Marine Composites

Webb Institute
Senior Elective

Test Methods

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Structural Complexity Levels

Constituent Testing: This evaluates the individual properties of fibers, fiber forms, matrix materials, and fiber-matrix preforms. Key properties, for example, include fiber and matrix density, and fiber tensile strength and tensile modulus.

Lamina Testing: This evaluates the properties of the fiber and matrix together in the composite material form. For the purpose of this discussion prepreg properties are included in this level, although they are sometimes broken-out into a separate level. Key properties include fiber areal weight, matrix content, void content, cured ply thickness, lamina tensile strengths and moduli, lamina compressive strengths and moduli, and lamina shear strengths and moduli.

Laminate Testing: Laminate testing characterizes the response of the composite material in a given laminate design. Key properties include tensile strengths and moduli, compressive strengths and moduli, shear strengths and moduli, interlaminar fracture toughness, and fatigue resistance.

Structural Element Testing: This evaluates the ability of the material to tolerate common laminate discontinuities. Key properties include open and filled hole tensile strengths, open and filled hole compressive strengths, compression after impact strength, and joint bearing and bearing bypass strengths.

Structural Subcomponent (or higher) Testing: This testing evaluates the behavior and failure mode of increasingly more complex structural assemblies.

MIL-HDBK-17-1F, Volume 1, Chapter 2 Guidelines for Property Testing of Composites

Characterize Composite Laminate

To fully characterize a composite laminate in general, 9 different material parameters are needed:

Tensile strength (σ_{1T}) in the fiber direction – 0˚

Compression strength (σ_{1C}) in the fiber direction – 0˚

Young's-modulus (E_1) in the fiber direction – 0˚

Tensile strength (σ_{2T}) perpendicular to the fiber direction – 90˚

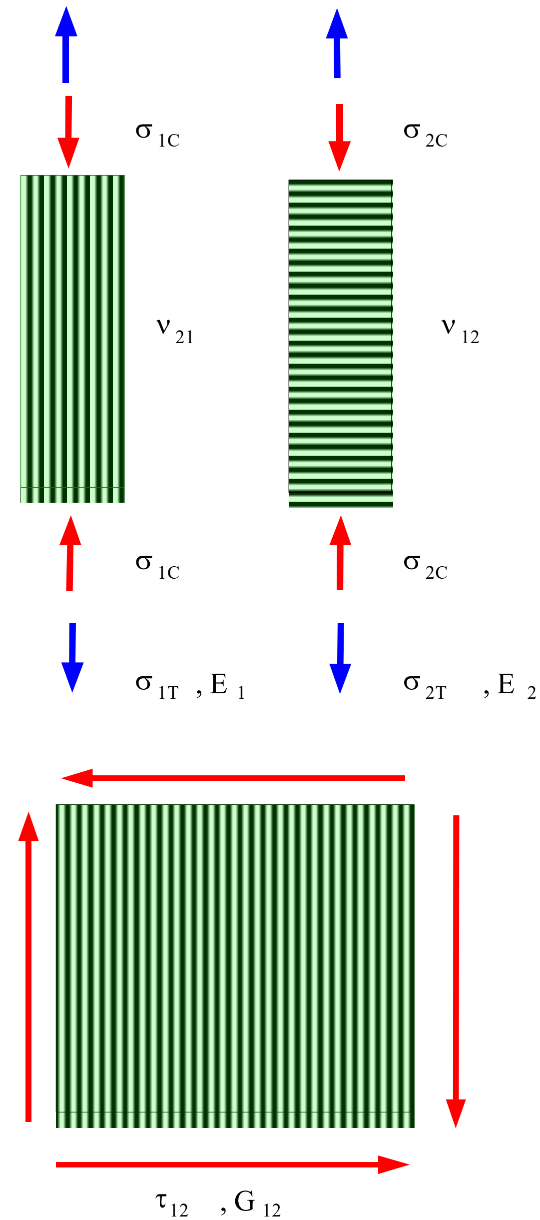
Compression strength (σ_{2C}) perpendicular to the fiber direction – 90˚

Young's-modulus (E_2) perpendicular to the fiber direction – 90˚

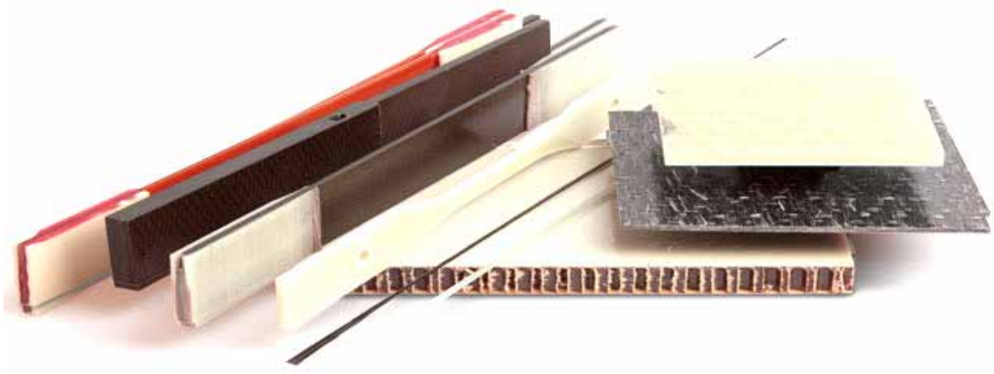
Poisson ratio (ν_{21}), for constraint in perpendicular direction (90˚) due to strain in the fiber direction (0˚).

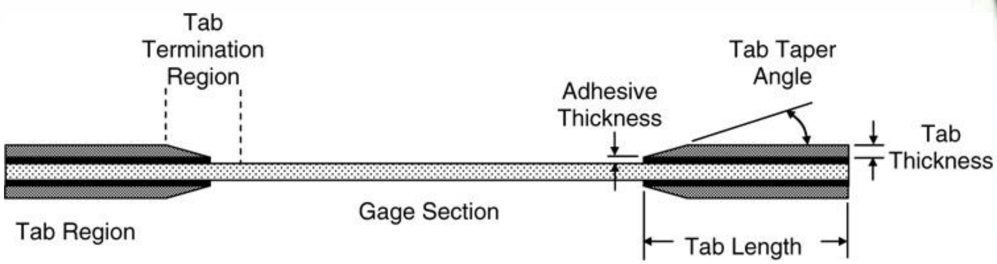
In-plane shear strength (τ_{12})

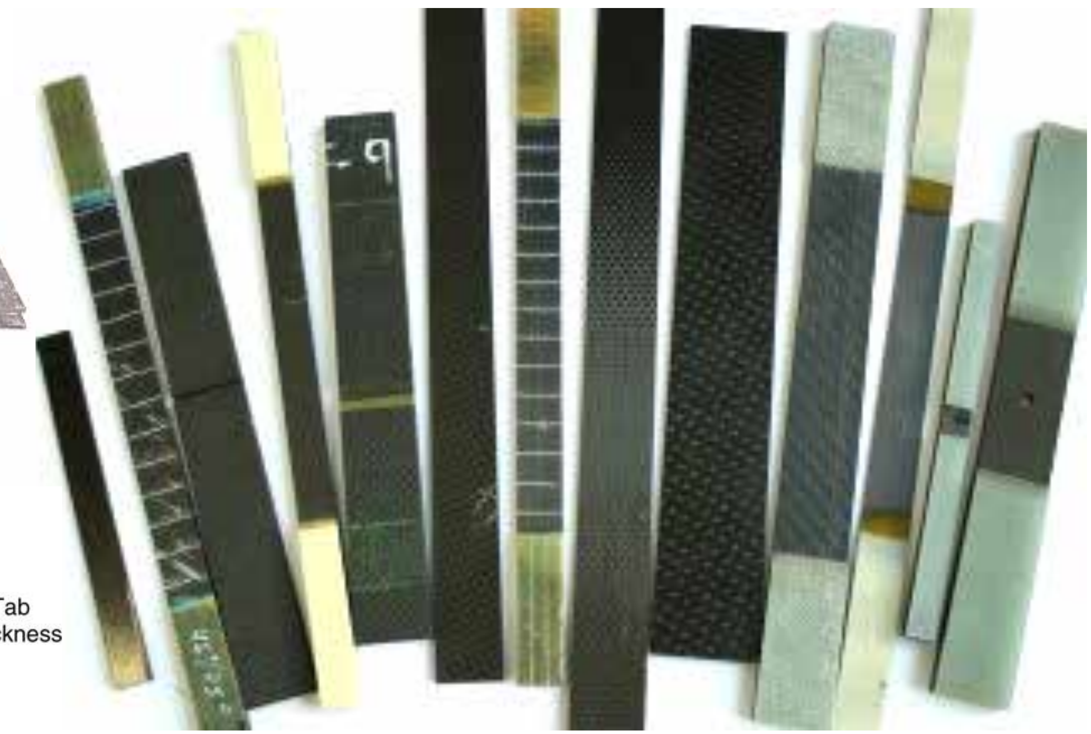
Shear modulus (G_{12}) for the laminate



Composite Test Specimens







Typical Laminate Mechanical Properties

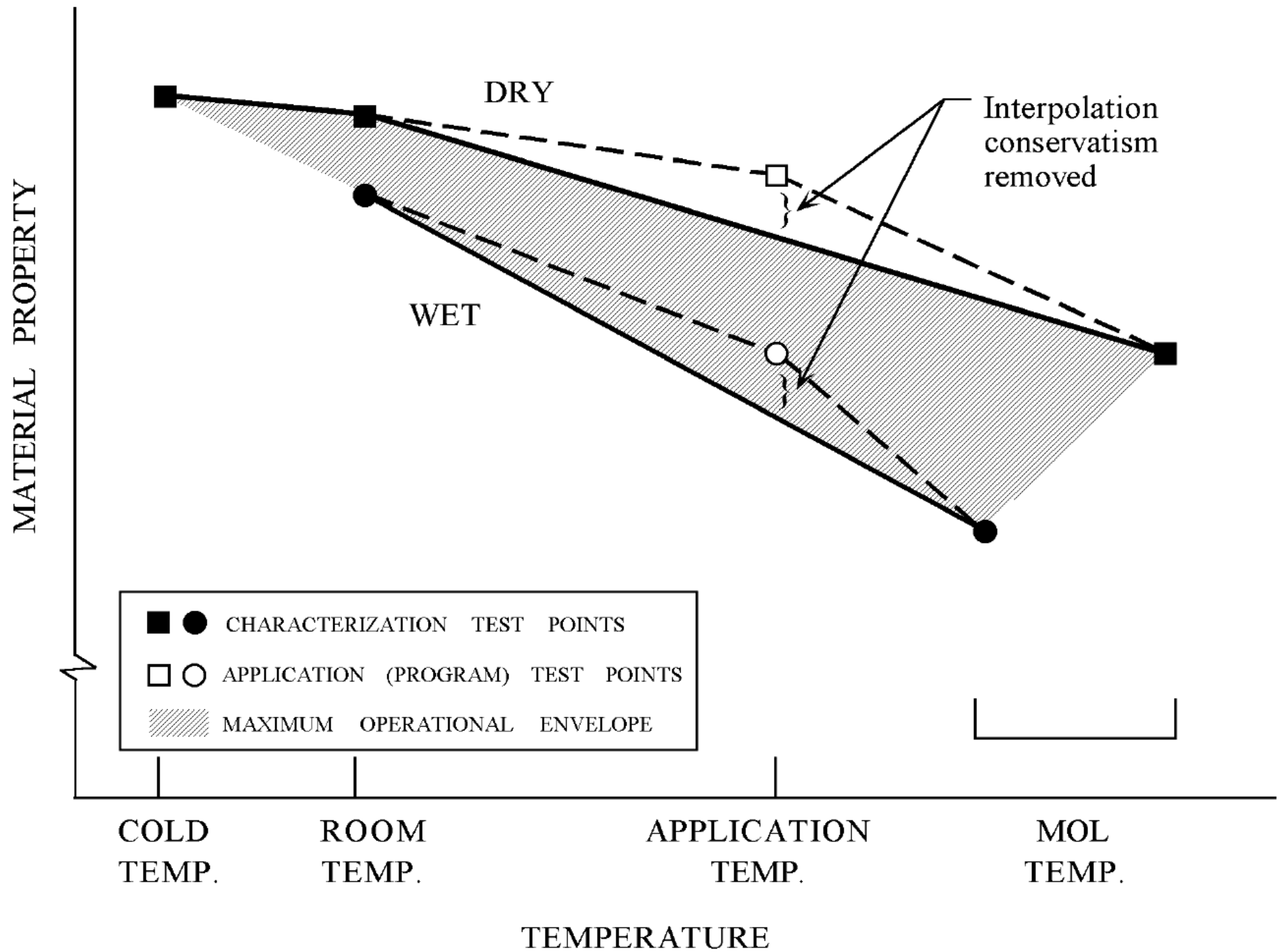
		Warps Parallel 24ozWR/8084	Quasi-Isotropic 24ozWR/8084	3:1 24 oz Fabric/ 510A VE Warp Parallel	Warps Parallel 24ozWR/8084
		E-Glass/Vinylester	E-Glass/Vinylester	E-Glass/Vinylester	E-Glass/Vinylester
Process		VARTM, VF=70 Wt %	VARTM, VF=70 Wt %	VARTM, VF=70 Wt %	Hand-Layup Vf=50 %
E_1^T	Msi	3.30	2.80	5.00	2.00
E_1^C	Msi	3.50	3.00	2.80	2.00
E_2^T	Msi	3.10	2.80	5.20	2.00
E_2^C	Msi	3.10	3.00	3.20	2.00
G_{12}	Msi	0.55	0.85	0.56	0.40
v_{12}		0.15	0.30	0.19	0.20
F_1^{TU}	ksi	60.00	45.00	88.20	30.00
F_1^{CU}	ksi	55.00	45.00	71.10	40.00
F_2^{TU}	ksi	55.00	45.00	34.30	25.00
F_2^{CU}	ksi	50.00	45.00	40.20	35.00
F_{12}	ksi	8.00	18.00	11.80	5.00
E_3	Msi	1.30	1.30	1.50	1.00
G_{13}	Msi	0.50	0.60	0.50	0.25
G_{23}	Msi	0.50	0.55	0.50	0.25
Density	lb/in^3	0.068	0.068	0.068	0.060

Test Method Summary

Geometry	Parameter	Test Method(s)
Single skin	Flexural strength and modulus	ASTM D790 or D790M or ISO 178
Single skin	Shear strength, perpendicular and parallel to warp	FTMS 406 1041 or ASTM D732 85
Single skin and sandwich	Glass content and ply-by-ply analysis	ASTM D2584 or ISO 1172
Single skin and sandwich (both skins)	Compressive strength and modulus	ASTM D695 or D695M or ISO 604
Single skin and sandwich (both skins)	Tensile strength and modulus	ASTM D3039 or D638 or D638M or ISO 3268
Single skin and sandwich (both skins)	Interlaminar shear strength	ASTM D3846
Sandwich: Core to skin bondline	Flatwise tensile test	ASTM C297
Sandwich: Core material	Shear strength and modulus	ASTM C273

U.S. Coast Guard Marine Safety Center Guidelines for Review of Structural Plans for Fiberglass Reinforced Plastic (FRP) Vessels

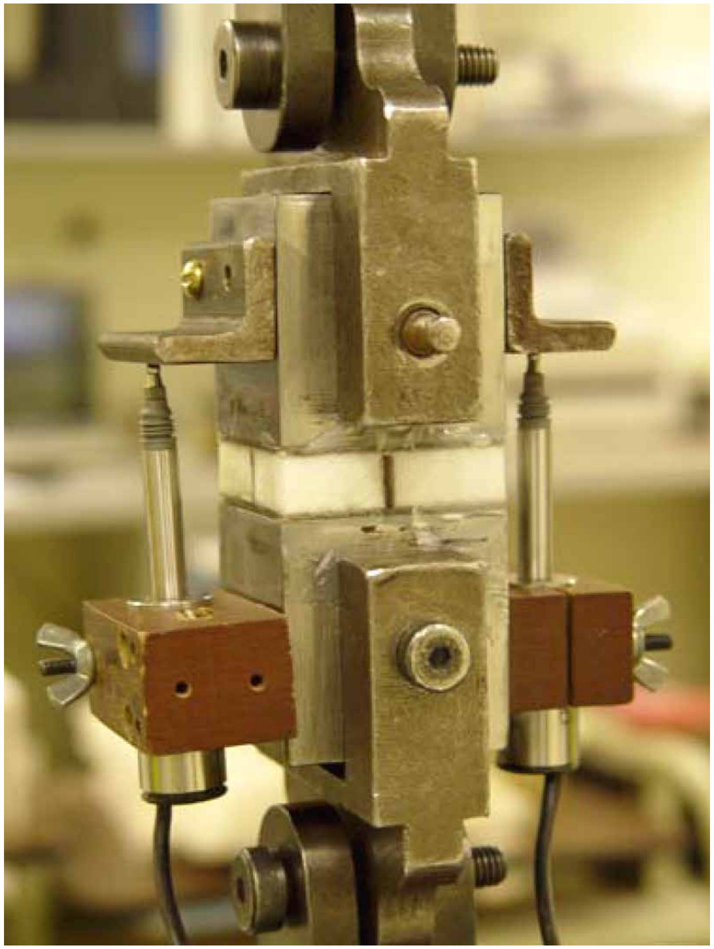
Material Operational Limit

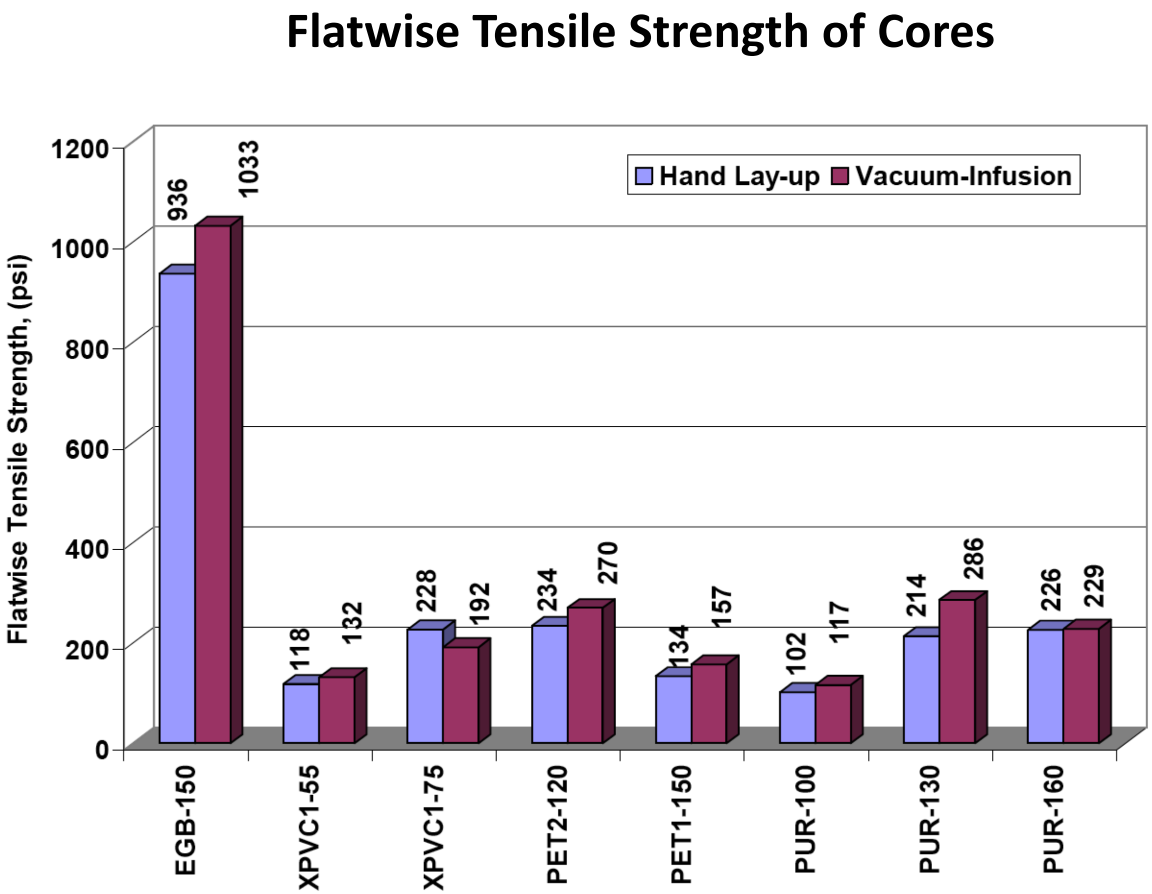


MIL-HDBK-17-1F, Volume 1, Chapter 2 Guidelines for Property Testing of Composites

Tensile Testing

ASTM C 297-00 Flatwise Tensile Testing

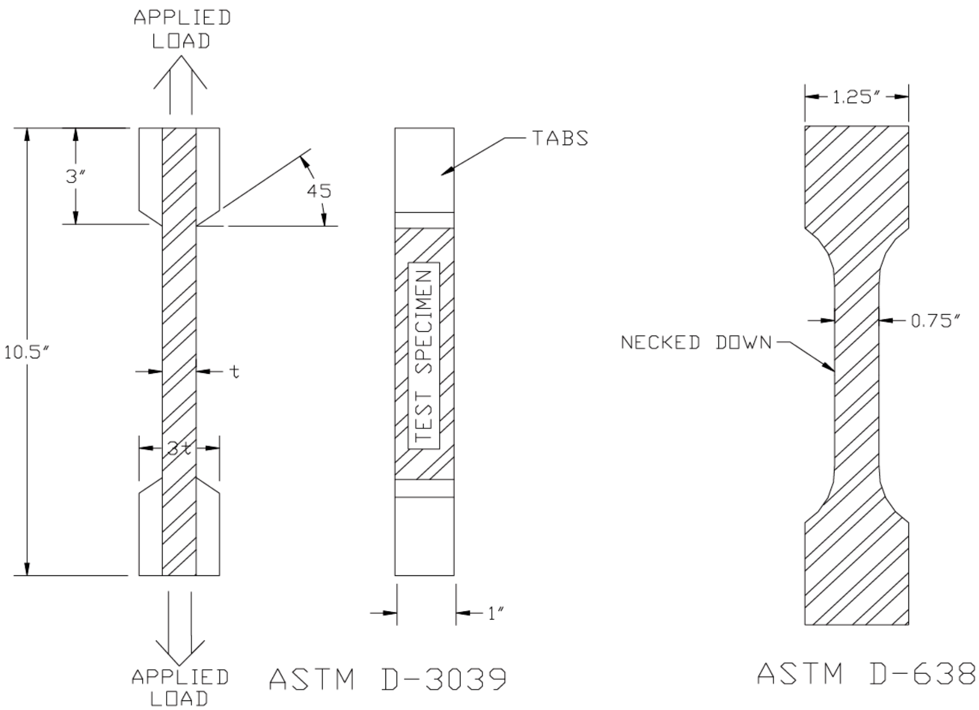




Kurt Feichtinger, Wenguang Ma and Russell Elkin, "Properties of Structural Sandwich Core Materials: Hand Lay-up vs. Vacuum-Infusion Processing," COMPOSITES 2006.

Tensile Tests

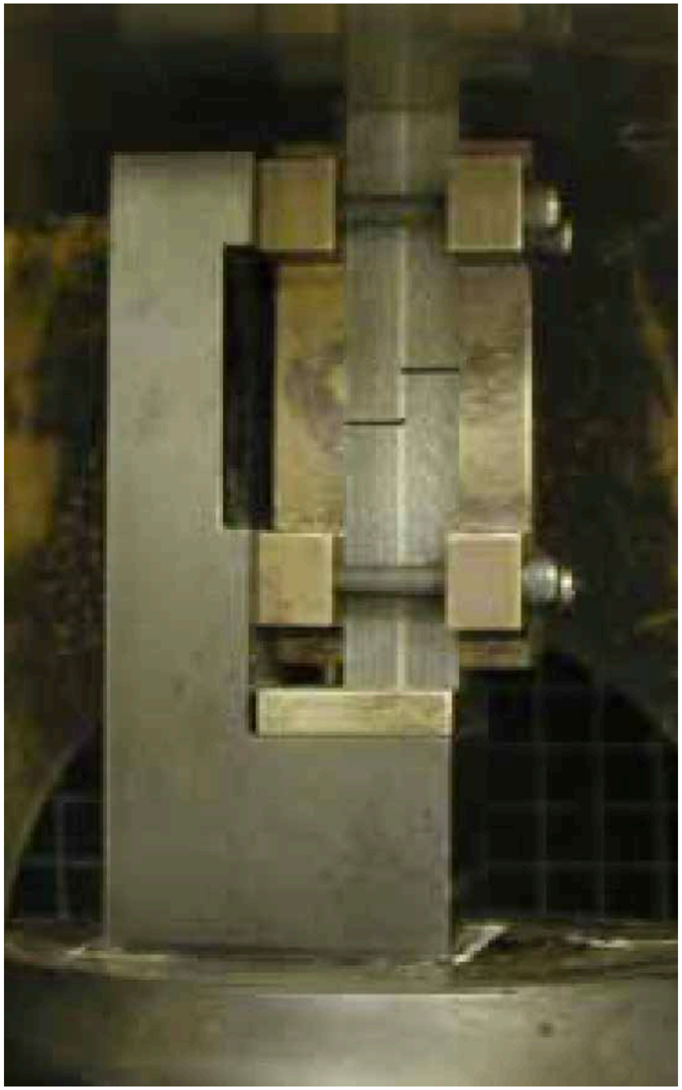
Test Specimen Configuration for ASTM D-3039 and D-638 Tensile Tests



These test methods provide procedures for the evaluation of tensile properties of single-skin laminates. The tests are performed in the axial, or in-plane orientation. Properties obtained can include tensile strength, tensile modulus, elongation at break (strain to failure), and Poisson's ratio.

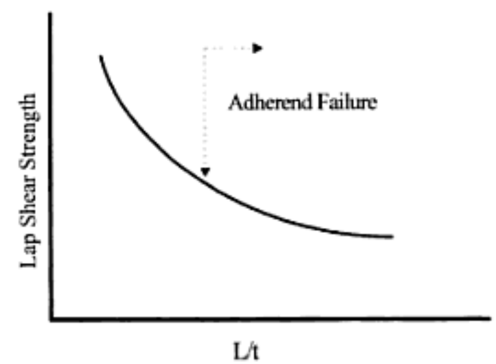
For most oriented fiber laminates, a rectangular specimen is preferred. Panels fabricated of resin alone (resin casting) or utilizing randomly oriented fibers (such as chopped strand) may be tested using dog-bone (dumbbell) type specimens. Care must be taken when cutting test specimens to assure that the edges are aligned in the axis under test. The test axis or orientation must be specified for all oriented-fiber laminates.

Compressive Lap Shear Test



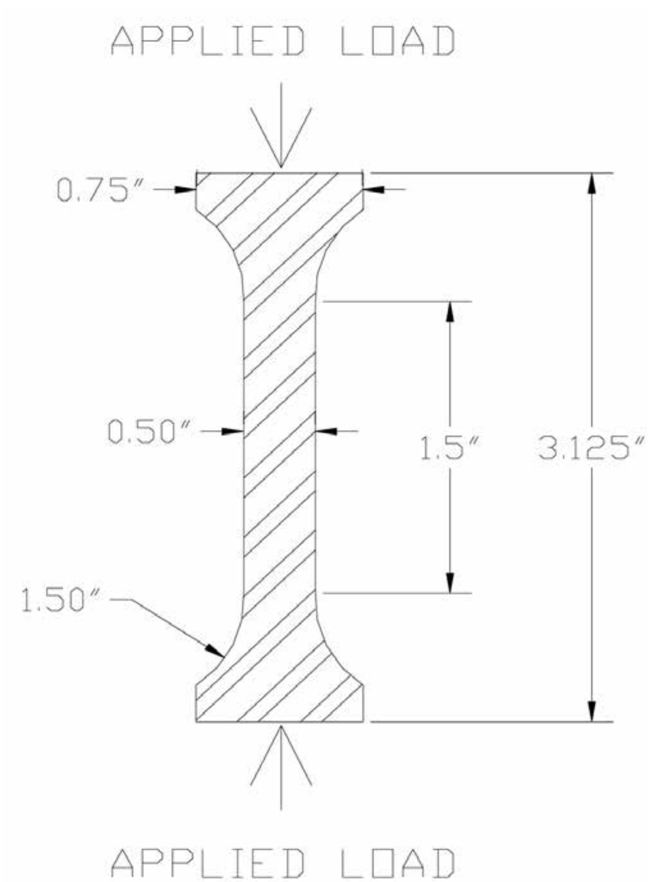
ASTM D5656 - 10 Standard Test Method for Thick-Adherend Metal Lap-Shear Joints for Determination of the Stress-Strain Behavior of Adhesives in Shear by Tension Loading

Adherends are thick enough so that bending at the ends of the lap is essentially eliminated. The force is applied through holes in the specimens, moving the adherends and shearing the adhesive.



Compressive Tests

Test Specimen Configuration for ASTM D-695 Compression Test



Several methods are available for determination of the axial (in-plane, edgewise, longitudinal) compression properties. The procedures shown are applicable for single-skin laminates. Other methods are utilized for determination of "edgewise" and "flatwise" compression of sandwich composites. Properties obtained can include compressive strength and compressive modulus.

For most oriented fiber laminates, a rectangular specimen is preferred. Panels fabricated of randomly oriented fibers such as chopped strand may be tested using dog-bone (dumbbell) type specimens.

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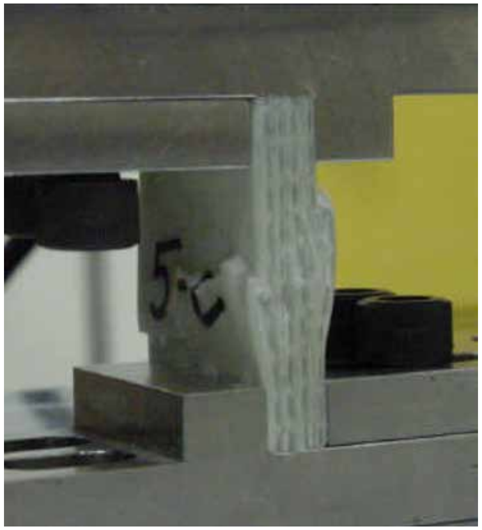
Test Coupon Failures

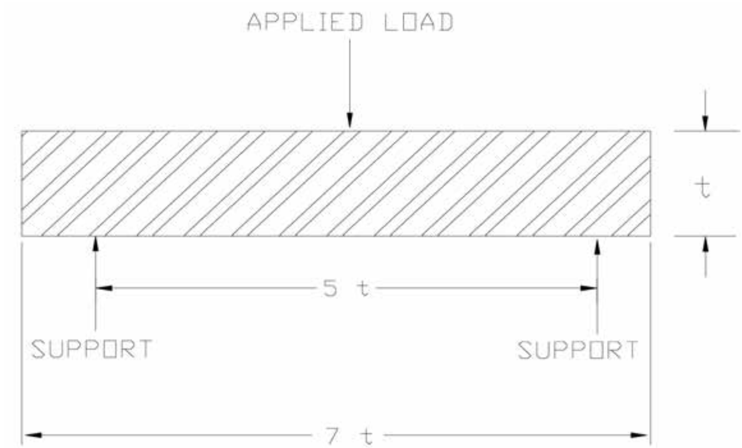
Compression



Tension

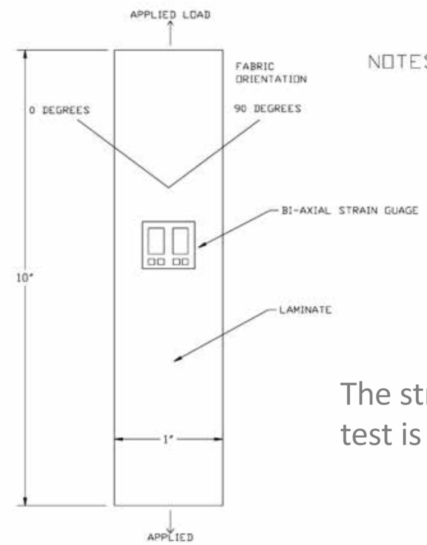
Shear Test Methods

ASTM D-2344 Short Beam Shear Test



The short beam strength test should only be used for qualitative testing such as material process development.

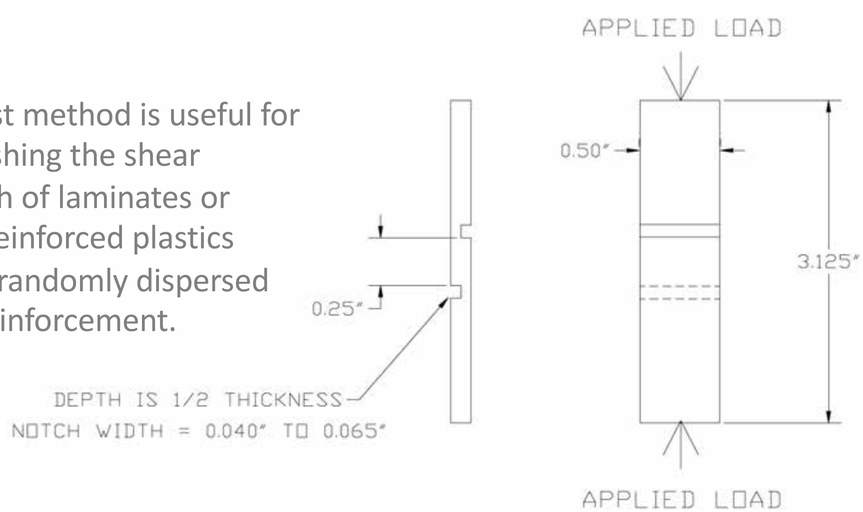
ASTM D-3518 In-Plane Shear Test



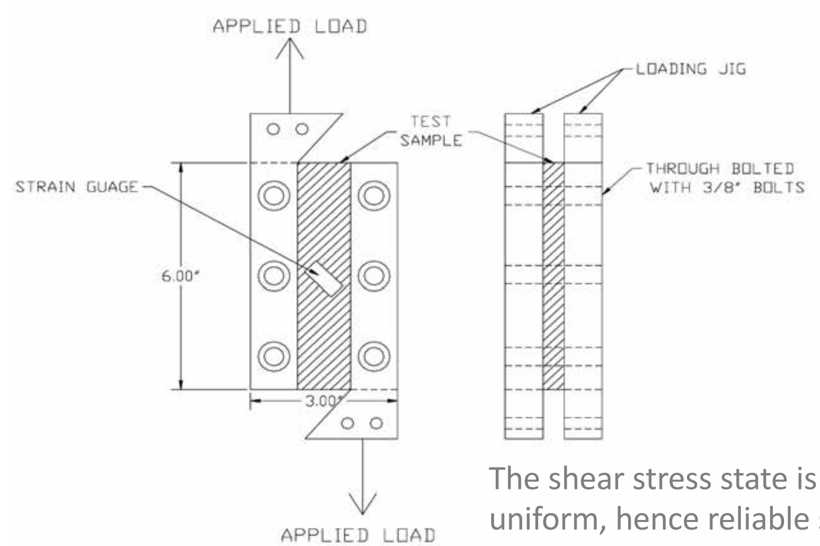
The stress-strain curve from this test is highly non-linear

ASTM D-3846 In-Plane Shear Test

This test method is useful for establishing the shear strength of laminates or other reinforced plastics having randomly dispersed fiber reinforcement.



ASTM D-4255 Rail Shear Test



The shear stress state is not uniform, hence reliable strength data cannot always be obtained.

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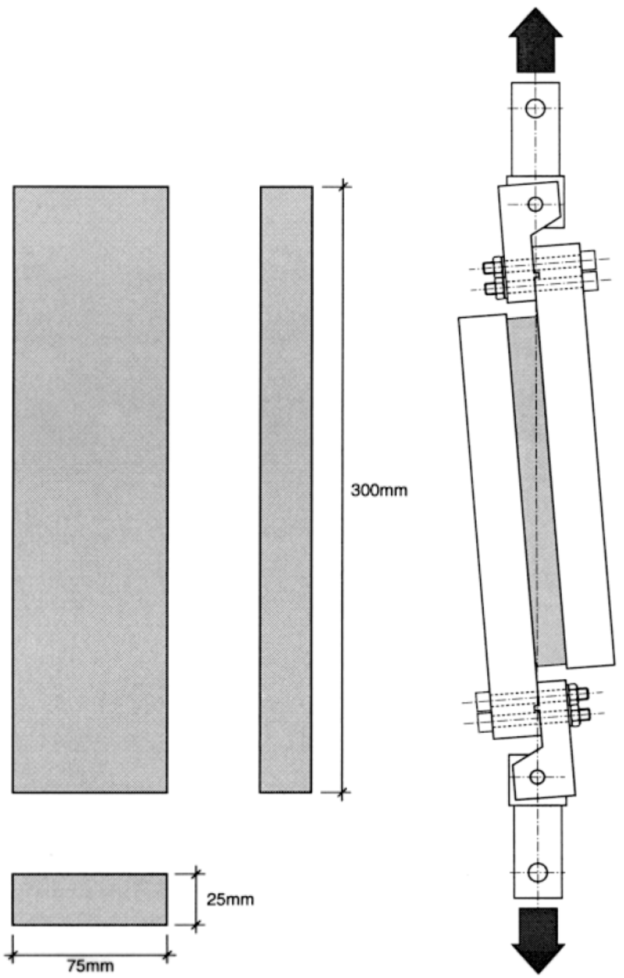
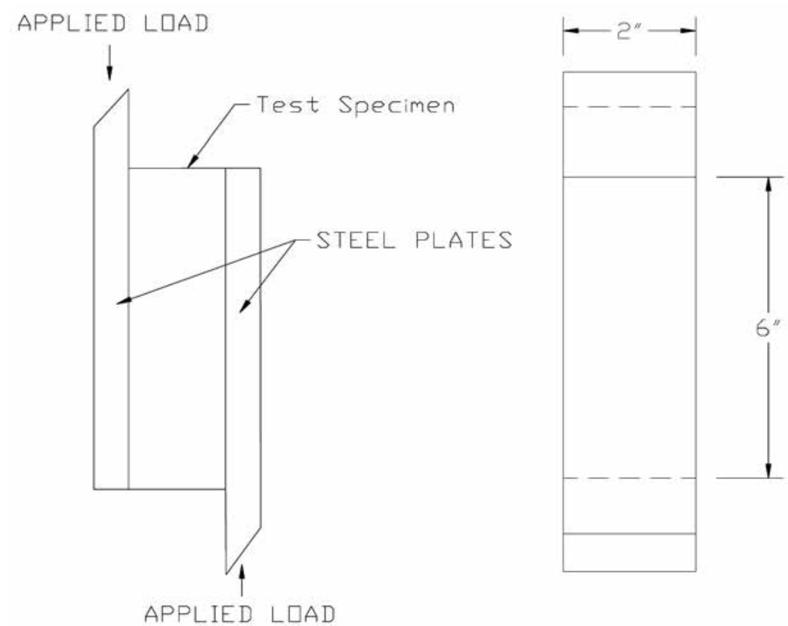
ASTM C-273 Core Shear Test



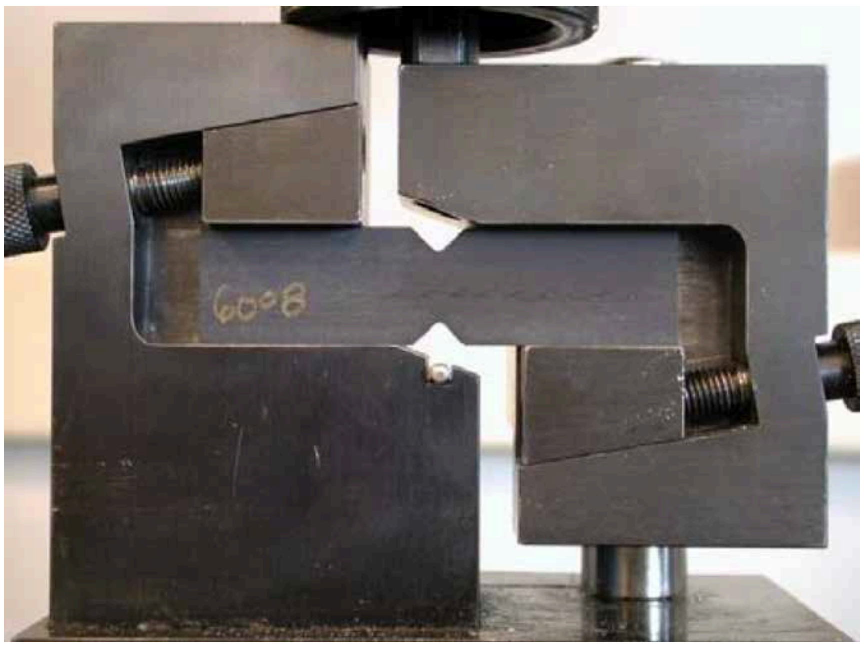
Test Specimen Configuration for ASTM C-273 Core Shear Test



This test method covers the determination of shear properties of sandwich construction core materials associated with shear distortion of planes parallel to the facings. It covers the determination of shear strength parallel to the plane of the sandwich, and the shear modulus associated with strains in a plane normal to the facings. The test may be conducted on core materials bonded directly to the loading plates or the sandwich facings bonded to the plates.

The Iosipescu or V-notched Shear Test

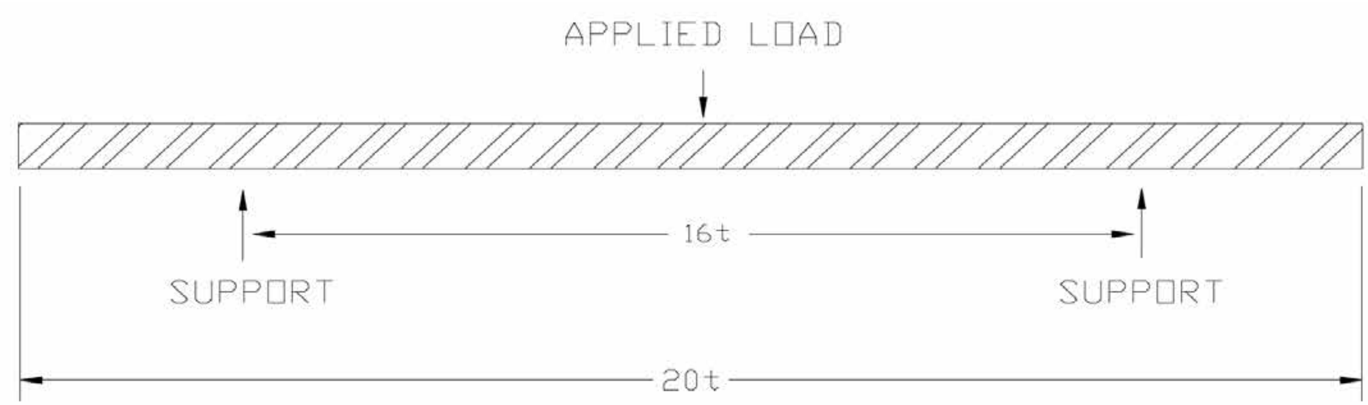
Interlaminar shear test arrangement for carbon fiber laminate



The Iosipescu or V-notched shear test, ASTM D 5379M, uses a rectangular beam with symmetrical centrally located V-notches. The beam is loaded by a special fixture applying a shear loading at the V notch. Either in-plane or out-of-plane shear properties may be evaluated, depending upon the orientation of the material co-ordinate system relative to the loading axis.

Flexural Tests

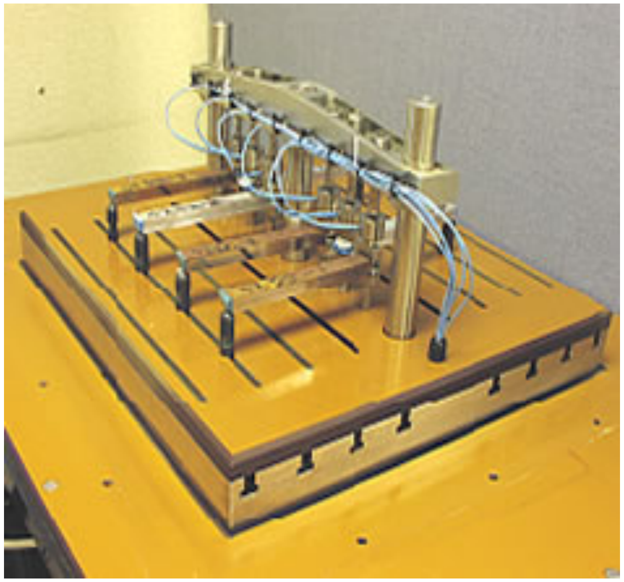
Test Specimen Configuration for ASTM D-790 Flexural Test, Method I, Procedure A



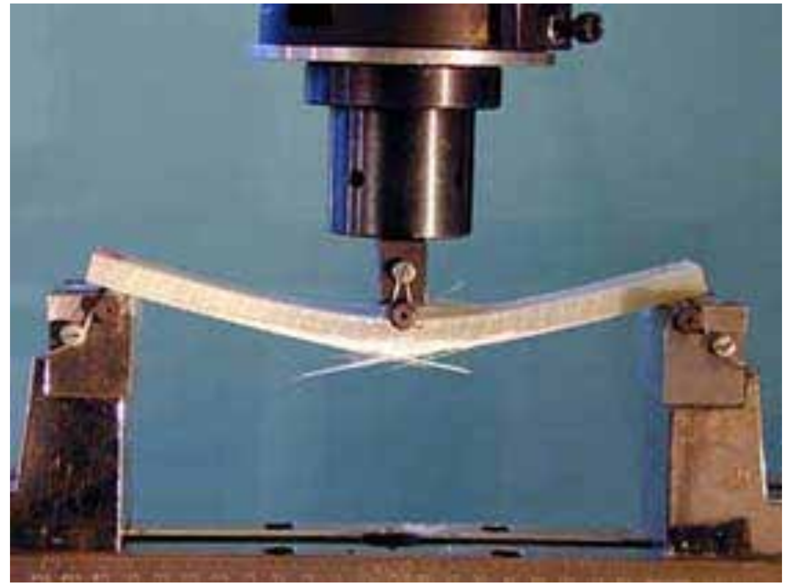
For evaluation of mechanical properties of flat single-skin laminates under bending (flexural) loading, several standard procedures are available. The methods all involve application of a load which is out-of-plane, or normal to, the flat plane of the laminate. Properties obtained include flexural strength and flexural modulus.

Rectangular specimens are required regardless of reinforcement type. Unreinforced resin castings may also be tested using these procedures. Generally, a support span-to-sample depth ratio of between 14:1 and 20:1 is utilized (support span is 14-20 times the average laminate thickness). Load may be applied at the midpoint of the beam (3-point loading), or a 4-point loading scheme may be used. Flexural tests are excellent for comparing laminates of similar geometry and are often used in Quality Assurance programs.

Fatigue Testing



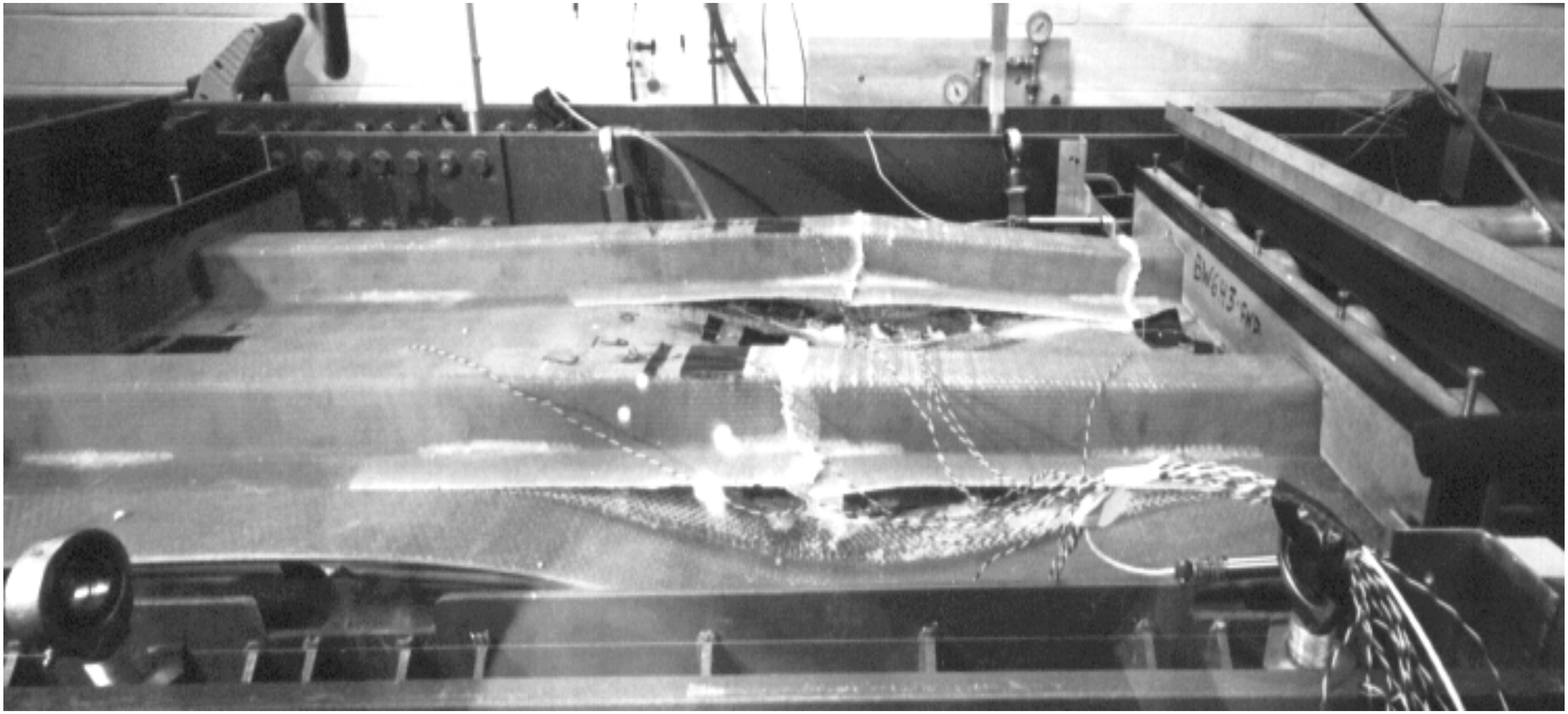
Multi-Station Fatigue Testing by MERL Ltd., Hitchin, UK



Composite beam fatigue testing at Risø, Denmark's national laboratory

Florida DOT Lab Tested of ZellComp® 5-inch Composite Decking System for 2 million cycles

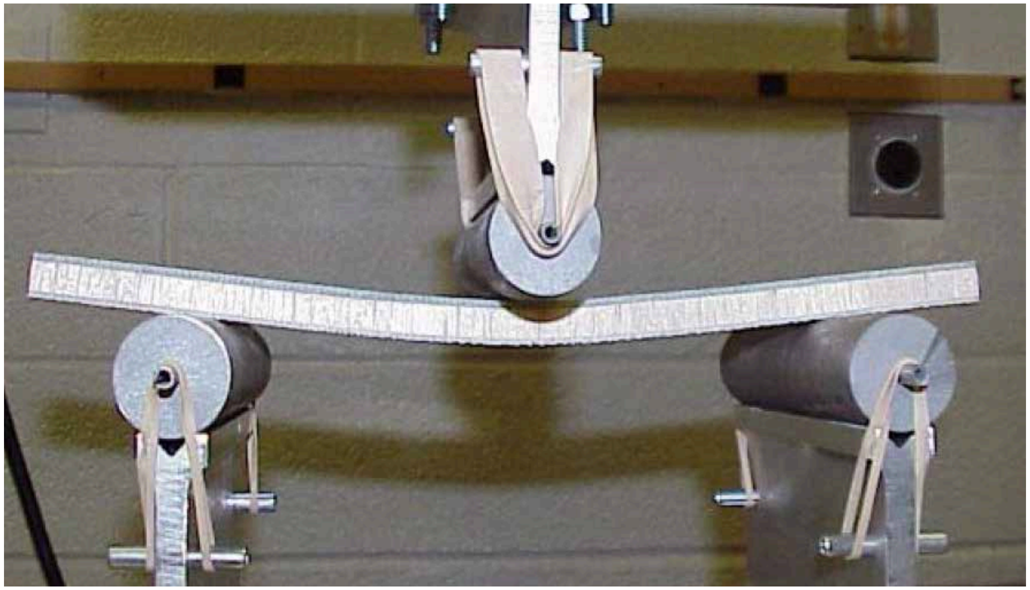
Panel Compression Testing



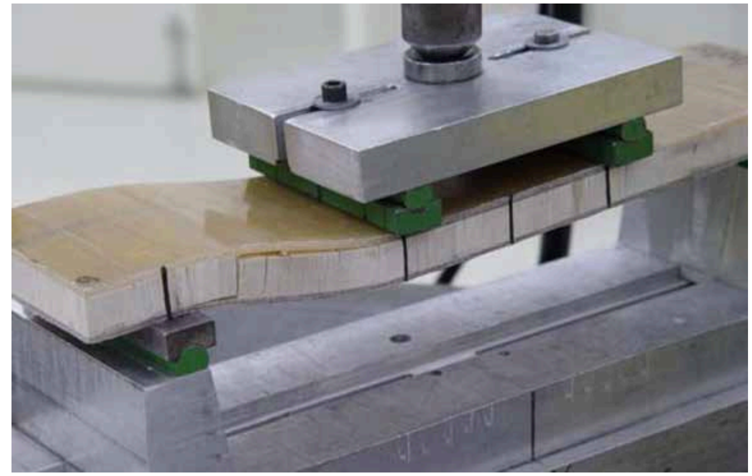
Multi-axial panel test apparatus at the US Navel Academy

Sandwich Flexural Tests

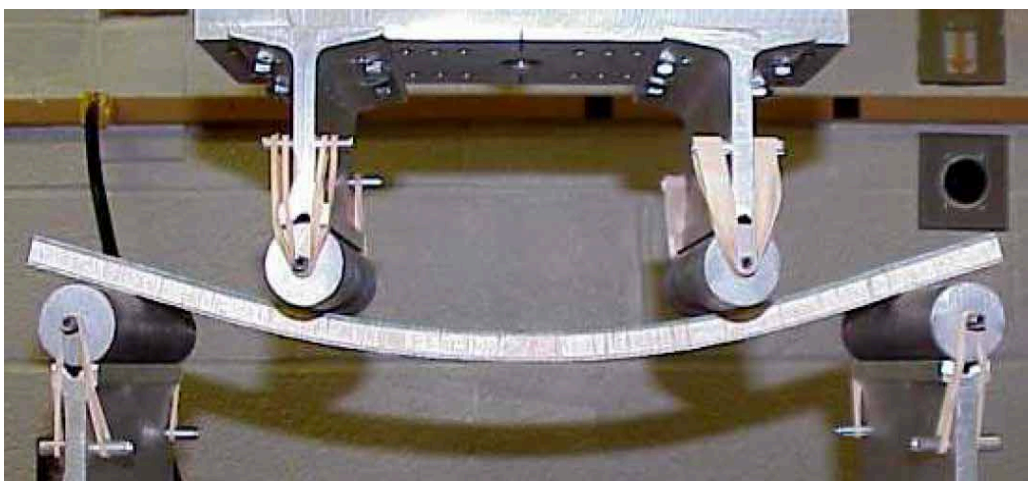
3-Point Bending



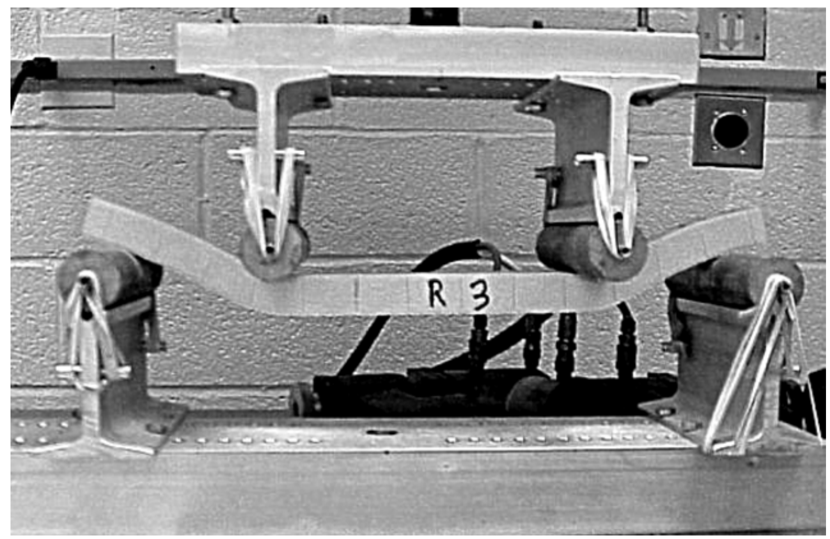
ASTM C 393-00 Sandwich Test



4-Point Bending



4-Point Bending

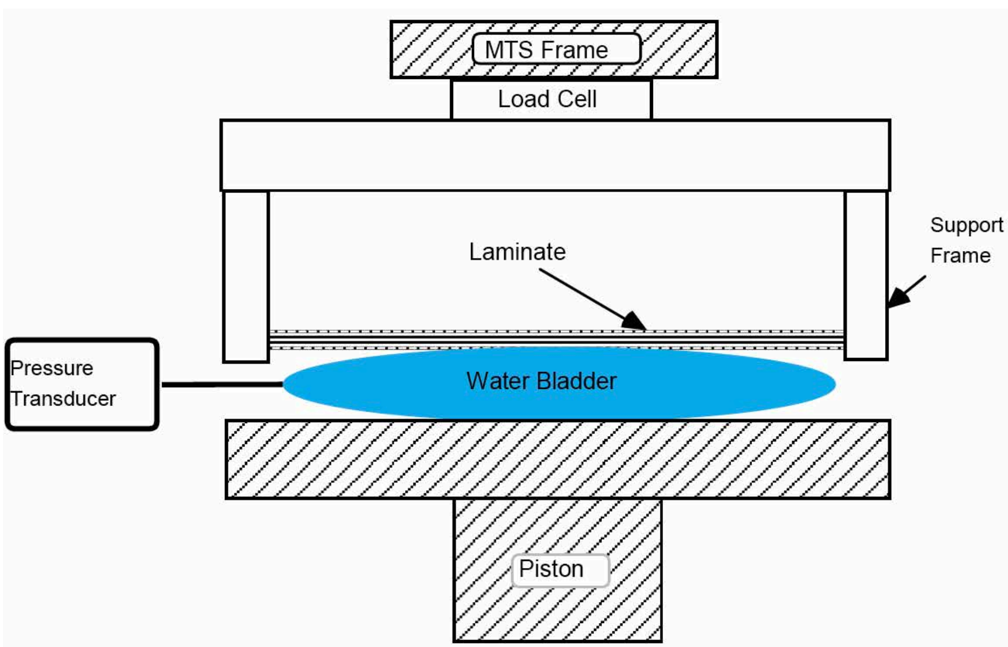


Panel Testing

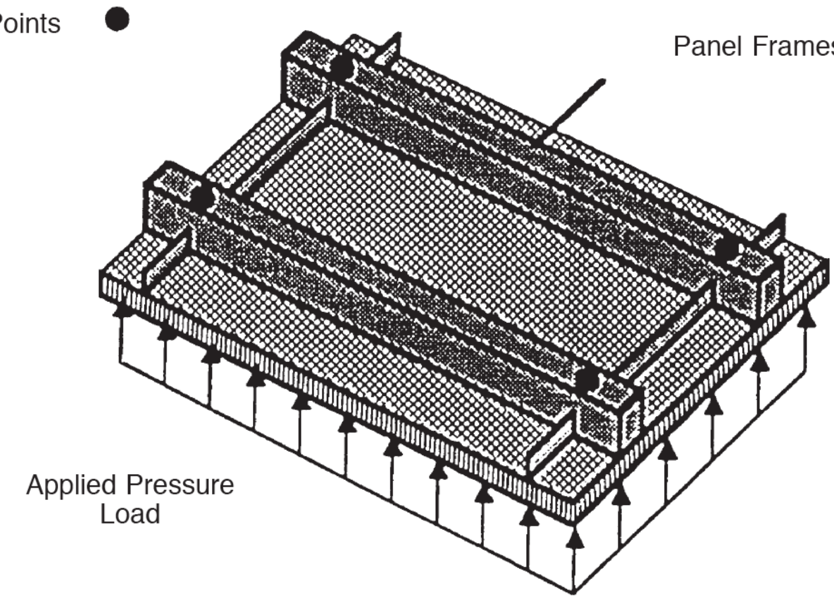
Hydromat Static Test

ASTM D6416, “Standard Test Method for Two-Dimensional Flexural Properties of Simply Supported Sandwich Composite Plates Subjected to a Distributed Load”

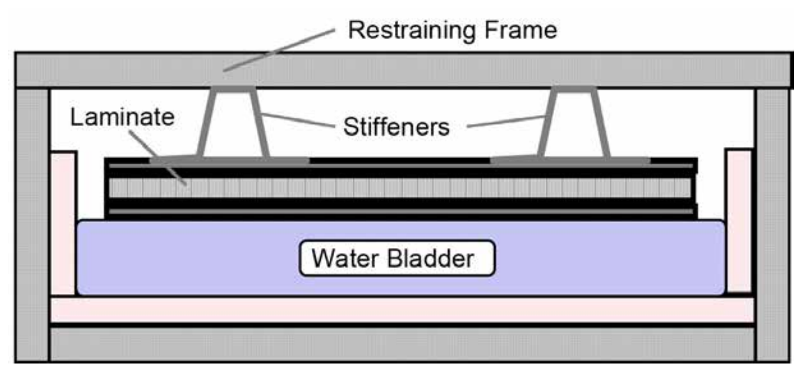
This test method determines the two-dimensional flexural properties of sandwich composite plates subjected to a distributed load. The test fixture uses a relatively large square panel sample which is simply supported all around and has the distributed load provided by a water- filled bladder.



Dynamic Panel Testing

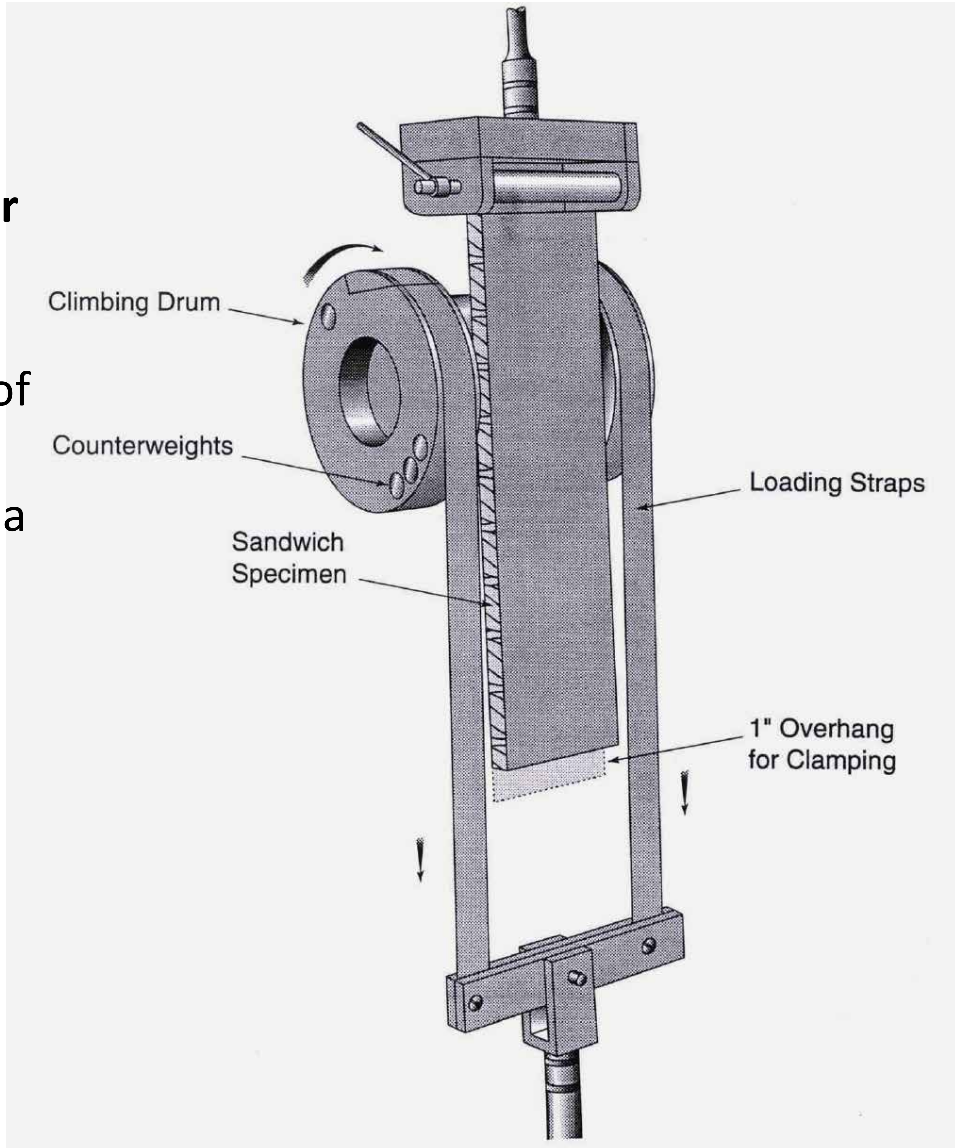


Schematic Diagram of Panel Testing Pressure Table Developed by Reichard [FIT]



Skin Peel Tests

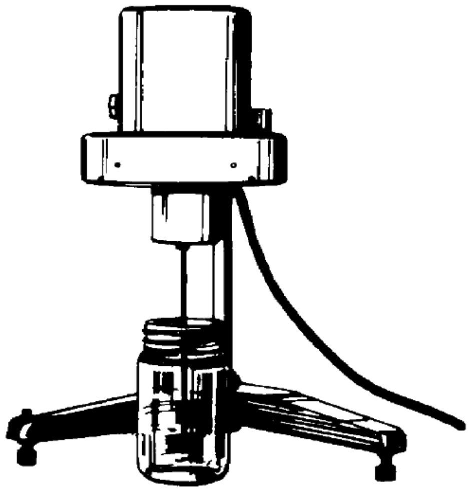
Climbing test with sandwich specimen



ASTM D1781-98, “Standard Test Method for Climbing Drum Peel for Adhesives”

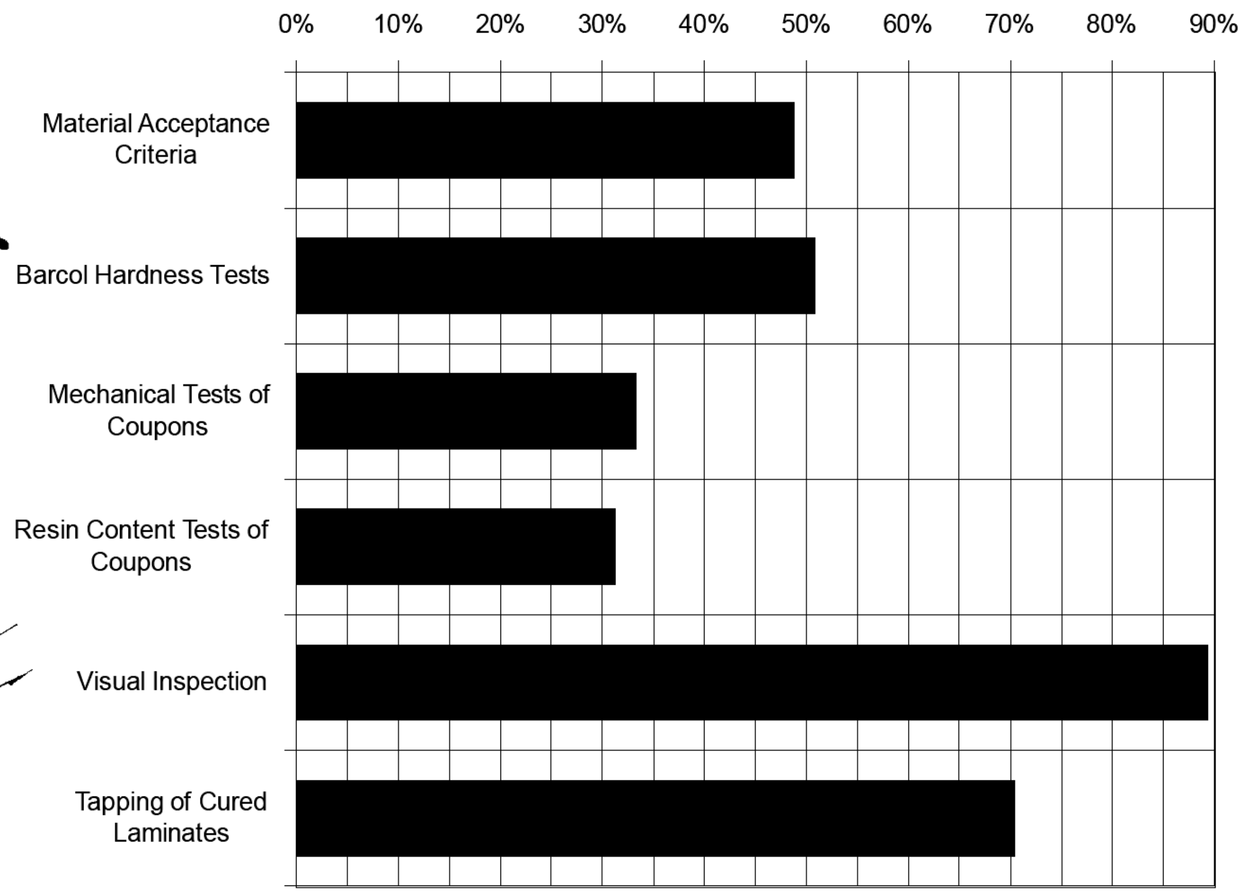
This test method covers the determination of the peel resistance of adhesive bonds between: a relatively flexible adherend and a rigid adherend; and the relatively flexible facing of a sandwich structure and its core, when tested under specified conditions

Quality Assurance



Brookfield Model LVF Viscometer and Spindles [Cook, Polycor Polyester Gel

Barcol Impressor (Model 934 or 935 for readings over 75) [Cook, Polycor Polyester Gel Coats and Resins]



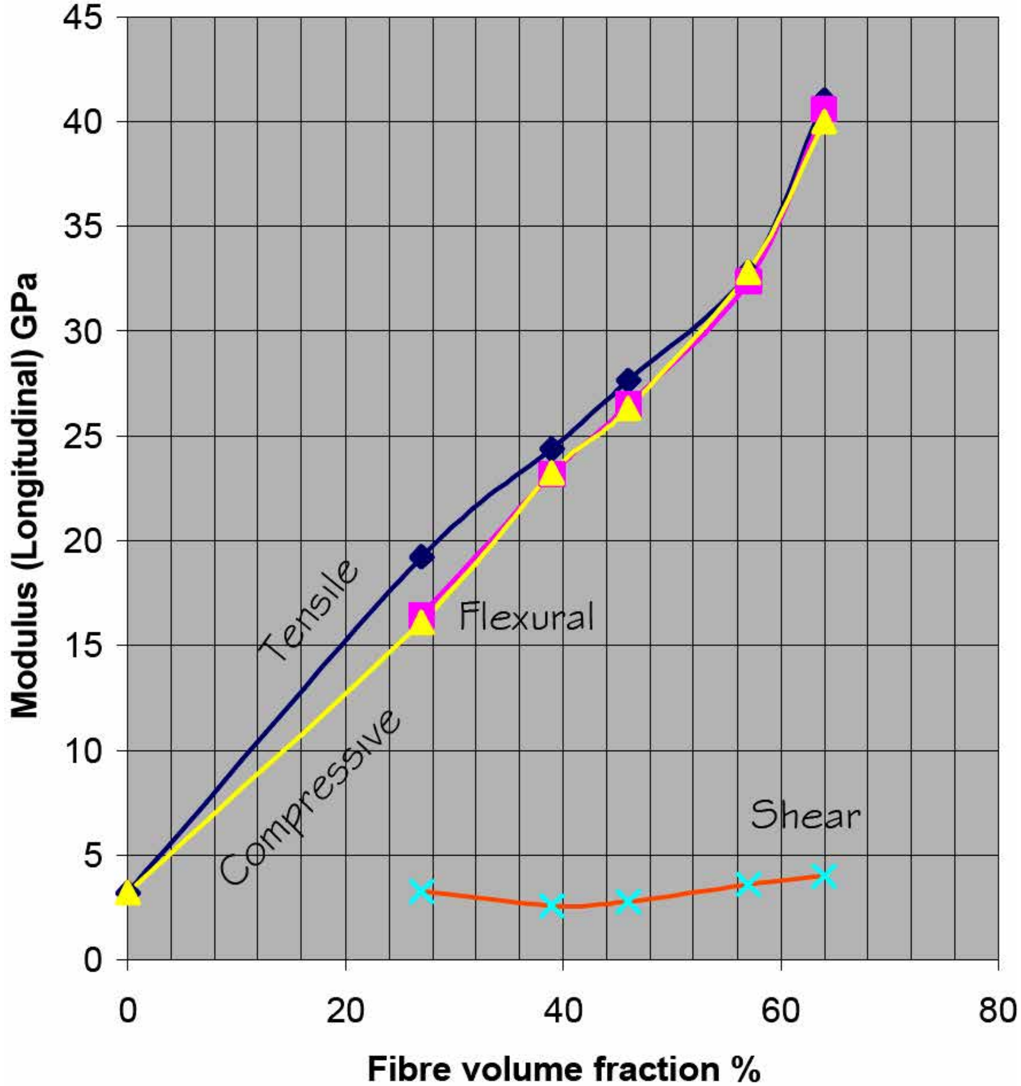
Marine Industry Quality Control Efforts [EGA Survey]

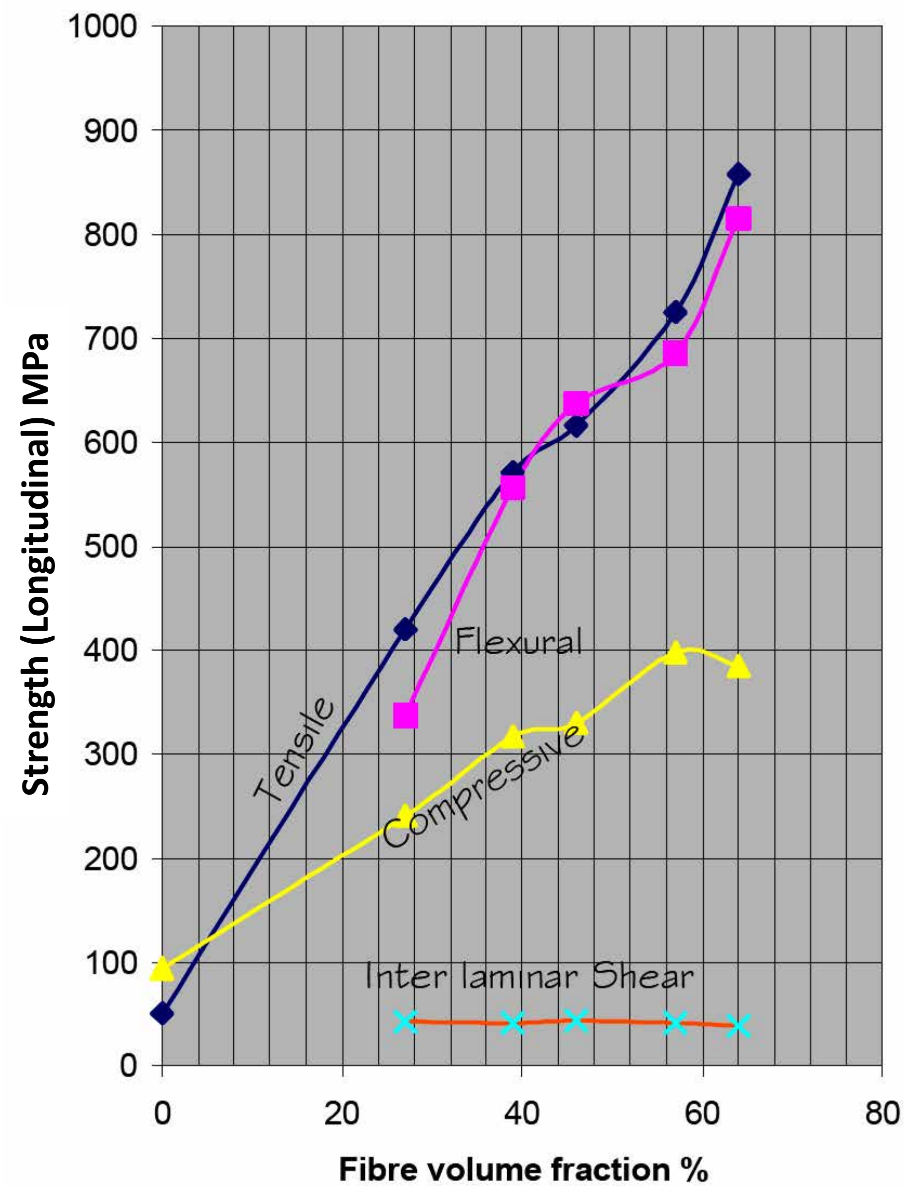
Barcol Hardness

Barcol Hardness - The Barcol hardness of a cured resin sample is measured with a calibrated Barcol impressor, as shown at right. This test (ASTM D 2583-81) will indicate the degree of hardness achieved during cure as well as the degree of curing during fabrication. Manufacturers will typically specify a Barcol hardness value for a particular resin.

Effect of Fiber Fraction

Stiffness (left) and Strength (right) as a function of fiber fraction

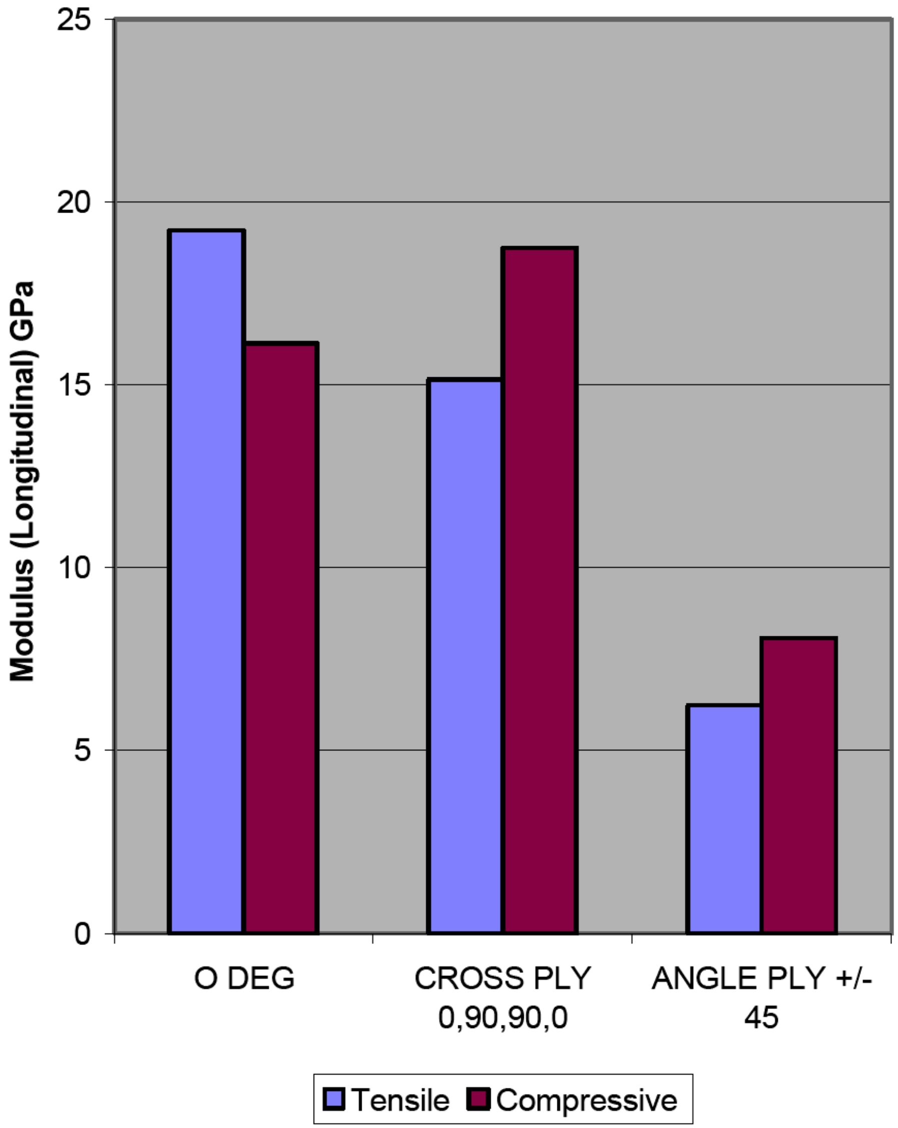




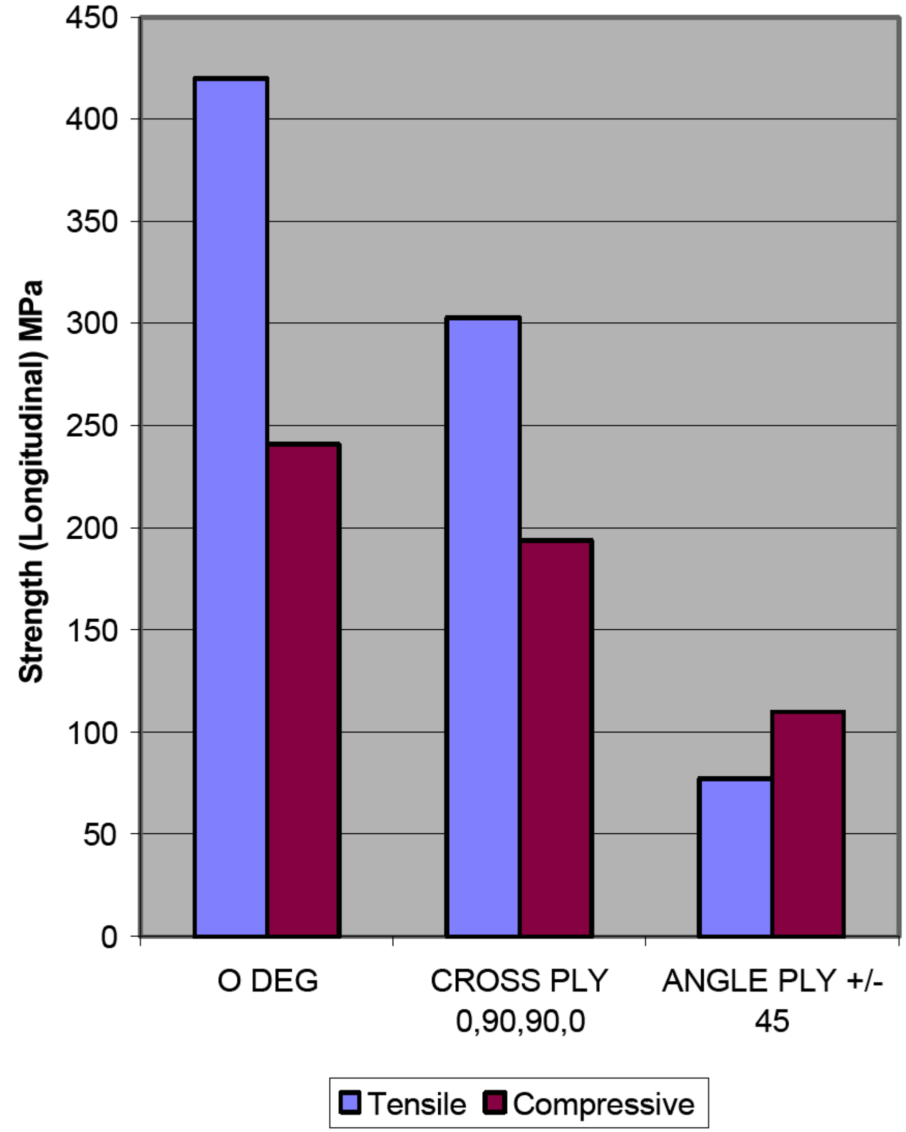
Holmes M Al-Khatat Q, :Structural Properties of GRP," Composites July 1975

Effect of Fiber Architecture (E-Glass)

Stiffness

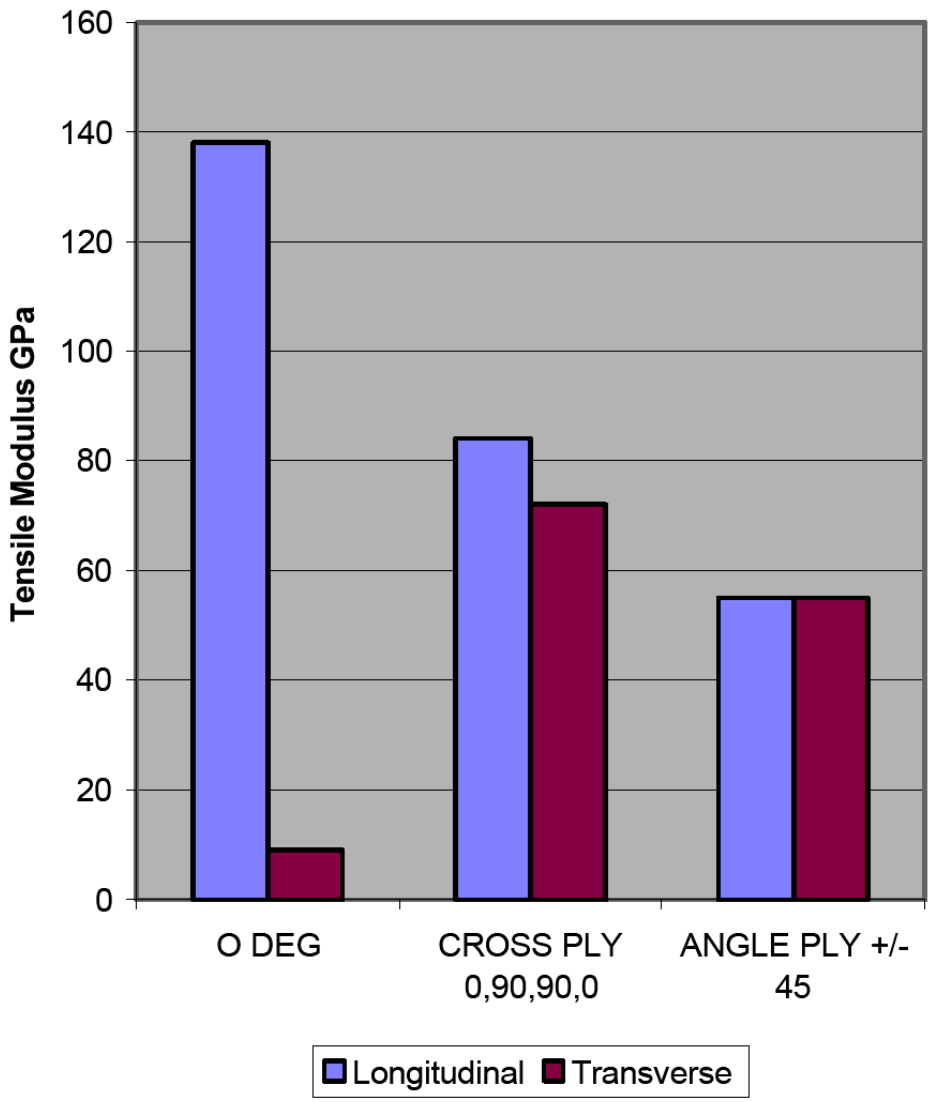


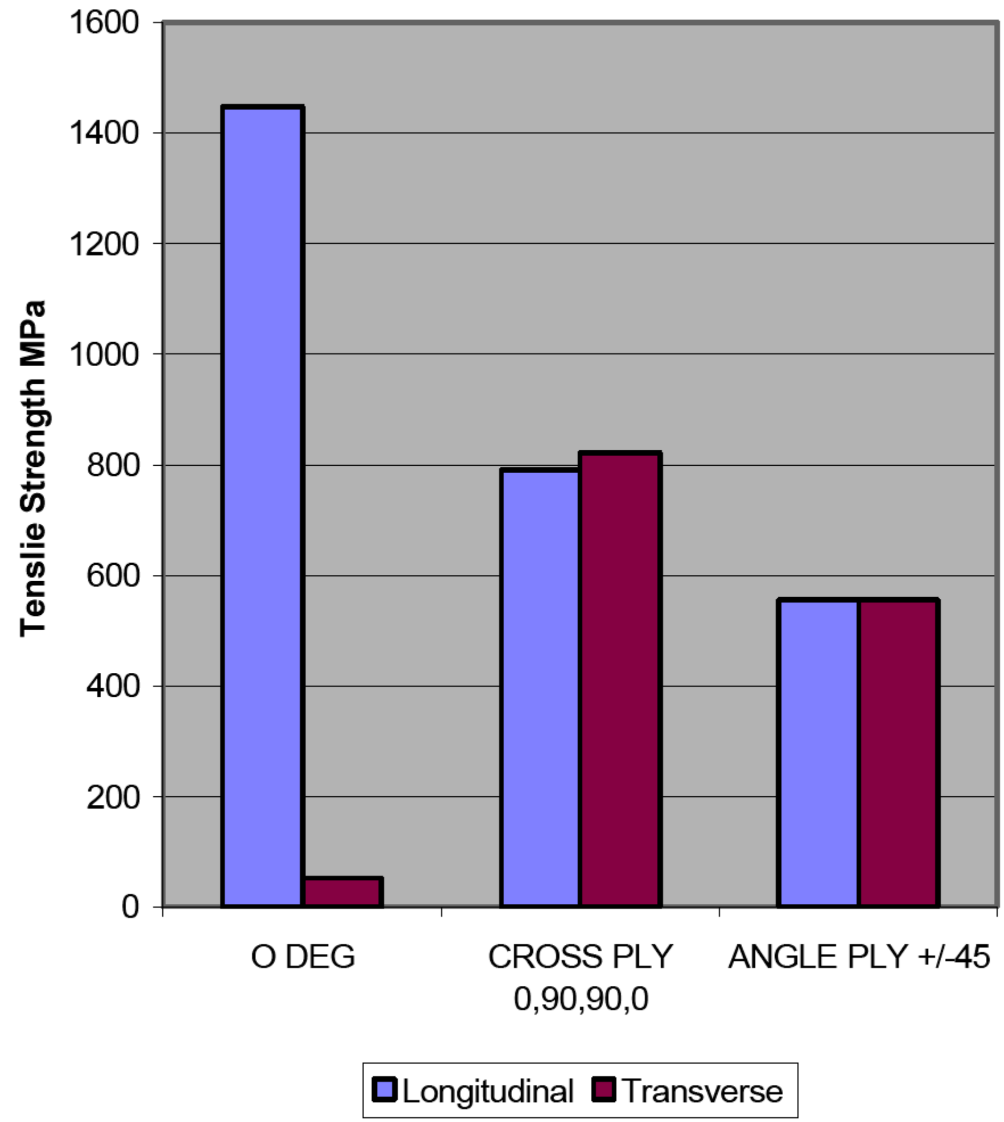
Strength



Holmes M Al-Khatat Q, :Structural Properties of GRP," Composites July 1975

Effect of Fiber Architecture (carbon)





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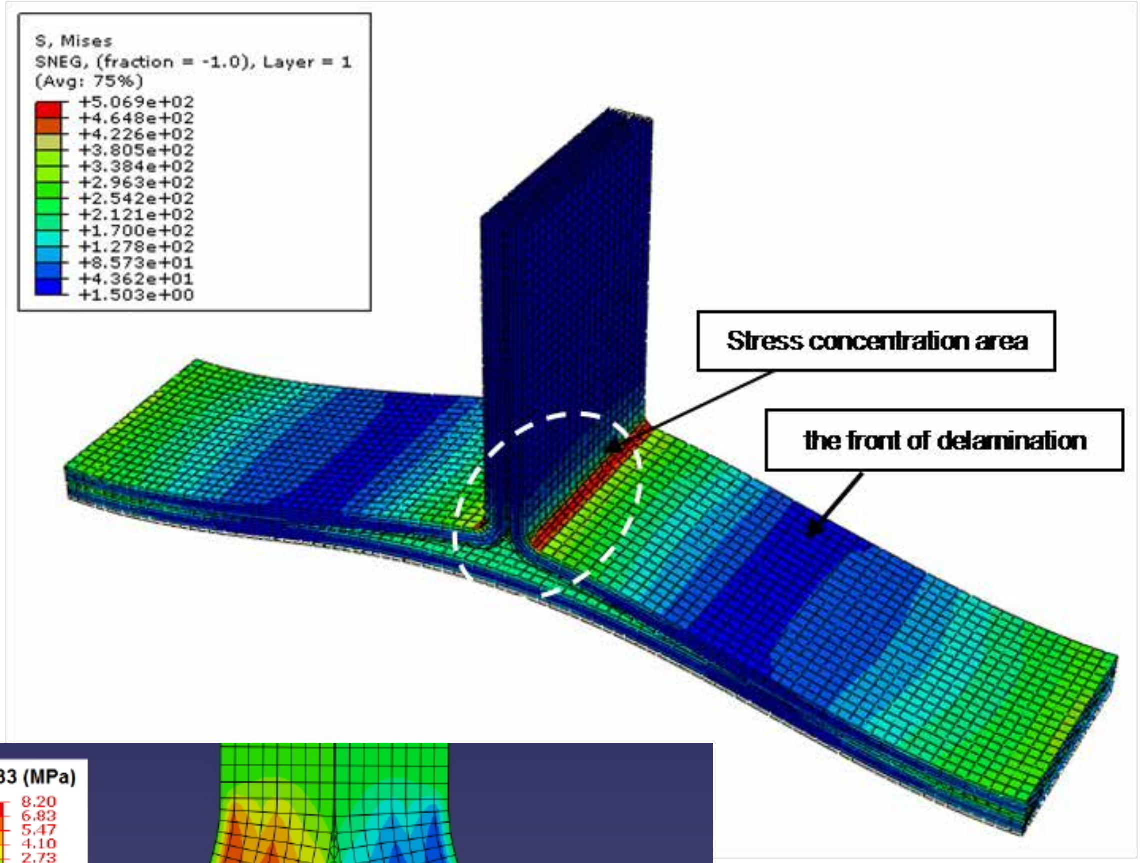
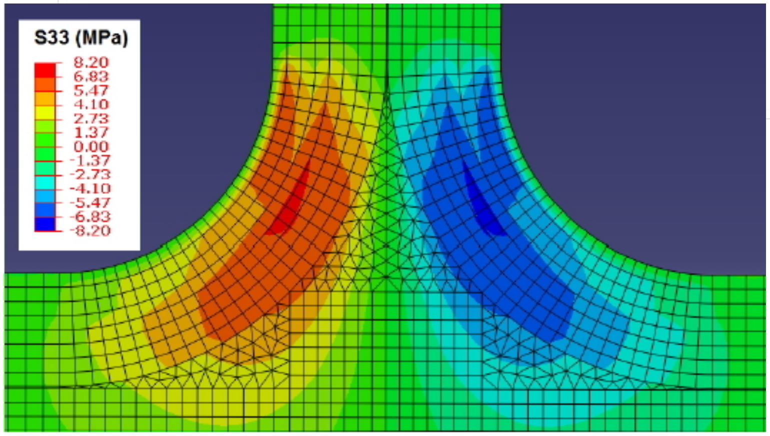
Full-Scale Joint Tests

Balsa-Cored T-Joint





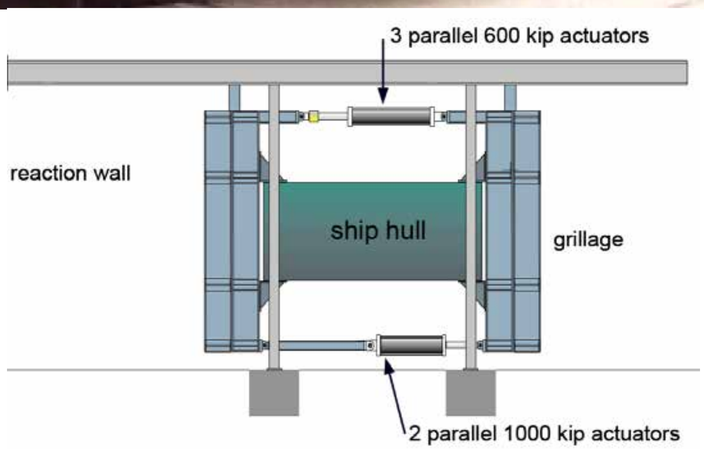
Full-Scale Joint Testing

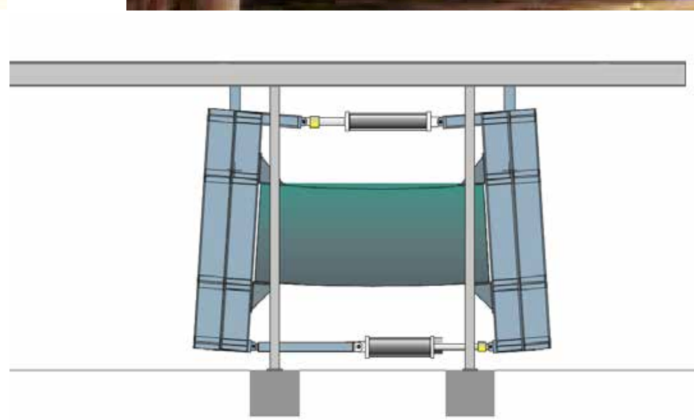
DDG 1000 Deckhouse Structural Joints

Full-Scale Hull Testing

Half-scale corvette hull section measuring 28ft L x 20ft W x 10ft H, ~ 20,000 Lbs

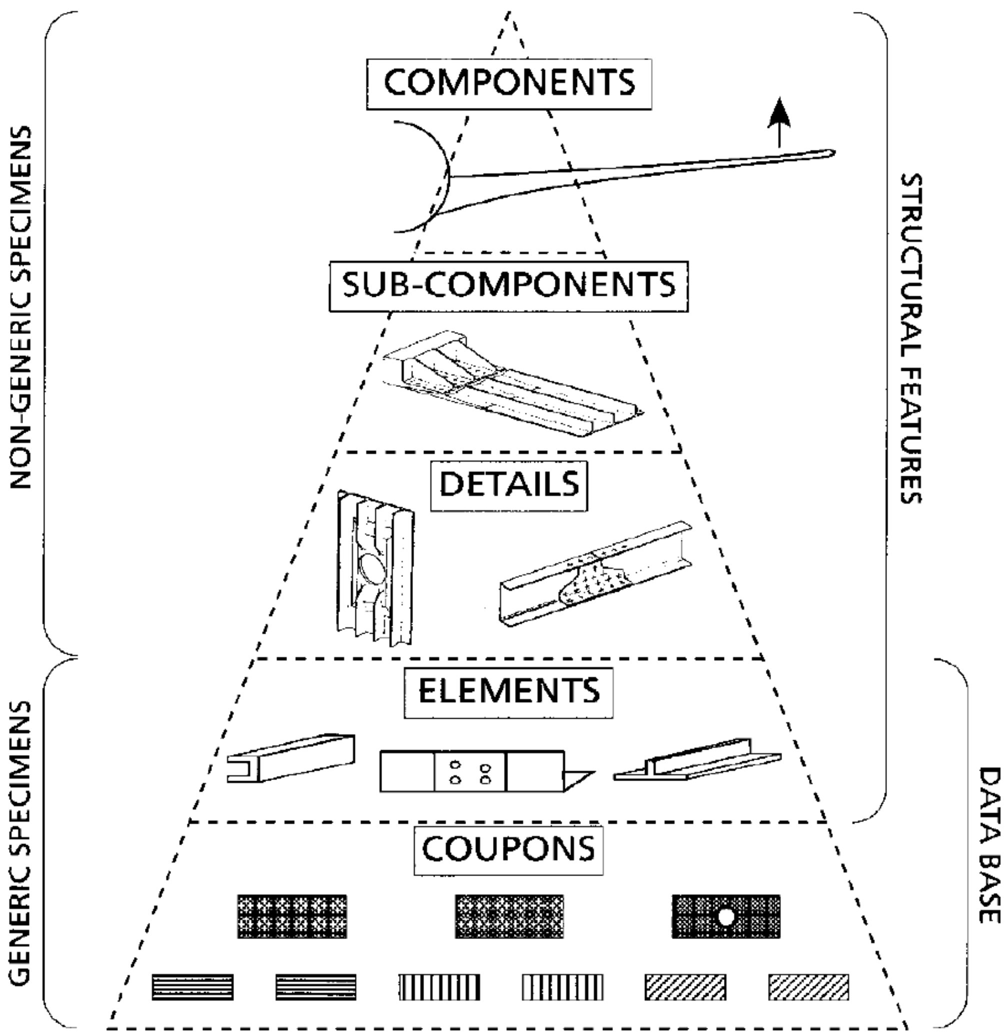
Grillage and Attachment Beams at the Lehigh University ATLSS facility





Roger Crane, "Overview of Composites Structures R&D at Carderock Division," Nov., 2003

Test Program Planning



- Testing matrices,
- Material sampling and pooling issues,
- Statistical calculations,
- Test method selection,
- Material and processing variation,
- Conditioning and non-ambient testing issues,
- Alternative coupon configurations,
- Data normalization and documentation, and
- Application-specific testing.

MIL-HDBK-17-1F, Volume 1, Chapter 2 Guidelines for Property Testing of Composites

Test Method Selection

- The strong influence of constituent content on material response, creating a need to measure the material response of every specimen,
- A need to evaluate properties in multiple directions,
- A need to condition specimens to quantify and control moisture absorption and desorption,
- Increased importance of specimen alignment and load introduction method, and
- A need to assume consistency of failure modes.
- Compressive strength often lower than tensile strength (though specific material systems like boron/epoxy may behave counter to this),
- Operating temperatures relatively closer to material property transition temperatures (compared to metals),
- Shear stress response uncoupled from normal stress response, and
- Heightened sensitivity to specimen preparation practices.

MIL-HDBK-17-1F, Volume 1, Chapter 2 Guidelines for Property Testing of Composites