


Transverse Isotropy: $S_2 = S_3$ $S_{12} = S_{13}$

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, ν_{12})
- Requires valid gage section failure





Tabbing of Composite Tension Specimens: Design Variables

Tab Material

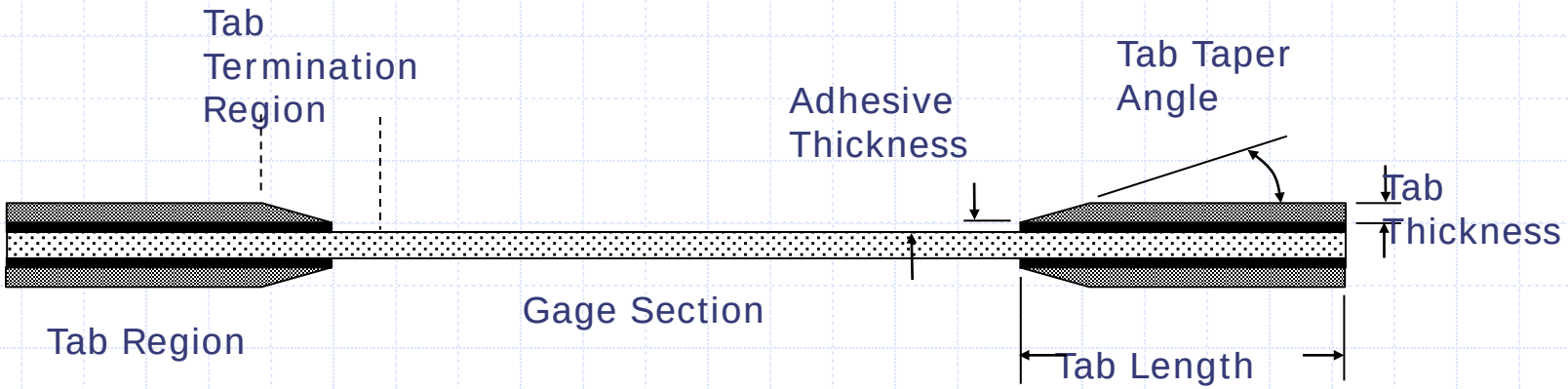
- G10 or G11 glass/epoxy circuit board material

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.)



Reference: Daniel O. Adams and Donald F. Adams, "Tabbing Guide for Composite Test Specimens," DOT/FAA/AR-02/106, October 2002. http://www.tc.faa.gov/its/worldpac/techrpt/ar02-106.pdf

Categories of Compression Testing

Shear loading methods

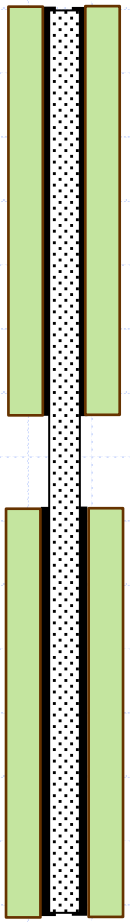
- IITRI compression test (ASTM D 3410)

End loading methods

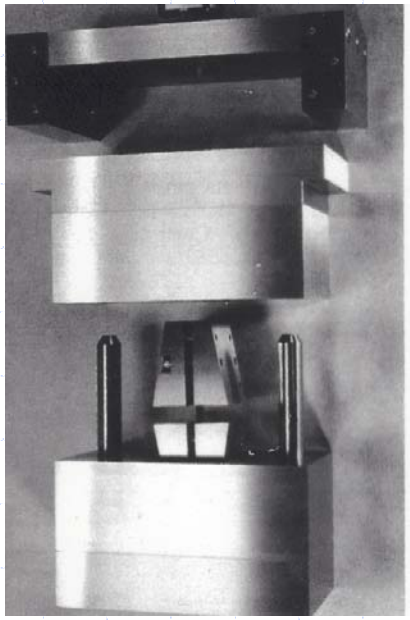
- Modified ASTM D 695

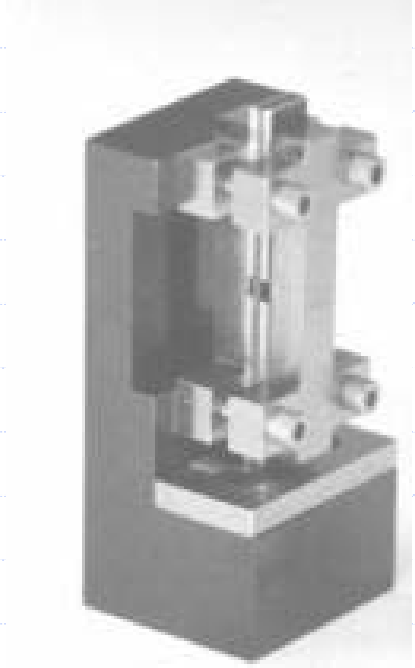
Combined loading methods

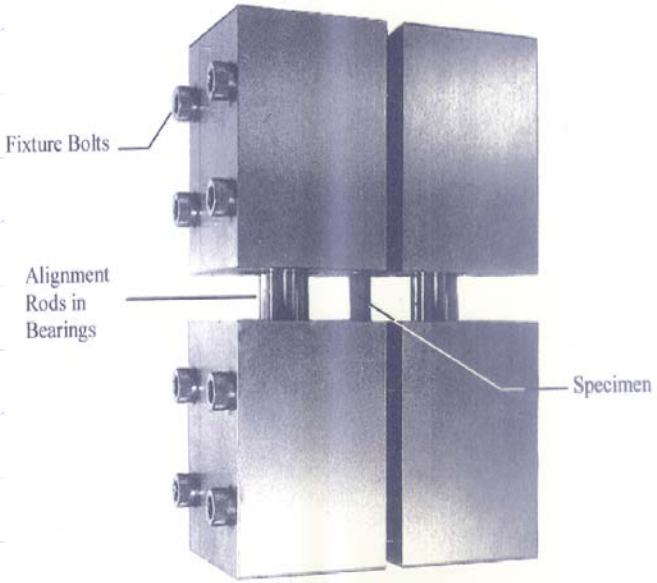
- Combined Loading Compression (CLC), ASTM D 6641



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

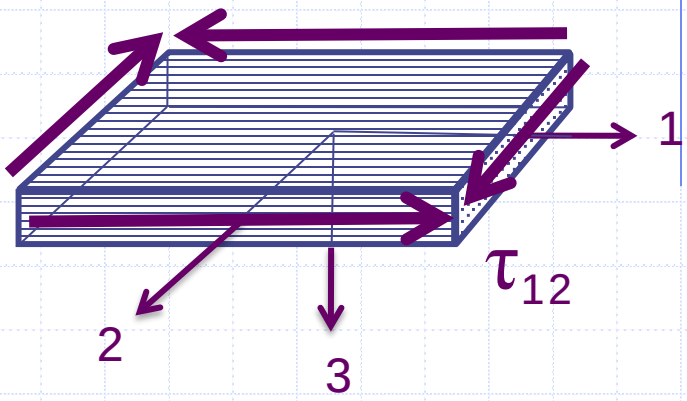
ASTM D 6641

- 5.5 in. long specimen
- 0.5 in. gage length
- Adjustable loading ratio via bolt torque

Shear Testing – Flat Composite Plates

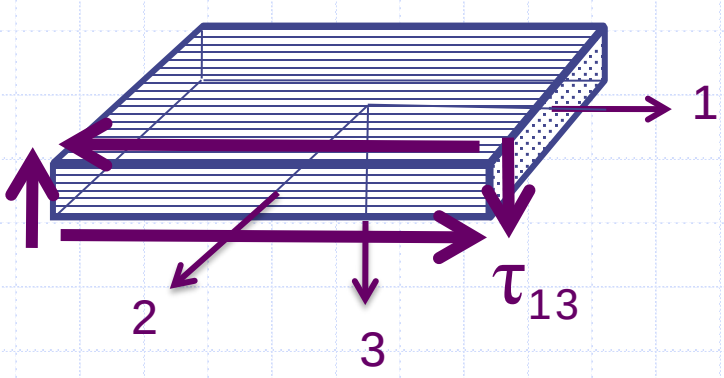
In-plane shear testing:

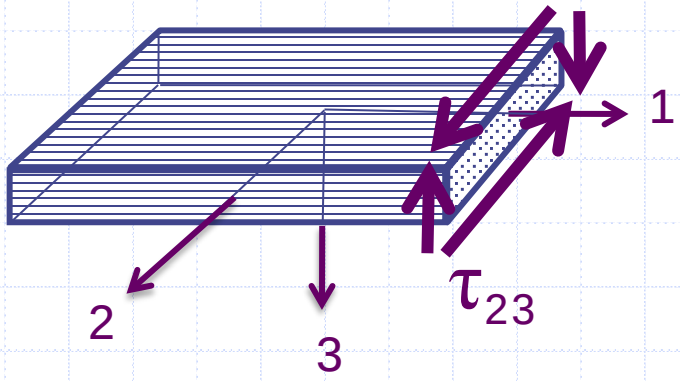
Stiffness: G_{12} Strength: S_{12}



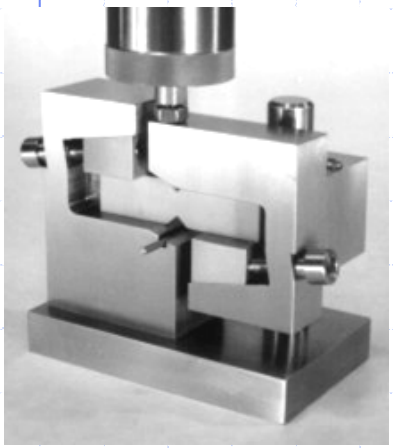
Out-of-plane (interlaminar) shear testing

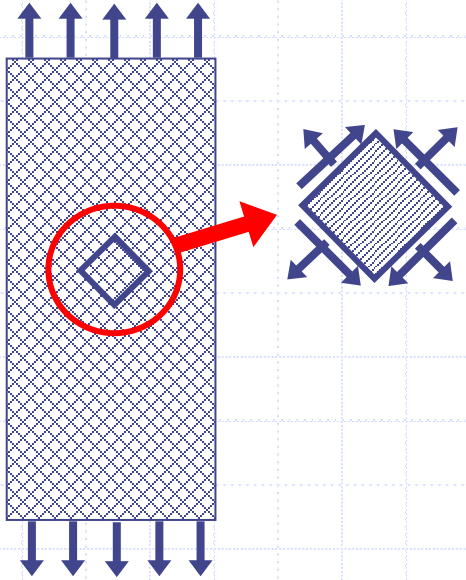
- Stiffness: G_{13}, G_{23} Strength: S_{13}, S_{23}





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

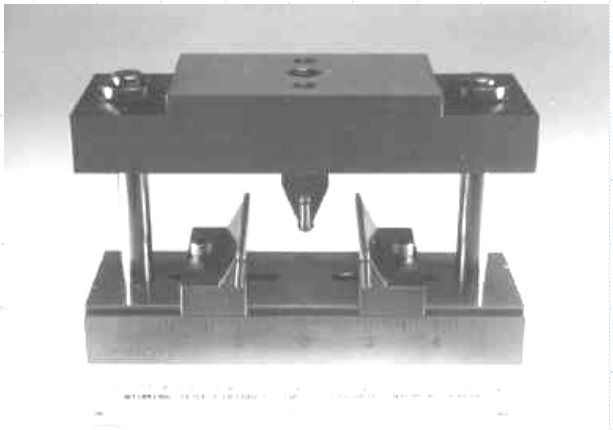
- 3 x 2.2 in. specimen
- Face loaded
- Recommended by CMH-17

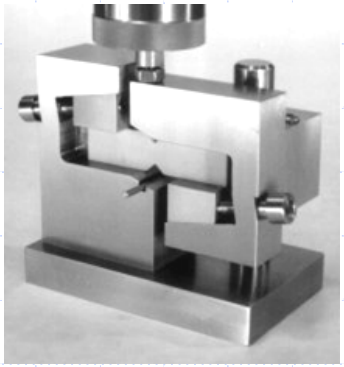
±45 Tension Shear

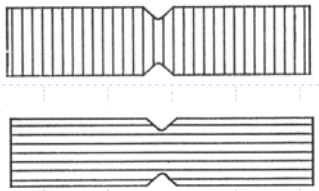
ASTM D 3518

- 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”)

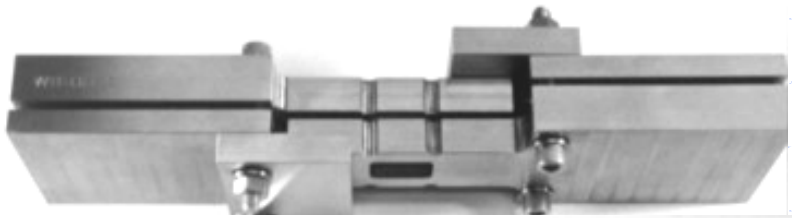
Open-hole tension	Filled-hole tension
Open-hole compression	Filled-hole compression

- 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

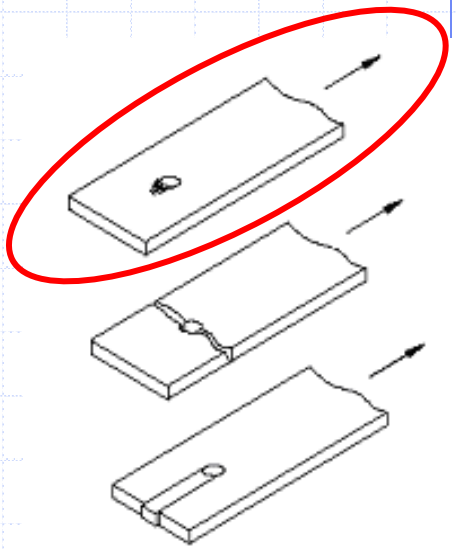
ASTM D 6484

- 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.



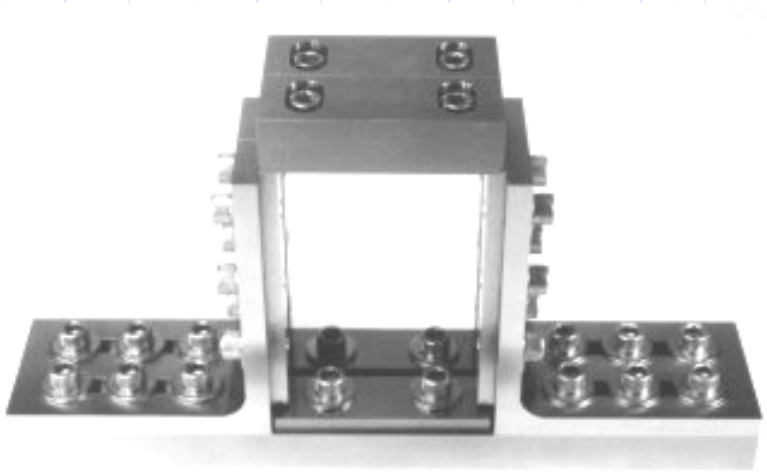
Bearing Testing

- Laminate test
- Utilizes specified bolted joint configuration
  - Single shear
    - One bolt
    - Two bolt
  - Double shear

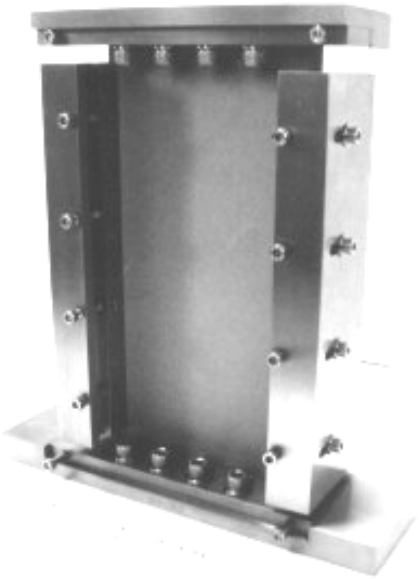


- Used to compare materials and provide design values
  - Not meant to be representative of actual joint designs
  - Yield and ultimate bearing strength
  - Governed by ASTM D 5961

Compression Strength After Impact (CSAI)



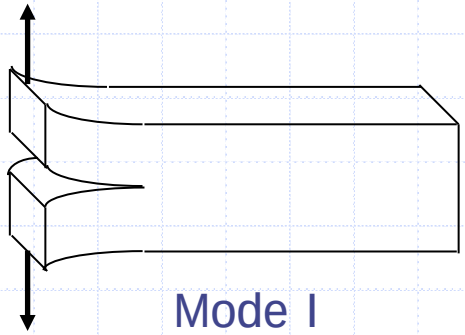
ASTM D 7136 - Damage Resistance
ASTM D 7137 – Damage Tolerance
- 4 in. x 6 in. specimen



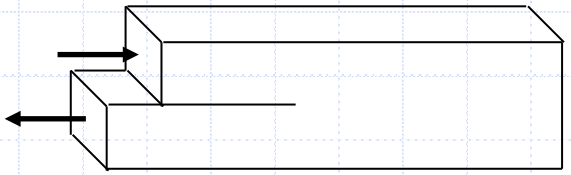
NASA CAI Test
- 5 in. x 10 in. specimen

Fracture Mechanics Testing

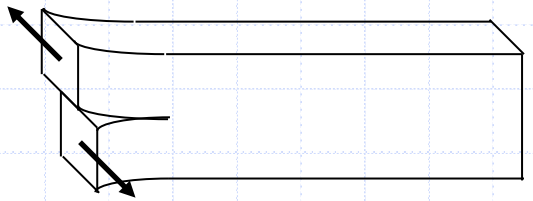
- Determine propagation characteristics of existing cracks/delaminations
- Considers three modes of crack growth
  - Mode I – opening or extension
  - Mode II – shear
  - Mode III – tearing or twist



Mode I



Mode II



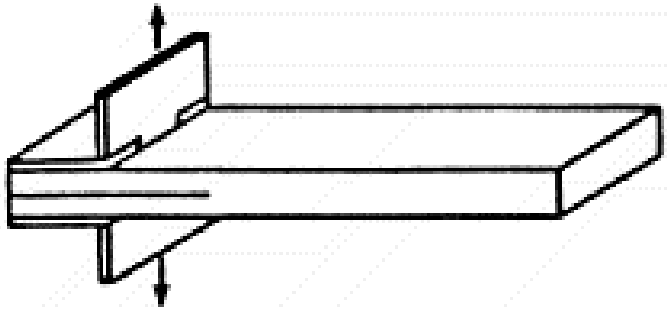
Mode III

τ_{yz}

Fracture Mechanics Test Methods

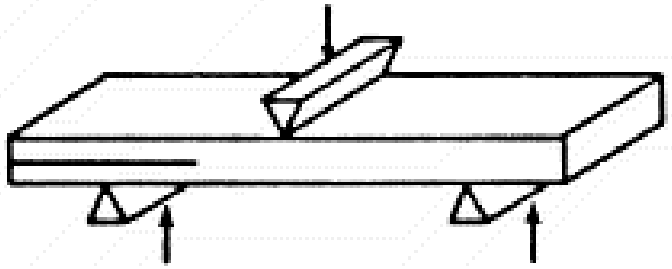
Mode I: ASTM D 5528

Double cantilever beam flexure test (tension)



Mode II: Currently no ASTM standard

End-notched flexure test (shear)



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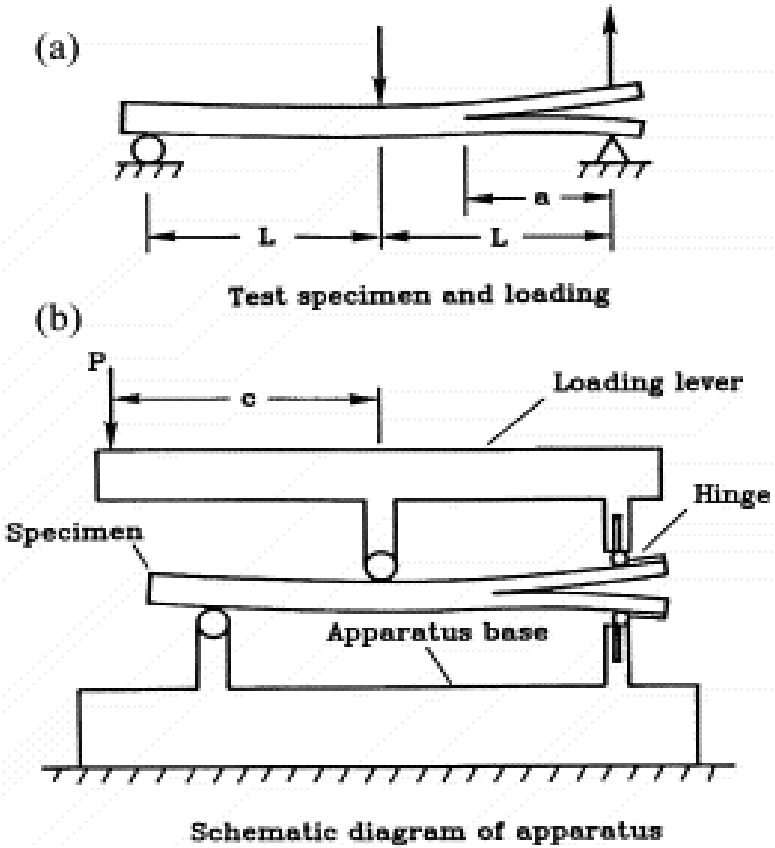
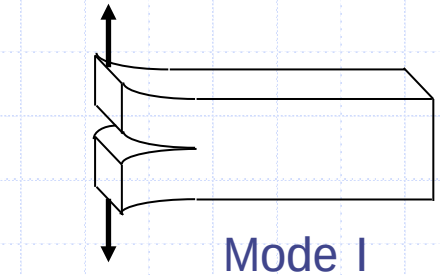
Fracture Mechanics Test Methods

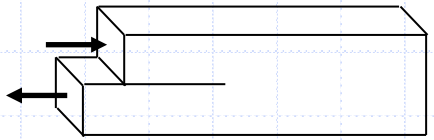
Mixed Mode (Mode I & II)

Mixed Mode Bending (MMB) Test, ASTM D 6671





Mode I



Mode II

τ_{yz}

Composite Materials Test Methods

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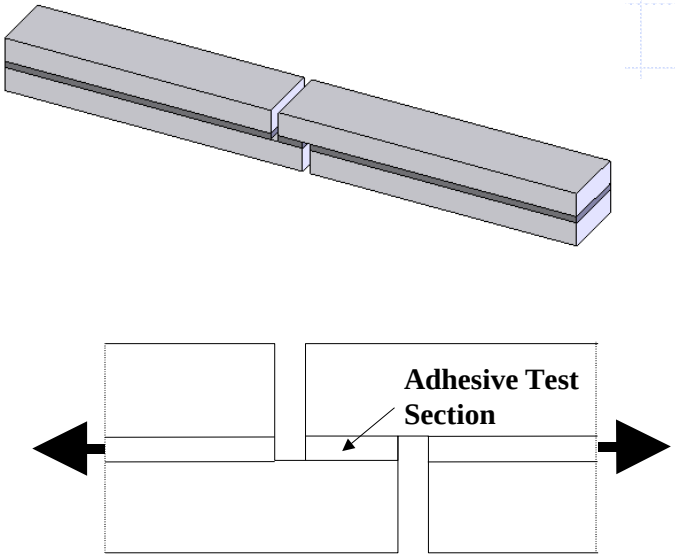
- **Adhesives Testing** (CMH-17 Vol. 1, Section 7.6)
- Test Methods for Sandwich Composites
- Non-Destructive Testing

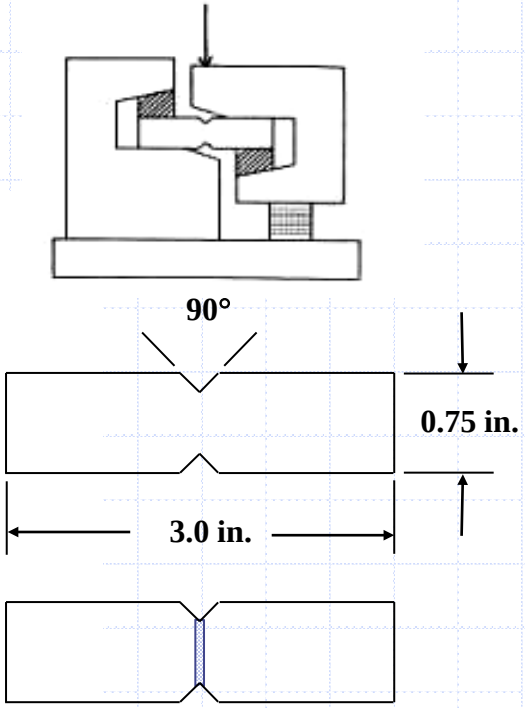
Categories of Adhesives Testing

- 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



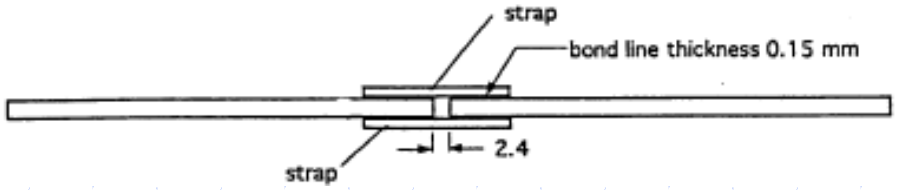
ASTM D 5656
Thick Adherend Specimen

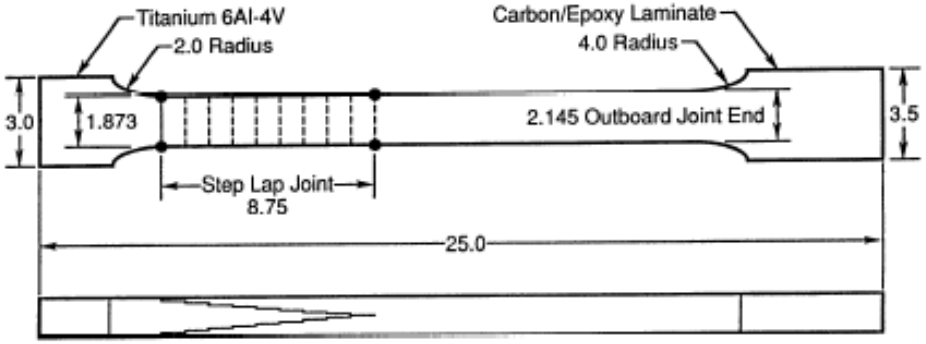


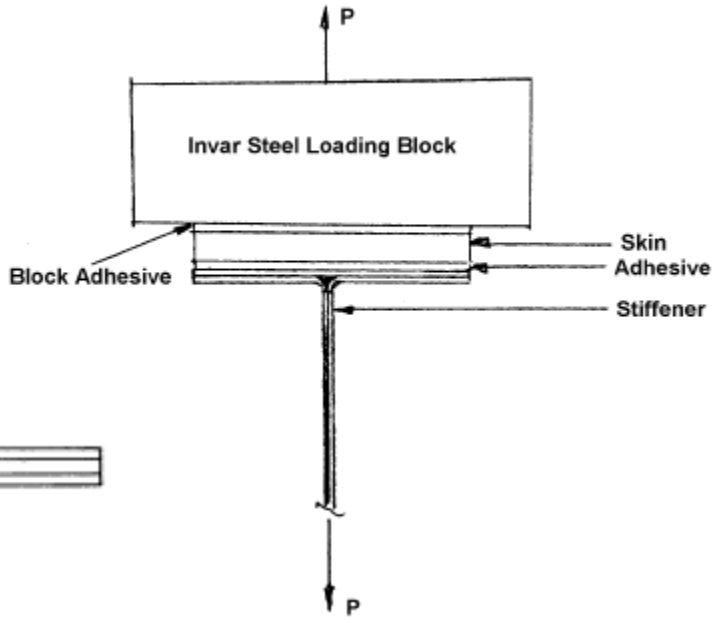
ASTM D 5379
Iosipescu Shear Specimen

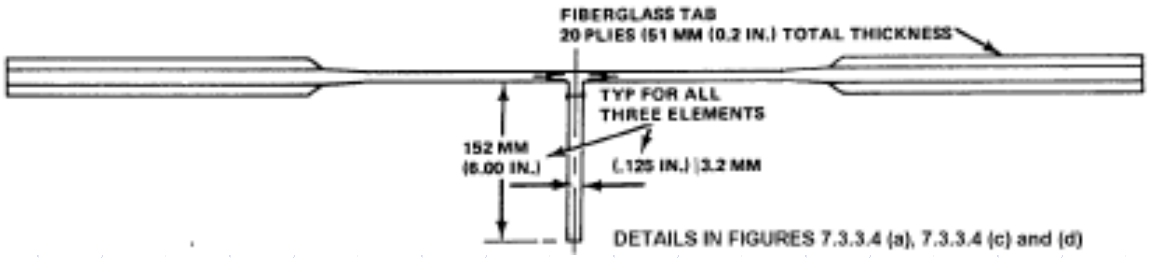
Reference: Nicholas Burst and Daniel O. Adams, "Investigating the Thin-Film Versus Bulk Material Properties of Structural Adhesives," DOT/FAA/AR-06/45, May 2008. http://www.tc.faa.gov/its/worldpac/techrpt/ar0645.pdf

Bonded Joint Characterization Testing







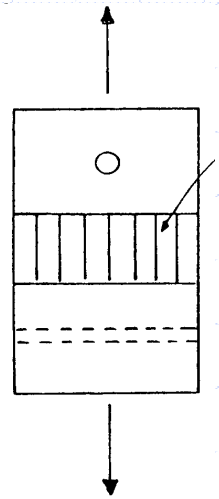


Composite Materials Test Methods

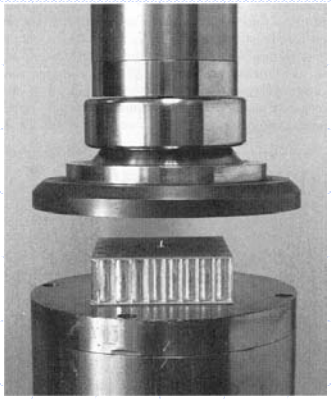
AGENDA

- Constituent and Prepreg Test Methods
- Physical Test Methods for Composites
- Mechanical Test Methods for Composites
- Adhesives Testing
- **Test Methods for Sandwich Composites** (CMH-17 Vol. 1, Section 6.8)
- Non-Destructive Testing

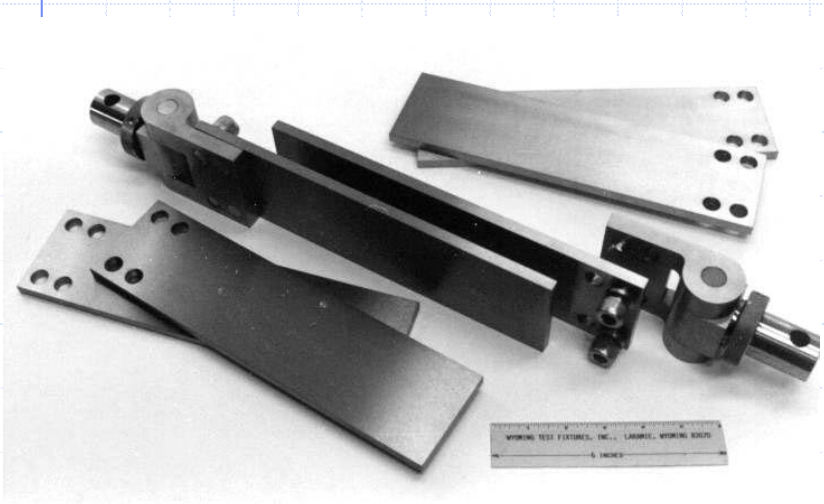
Mechanical Test Methods for Sandwich Composites



- 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



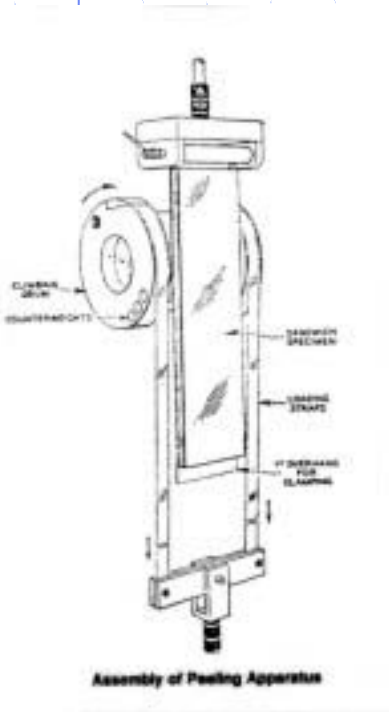
Sandwich Panel Shear Test
ASTM C 273

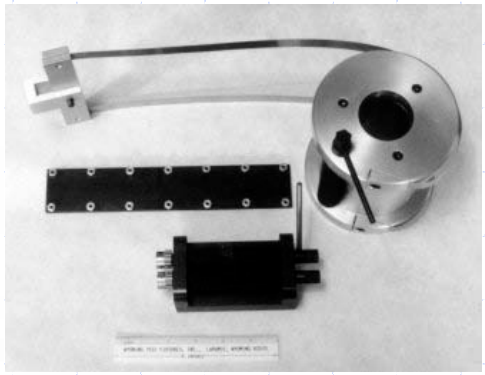


Tension Loading

Compression Loading

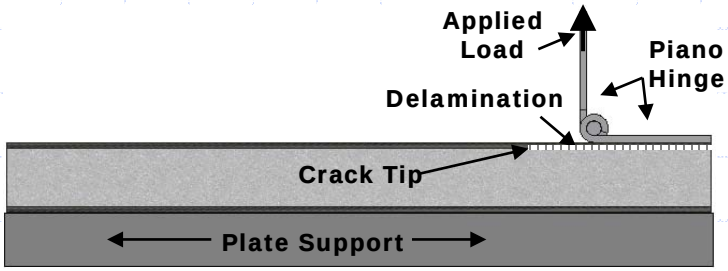
Other Sandwich Panel Tests

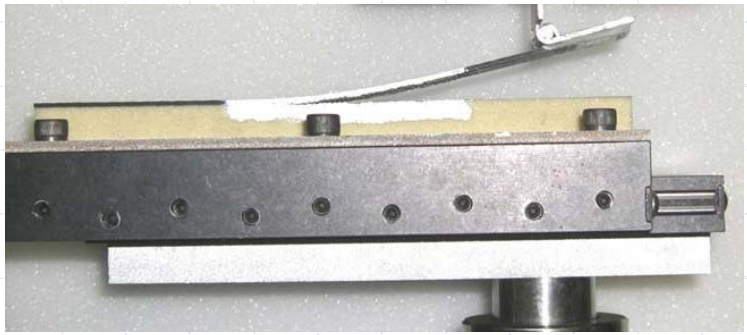




Climbing Drum Peel

ASTM D 1781





Mode I Fracture Mechanics: Single Cantilever Beam)

(Proposed ASTM standard)

Composite Materials Test Methods

AGENDA

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

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

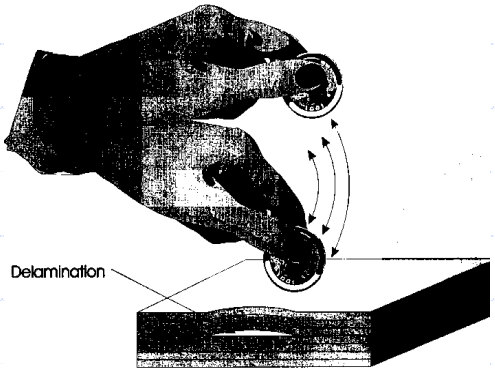
- Visual Inspection
- Tap Testing
- Ultrasonic Methods
- X-Ray
- Thermography
- Shearography

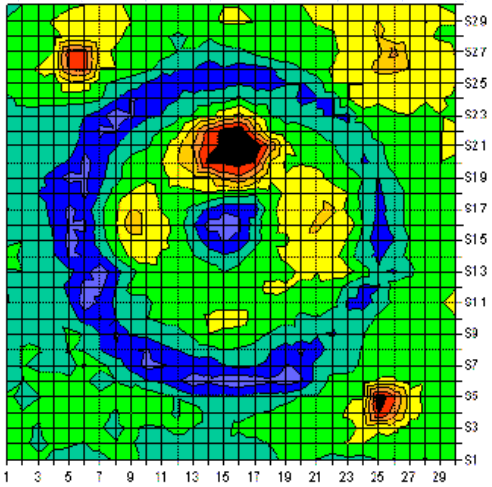
Visual Inspection

- 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

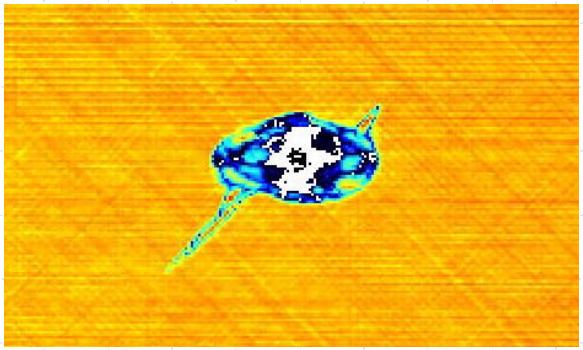




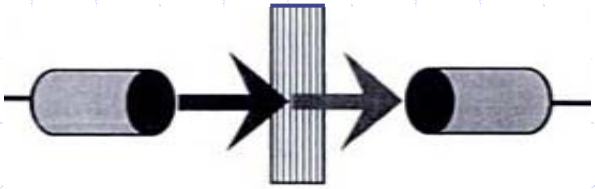
http://www.asi-nde.com

Ultrasonic Test Methods

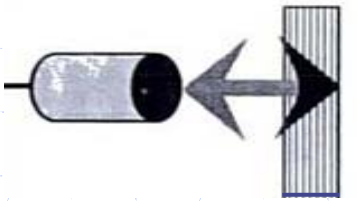
Used to monitor for delaminations, voids/porosity, fiber/matrix damage



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

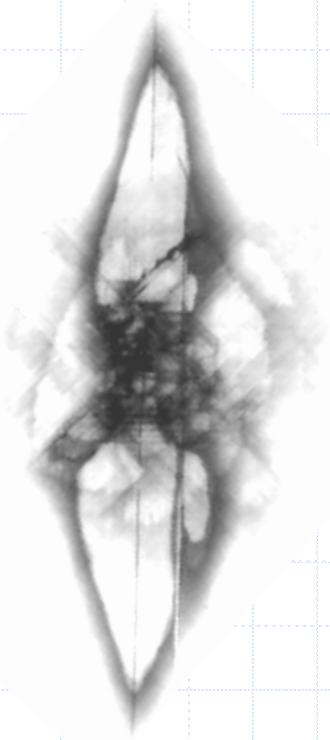


- Pulse echo
  - Requires access from only one side of composite structure
  - More applicable to field inspections



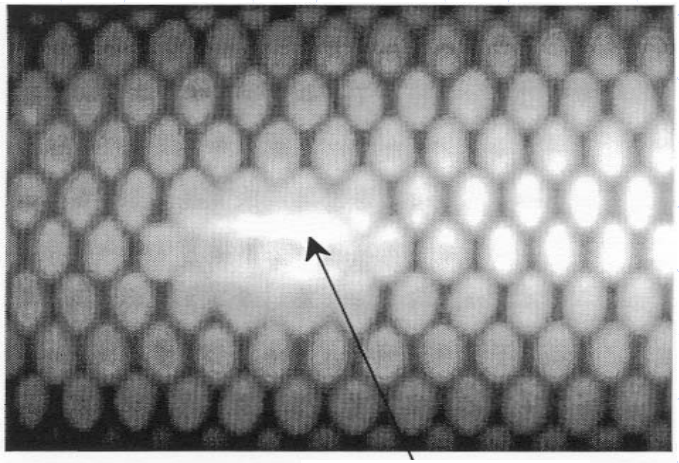
X-Ray Inspection

- 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
- “Experimental Characterization of Advanced Composite Materials,” by Donald F. Adams, Leif A. Carlsson, and R. Byron Pipes, CRC Press.
- ASTM Annual Book of ASTM Standards, Volume 15.03, Space Simulation; Aerospace and Aircraft; Composite Materials
- ASTM D 4762, “Standard Guide for Testing Polymer Matrix Composite Materials”