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ASTM TEST METHODS FOR COMPOSITE CHARACTERIZATION AND EVALUATION

John E. Masters

Lockheed Engineering and Science
144 Research Drive
Hampton, Virginia 23666

Telephone 804-766-9474



Outline of Presentation:

- Introduction
 - Objectives
- Discussion of ASTM
 - General Discussion
 - Subcommittee D-30
- Composite Materials Characterization and Evaluation
 - General Industry Practice
 - Test Methods for Textile Composites

Objectives :

- **Introduce ASTM Organization and Activities**
- **Offer ASTM as a Resource**
- **Recruit New, Active Members**

American Society for Testing and Materials

Definition :

A not-for-profit, voluntary, full-consensus
Standards Development Organization.

ASTM publishes standards for *Materials, Products, Systems* and *Services*

Activities encompass *Metals, Composites, Adhesives, Plastics, Textiles*, paints, petroleum, construction, energy, the environment, consumer products, medical services and devices, computer systems, electronics, and many others.

American Society for Testing and Materials

Purpose :

"the Development of *Standards* . . . and the Promotion of *Related Knowledge*."

Promotion of *Related Knowledge* Accomplished through:

- **Symposia and Workshops**
- **Technical Publications**

American Society for Testing and Materials

ASTM produces six principal types of **Standards**. They are:

Standard Test Methods - a definitive procedure for the identification, measurement, and evaluation of one or more qualities, characteristics, or properties of a material, product, system, or service that produces a test result.

Standard Specification - a precise statement of a set of requirements to be satisfied by a material, product, system, or service that also indicates the procedures for determining whether each of the requirements is satisfied.

Standard Practice - a definitive procedure for performing one or more specific operations or functions that does not produce a test result.

Standard Terminology - a document comprised of terms, definitions, descriptions of terms, explanations of symbols, abbreviations, or acronyms.

Standard Guide - a series of options or instructions that do not recommend a specific course of action.

Standard Classification - a systematic arrangement or division of materials, products, systems, or services into groups based on similar characteristics such as origin, composition, properties, or use.

American Society for Testing and Materials

Technical Publications :

ASTM publishes a variety of technical documents other than standards. They include:

Special Technical Publications (STPs) - collections of peer-reviewed technical papers. Most STPs are based on symposia sponsored by ASTM Technical Committees.

Manuals, Monographs, and Data Series -

Technical Journals:

- *Journal of Composites Technology and Research*
- *Journal of Testing and Evaluation*
- *Cement, Concrete, and Aggregates*
- *Geotechnical Testing Journal*
- *Journal of Forensic Sciences*

Note: Papers presented in all publications are peer reviewed.

American Society for Testing and Materials

Facts and Figures :

- Organized In 1898.
- Membership Totals 34,000 Worldwide.
- 132 Standards-Writing Committees.
- Publishes 9000 ASTM Standards In The 69 Volume Annual Book Of ASTM Standards.
- Conducts Approximately 40 Symposia Annually.
- Publishes 40 To 50 Standard Technical Publications (STPs) Annually.

American Society for Testing and Materials

Information :

American Society for Testing and Materials
1916 Race Street
Philadelphia, Pa
19103-1187

Telephone: (215) 299-5400
FAX: (215) 977-9679

ASTM Committee D-30, on High Modulus Fibers and Their Composites

Roster of Officers and Subcommittee Chairmen :

Chairman:

Dale W. Wilson
ASHRAE
1791 Tullie Circle
Atlanta, Ga 30329
Tel. (404) 636-8400

Vice Chairman:

John E. Masters
Lockheed Eng. and Science
144 Research Drive
Hampton, Va 23666
Tel. (804) 766-9474

Subcommittees and their Chairmen:

Subcommittee D30.01 - Editorial

Elizabeth C. Goeke
U. S. Army Materials Technology Lab.
Attn. SLCMT-MRM
Watertown, Massachusetts 02172-0001
Tel. (617) 923-5466

Subcommittee D30.02 - Research and Mechanics

Roderick H. Martin
Analytical Services and Materials, Inc.
107 Research Drive
Hampton, Va 23666
Tel. (804) 865-7093

Subcommittee D30.03 - Constituent Properties

Christopher J. Spragg
Amoco Performance Products
4500 McGinnis Ferry Road
Alpharetta, Georgia 30202-3944
Tel. (404) 772-8349

Subcommittee D30.04 - Lamina/Laminate Properties

Richard E. Fields
Martin Marietta
P. O. Box 628007
Mail Point 1404
Orlando, Florida 32862-8007
Tel. (407) 356-5842

ASTM Committee D-30, on High Modulus Fibers and Their Composites

Roster of Officers and Subcommittee Chairmen (Cont.) :

Subcommittee D30.05 - Structural Properties

Ronald F. Zabora
Boeing Commercial Airplanes
P. O. Box 3707
Mail Stop 48-02
Seattle, Washington 98124-2207
Tel. (206) 662-2655

Subcommittee D30.06 - Interlaminar Properties

T. Kevin O'Brien
U. S. Army Aeronautical Directorate
NASA Langley Research Center
Mail Stop 188E
Hampton, Virginia 23665-5225
Tel. (804) 864-3465

Subcommittee D30.07 - Metal Matrix Composites

W. Steven Johnson
NASA Langley Research Center
Mail Stop 188E
Hampton, Virginia 23665-5225
Tel. (804) 864-3463

Subcommittee D30.08 - Thermomechanical Properties

Thomas S. Gates
NASA Langley Research Center
Mail Stop 188E
Hampton, Virginia 23665-5225
Tel. (804) 864-3400

ASTM Staff Manager

Kathie Schaaf
ASTM
1916 Race Street
Philadelphia, Pennsylvania
19103
Tel. (215) 299-5529

ASTM Committee D-30, on High Modulus Fibers and Their Composites

Test Methods, Practices, Guides, and Terminology Documents:

High Modulus Fibers and Their Composite Materials

Test Methods:

- | | |
|-------------------|--|
| D2344 - 84 (1989) | Apparent Interlaminar Shear Strength of Parallel Fiber Composites by Short-Beam Method |
| D2290 - 87 | Apparent Tensile Strength of Ring or Tubular Plastics and Reinforced Plastics by Split Disk Method |
| D3410 - 87 | Compressive Properties of Unidirectional or Crossply Fiber-Resin Composites |
| D3171 - 76 (1990) | Fiber Content of Resin-Matrix Composites by Matrix Digestion |
| D3553 - 76 (1989) | Fiber Content by Digestion of Reinforced Metal Matrix Composites |
| D3532 - 76 (1989) | Gel Time of Carbon Fiber-Epoxy Prepreg |
| D2586 - 68 (1990) | Hydrostatic Compressive Strength of Glass-Reinforced Plastic Cylinders |
| D2585 - 68 (1990) | Preparation and Tension Testing of Filament-Wound Pressure Vessels |
| C613 - 67 (1990) | Resin Content of Carbon and Graphite Prepregs by Solvent Extraction |
| D3531 - 76 (1989) | Resin Flow of Carbon Fiber-Epoxy Prepreg |
| D3529/3529M - 90 | Resin Solids Content of Carbon Fiber-Epoxy Prepreg |
| D3552 - 77 (1989) | Tensile Properties of Fiber Reinforced Metal Matrix Composites |
| D3039 - 76 (1989) | Tensile Properties of Fiber-Resin Composites |
| D3479 - 76 (1990) | Tension-Tension Fatigue of Oriented Fiber Resin Matrix Composites |
| D4108 - 87 | Thermal Protective-Performance of Materials for Clothing by Open-Flame Method |
| D3530/D3530M-90 | Volatiles Content of Epoxy-Matrix Prepreg by Matrix Dissolution |

ASTM Committee D-30, on High Modulus Fibers and Their Composites

Test Methods, Practices, Guides, and Terminology Documents (Cont.) :

Practices:

- D2291 - 83 (1989) Fabrication of Ring Test Specimens for Glass-Resin Composites
- D3518 - 91 Inplane Shear Stress-Strain Response of Unidirectional Reinforced
Plastics

Terminology Relating:

- D3878 - 87 High-Modulus Reinforcing Fibers and Their Composites

Guides:

- D4762 - 88 Automotive/Industrial Composite Materials, Testing of
- D4255 - 83 Inplane Shear Properties of Composite Laminates, Testing

High Modulus Fibers

Test Methods:

- D3800 - 79 (1990) Density of High-Modulus Fibers
- D4018 - 81 Tensile Properties of Continuous Filament Carbon and Graphite
Yarns, Strands, Rovings, and Tows
- D3379 - 75 (1989) Tensile Strength and Young's Modulus for High-Modulus Single-
Filament Materials
- D4102 - 82 (1987) Thermal Oxidative Resistance of Carbon Fibers

Terminology Relating:

- D3878 - 87 High-Modulus Reinforcing Fibers and Their Composites

Guides:

- D3544 - 76 (1989) Reporting Test Methods and Results on High Modulus Fibers

ASTM Committee D-30, on High Modulus Fibers and Their Composites

Recent Special Technical Publications:

STP 1059 : Composite Materials: Test and Design (Ninth Volume)

S. P. Garbo, Ed. - 1990

STP 1080 : Thermal and Mechanical Behavior of Metal Matrix and Ceramic Matrix Composite Materials

J. M. Kennedy, H. H. Moeller, and W. S. Johnson, Eds. - 1990

STP 1110 : Composite Materials: Fatigue and Fracture (Third Volume)

T. K. O'Brien, Ed. - 1991

STP 1120 : Composite Materials: Testing and Design (Tenth Volume)

G. C. Grimes, Ed. - 1992

STP 1128 : Damage Detection in Composite Materials

J. E. Masters, Ed. - 1992

STP 1156 : Composite Materials: Fatigue and Fracture (Fourth Volume)

W. W. Stinchcomb and N. E. Ashbaugh, Eds. - 1993

STP 1174 : High Temperature and Environmental Effects on Polymeric Composites

C. E. Harris and T. S. Gates, Eds. - 1993

STP 1203 : Fractography of Modern Engineering Materials: Metals and Composites, Second Volume

J. E. Masters and L. N. Gilbertson, Eds. - 1993

STP 1206 : Composite Materials: Testing and Design (Eleventh Volume)

E. T. Camponeschi, Ed. - 1993

Composite Material : Characterization and Evaluation

A Survey Of Major Aircraft Manufacturers Indicates that:

- Procedures Are Designed to Minimize the Risk of Spending A Large Amount Of Funds On Materials Which Do Not Meet *Structural* or *Processing* Requirements.
- Materials Evaluation Conducted in Three Stages: *Material Screening, Material Characterization,* and *Development of Design Allowables.*
- Although The Tests Employed Were Not Identical, The Properties Measured At Each Level Of Investigation Were Similar From Company To Company.
- Majority Of Tests Focus On Obtaining The Mechanical Properties Which Are Most Useful To The *Designer* And The *Structural Analyst* But Which May Not Be Of Great Interest To The *Material Scientist.*
- Three Major Design Factors that Control the Weight of an Aircraft: *Stiffness, Damage Tolerance, and Stress Concentrations at Cut-Outs and Loaded Bolt Holes.*

Composite Material : Characterization and Evaluation

Screening Evaluation :

- First Step In the Material Characterization and Evaluation Process.
- Objective: Determine Material Acceptability for Aircraft Structural Applications.
- Compared Candidate Material To A Baseline Material To Determine if a More Extensive Evaluation Program is Warranted.
- 50 to 60 Tests Typically Performed.

Composite Material : Characterization and Evaluation

Screening Evaluation Tests :

A list of test methods commonly employed in screening evaluations is contained in the following table.

Test Type	Properties Measured	Environmental Condition
0° Tension	Strength, Modulus	RTA
0° Compression	Strength, Modulus	RTA, ETW
+/- 45° Tension	Strength, Modulus	CTA, RTA, ETW
Interlaminar Shear	Strength	RTA
Laminate Compression	Strength	RTA
Open Hole Tension	Strength	CTA, RTA, ETW
Open Hole Compression	Strength	CTA, RTA, ETW
Compression after Impact	Strength	RTA
Bolt Bearing Tension	Strength	RTA

Note: CTA indicates -65 ° F/ Ambient Moisture Conditions
 RTA indicates Room Temperature/ Ambient Moisture Conditions
 ETW indicates Elevated Temperature/ Saturated Moisture Conditions

Composite Material : Characterization and Evaluation

Material Characterization :

- Objective: Establish *Preliminary* Design Properties for Design and Analysis of Test Components for Design Trade Studies.
- Measure Lamina Properties Required to Support Laminated Plate Theory and Failure Criteria.
- Measure Laminate Properties to Support Analysis and Design.
- 200 to 250 Tests Typically Performed.

Composite Material : Characterization and Evaluation

Materials Characterization Tests :

A list of test methods commonly employed in materials characterization tests is contained in the following table.

Test Type	Properties Measured	Environmental Condition
0° Tension	Strength, Modulus, Poisson's Ratio	CTA, RTA, ETW
90° Tension	Strength, Modulus, Poisson's Ratio	CTA, RTA, ETW
0° Compression	Strength, Modulus	CTA, RTA, ETW
90° Compression	Strength, Modulus	CTA, RTA, ETW
+/- 45° Tension	Modulus	CTA, RTA, ETW
In-Plane Shear	Strength	RTA
Interlaminar Shear	Strength	RTA
Interlaminar Tension	Strength	RTA
Laminate Compression	Strength, Modulus	CTA, RTA, ETW
Open Hole Tension	Strength	CTA, RTA, ETW
Open Hole Tension (Fatigue)	S - N Data	RTA
Filled Hole Tension	Strength	RTA
Open Hole Compression	Strength	CTA, RTA, ETW
Filled Hole Compression	Strength	RTA
Compression after Impact	Strength	RTA
Bolt Bearing Tension	Strength	RTA
Mode I Delamination Resistance	G _{IC}	RTA
Mode II Delamination Resistance	G _{IIC}	RTA

Note: **Bold Type** indicates tests performed in Screening Evaluation
 CTA indicates -65 ° F/ Ambient Moisture Conditions
 RTA indicates Room Temperature/ Ambient Moisture Conditions
 ETW indicates Elevated Temperature/ Saturated Moisture Conditions

Composite Material : Characterization and Evaluation

Development Of Design Allowables :

- Objective: Develop Complete Database for Final Design and Certification.
- Same Types of Tests Used in Materials Screening and Characterization Evaluations.
- Test Matrix Expanded to Include Additional Laminate Configurations, Alternate Specimen Geometries (e.g. Width/Diam. Ratios), Additional Environmental Conditions, More Replicate Tests on Samples taken from Several Batches of Material.
- Could Total Thousands of Tests Depending on Certification Requirements.

Composite Material : Characterization and Evaluation

Tests Applied to Laminated Tape Composites :

<u>TEST TYPE</u>	<u>TEST METHOD</u>
• TENSION:	
Unnotched	ASTM D3039, D3518 MISC. COMPANY METHODS
Notched	SACMA SRM 5 NASA 1142- B9
• COMPRESSION:	
Unnotched	ASTM 3410 SACMA SRM1 NASA SHORT BLOCK MISC. COMPANY METHODS
Notched	SACMA SRM 3 NASA 1092 ST-4 MISC. COMPANY METHODS
• COMPRESSION AFTER IMPACT	SACMA SRM 2 NASA 1142 B11
• BOLT BEARING	MISC. COMPANY METHODS
• INTERLAMINAR TENSION	FLATWISE TENSION CURVED BEAM
• INTERLAMINAR SHEAR	ASTM D2344
• MODE I DELAMINATION	DOUBLE CANTILEVER BEAM
• MODE II DELAMINATION	END NOTCHED FLEXURE

Note: SACMA Indicates Test Methods Developed by the Suppliers of Advanced Composite
Materials Association

Composite Material : Characterization and Evaluation

Physical Properties Measured :

Prepreg Tape:

Resin Content
Fiber Content
Volatile Content

Cured Laminates:

Resin Content
Fiber Content
Void Content
Density/Specific Gravity
Glass Transition Temperature (Dry and Wet)
Equilibrium Moisture Content
Thermal Conductivity
Heat Capacity
Coefs. of Thermal Expansion
Thermal Oxidative Stability

Development of Test Methods for Textile Composites

Program Objective :

As indicated below, the objective of this on-going effort, simply stated, is to develop a set of test methods and guidelines to be used to measure the mechanical and physical properties of composite materials reinforced with fibrous textile preforms. Investigations conducted to date have indicated that existing methods, which were developed largely to evaluate laminated tape type composites, may not adequately address the subtleties of these new material forms.

Develop And Verify Recommended Mechanical
Test Procedures And Instrumentation
Techniques For Textile Composites

Development of Test Methods for Textile Composites

Statement of Problem :

The problem to be addressed is summarized in the two bullet statements given below. Simply stated, the test methods listed in the previous figures were developed to evaluate composite materials formed by laminating layers of pre-impregnated fiber-reinforced tape. The microstructure of these laminated composite materials differs significantly from the braided, woven, and stitched materials to be evaluated in this program. The fiber architecture will play a prime roll in determining the mechanical response of these textile composite materials. Will existing methods and practices accurately reflect the material response of these materials?

- **TEST METHODS DEVELOPED FOR
LAMINATED TAPE COMPOSITES**

- **TEXTILE ARCHITECTURE CONTROLS
MATERIAL RESPONSE**

Development of Test Methods for Textile Composites

Textile Composites Testing Issues :

It is not difficult to identify a number of specific testing issues relative to textile composites. Several of these concerns, which are applicable to virtually all of the test methods listed on the previous page, are listed below.

The first two reflect the unique size effects these materials may present. A unit cell is defined as the smallest unit of repeated fiber architecture. It may be considered the building block of the material. The size of the unit cell is dependent on a number of factors including the size of the yarns, the angle at which they are intertwined or interwoven, and the intricacy of the braid or weave pattern. A representative volume of material must be tested and monitored to accurately reflect true material response. Specimen geometry and strain gage sizes must be reexamined in terms of unit cell size. The effect of the sizes of the yarn bundles must also be considered since they may also affect the performance and the measurements. This is expressed in the third statement.

The final three items on the list reflect concerns over specimen geometry. Test specimen dimensions established for tape type composites may not be applicable to textile composites. The degree of heterogeneity present in the latter materials is quite different than that encountered in the former. The potential effects of these differences must be also quantified.

A limited amount of relevant data has been developed for 2-D triaxially braided textile composites. These results will be reviewed in the following section. They include Moiré interferometry and strength and modulus measurements.

- **EFFECT OF UNIT CELL SIZE ON MECHANICAL PERFORMANCE**
- **EFFECT OF UNIT CELL SIZE ON STRAIN GAGE AND DISPLACEMENT MEASUREMENTS**
- **EFFECT OF TOW SIZE AND FIBER ARCHITECTURE ON MECHANICAL PERFORMANCE**
- **EFFECT OF FINITE WIDTH ON UNNOTCHED AND OPEN-HOLE SPECIMENS**
- **EFFECT OF EDGE CONDITIONS ON MECHANICAL PERFORMANCE**
- **EFFECT OF TEXTILE THICKNESS ON MECHANICAL PERFORMANCE**

Development of Test Methods for Textile Composites

Program Approach :

A straightforward approach has been adopted to meet the objective outlined in the previous figure. An extensive test program will be conducted to gather data addressing the concerns listed earlier. The program, which will include a wide variety of woven, braided, and stitched preform architectures, will consider several loading conditions.

The general approach is outlined below. Details of material tested and test methods are supplied in the following pages.

- **IDENTIFY AND/OR DESIGN AND DEVELOP SPECIMEN CONFIGURATIONS AND TEXT FIXTURES**

- **CONDUCT MECHANICAL TEST PROGRAM**
 - **Variety of Test Methods**
 - **Variety of Instrumentation Techniques**
 - **Full Field Strain Measurements**
 - **Analytical Support**

- **IDENTIFY SMALLEST LEVEL OF HOMOGENEITY**

- **IDENTIFY APPROPRIATE TEST METHODS AND INSTRUMENTATION GUIDELINES**

Development of Test Methods for Textile Composites

Description of Material Tested : Preforms and Textile Parameters Studied

Fifteen woven, braided, and stitched preforms will be evaluated in the program. The preform types are listed below in the table; the number of each type to be tested is indicated in parentheses. The table also lists the braid parameter that will be varied for each preform type. The list of materials reflects the material forms that are being evaluated by the aircraft manufacturers in the ACT program.

TEXTILE PREFORM TYPES :

- **2-D TRIAXIAL BRAIDS - (4)**
 - Tow Size
 - % Longitudinal Tows
 - Braid Angle

- **3-D INTERLOCK WEAVE - (6)**
 - Weave Type - (3)
 - Warp, Weft, and Weaver Tow Size

- **STITCHED UNIWEAVE - (5)**
 - Stitch Material
 - Stitch Spacing
 - Stitch Yarn Size

MATERIALS :

FIBER: HERCULES AS4

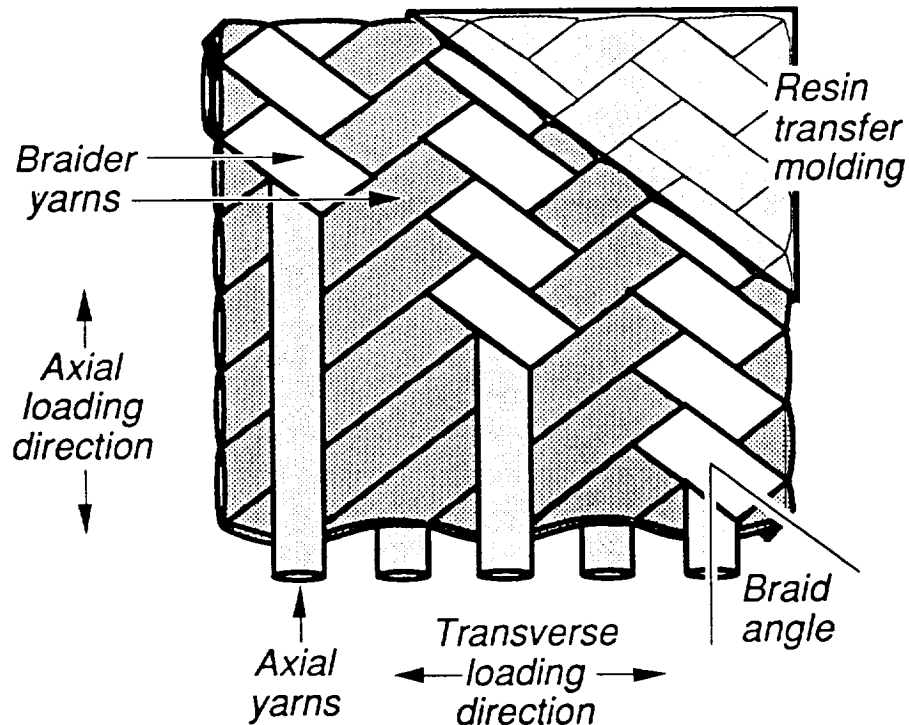
RESIN: SHELL 1895

Development of Test Methods for Textile Composites

Description of Material Tested : Triaxial Braid Pattern

The specimens studied in this investigation featured 2-D triaxially braided AS4 graphite fiber preforms impregnated with Shell 1895 epoxy resin. In a triaxially braided preform three yarns are intertwined to form a single layer of $0^\circ/\pm \Theta^\circ$ material. In this case, the braided yarns are intertwined in a 2 x 2 pattern. Each $+\Theta$ yarn crosses alternatively over and under two $-\Theta$ yarns and vice versa. The 0° yarns were inserted between the braided yarns. This yields a two dimensional material. The figure below schematically illustrates the fiber architecture and establishes the nomenclature used in the paper.

The yarns were braided over a cylindrical mandrel to a nominal thickness of 0.125 in. The desired preform thickness was achieved by overbraiding layers; there are no through-the-thickness fibers. After braiding, the preforms were removed from the mandrel, slit along the 0° fiber direction, flattened, and border stitched to minimize fiber shifting. The resin was introduced via a resin transfer molding process.



Development of Test Methods for Textile Composites

Triaxial Braid Configurations Tested :

Three preform parameters, braid angle, yarn size, and 0° yarn content, were varied in this study. The last parameter listed is typically expressed as a percentage of 0° yarns. It is the volumetric proportion of longitudinal yarns to total yarn content and is a function of braid angle and yarn size. Yarn size is expressed in terms of the number of filaments per yarn. The AS4 fibers used in these materials have a nominal diameter of 7 microns. The longitudinal yarns were larger than the braided yarns in all cases. The B1 and B2 architectures had the same yarn sizes; they differed in braid angle and 0° yarn content. The preform parameters are listed in the table.

The fabrics were formed with a 144 carrier New England Butt triaxial braider, incorporating 72 longitudinal yarns. The mandrel diameters varied for each architecture. Since the number of carriers was constant, this had the effect of changing the yarn spacing. These parameters are also listed in the table.

MATERIAL	BRAID PATTERN	BRAIDER YARN SIZE	0° YARN SIZE	0° YARN CONTENT (%)	0° YARN SPACING (Yarn/In.)	BRAID YARN SPACING (Yarn/In.)
A1	0/± 63°	12K	24K	31.5	4.17	9.16
B1	0/±66.5°	6K	18K	37.6	4.77	11.98
B2	0/±70°	6K	18K	34.0	4.37	12.74

Note: K indicates thousands. For the AS-4 yarns, each filament is 7 microns in diameter

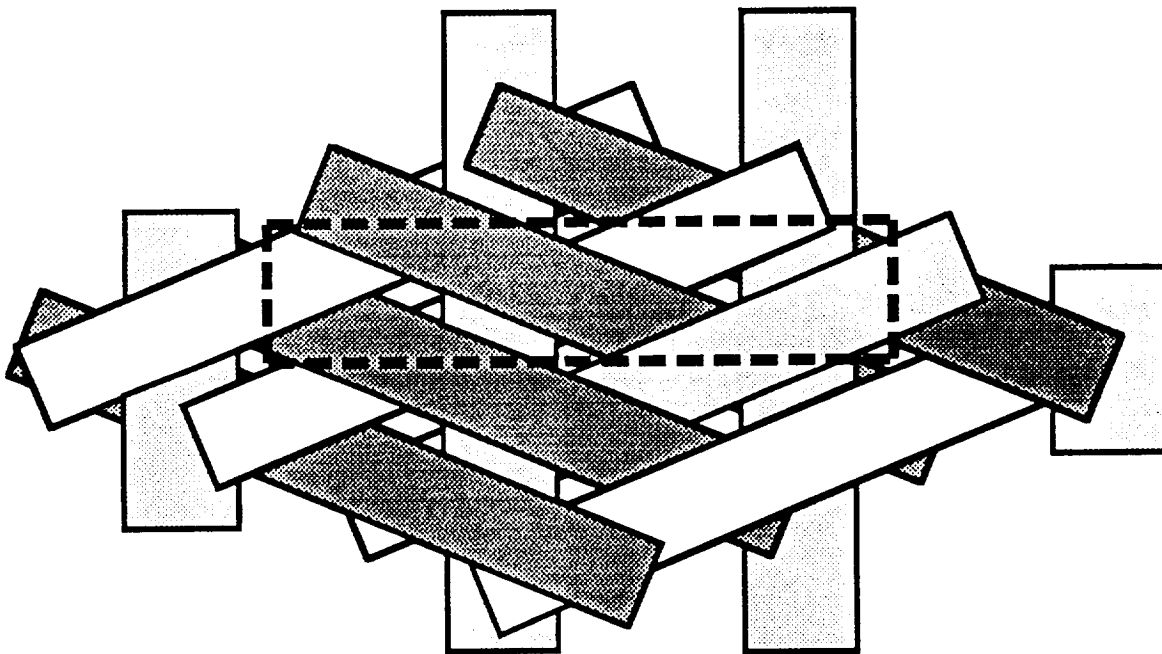
Development of Test Methods for Textile Composites

Unit Cell Definition :

A convenient way to describe textile preforms is to identify a unit cell of material - a repeatable unit of fabric geometry. The unit cell represents the complete yarn intertwinement pattern. The unit cell approach has become the foundation of textile analysis and serves as a convenient framework in which to interpret experimental data.

The rhombic frame shown in the figure defines a unit cell for the 2-D triaxially braided material studied in this program. For computational purposes, it is desirable to define the smallest unit cell possible. In some analyses, rectangular unit cells are also required. The rectangular section shown in the figure represents the smallest unit cell identified.

The table shown below contains the dimensions of the unit cells for the three architectures tested. The unit cell width is dependent on the mandrel diameter and the number of yarns braided. The height of the unit cell is dependent on the cell width and the braid angle. Even though a conservative definition of the unit cell was applied in this case, the data in the table indicate that the unit cells can be quite large compared to typical specimen and strain gage dimensions.



UNIT CELL DIMENSIONS

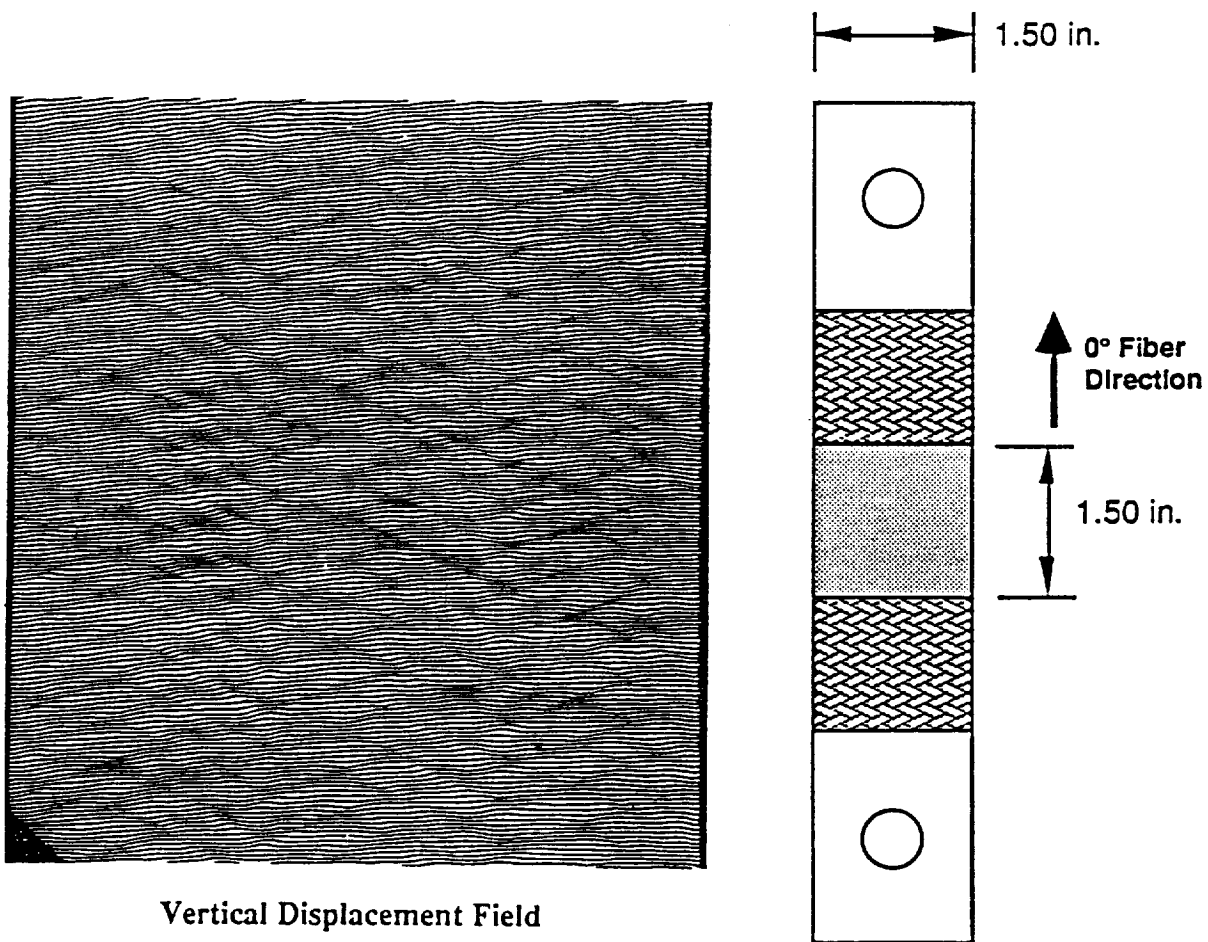
MATERIAL	WIDTH (in.)	HEIGHT (in.)
A1	0.48	0.12
B1	0.42	0.09
B2	0.46	0.08

MOIRÉ INTERFEROMETRY Axial Load - Vertical Displacement Field

As indicated earlier, Moiré interferometry was used to define the full field strain distribution in these braided specimens. The technique defines deformation patterns in both the vertical and horizontal directions. The technique was applied to specimens subjected to longitudinal and transverse loading. These results are shown in this and the following figures.

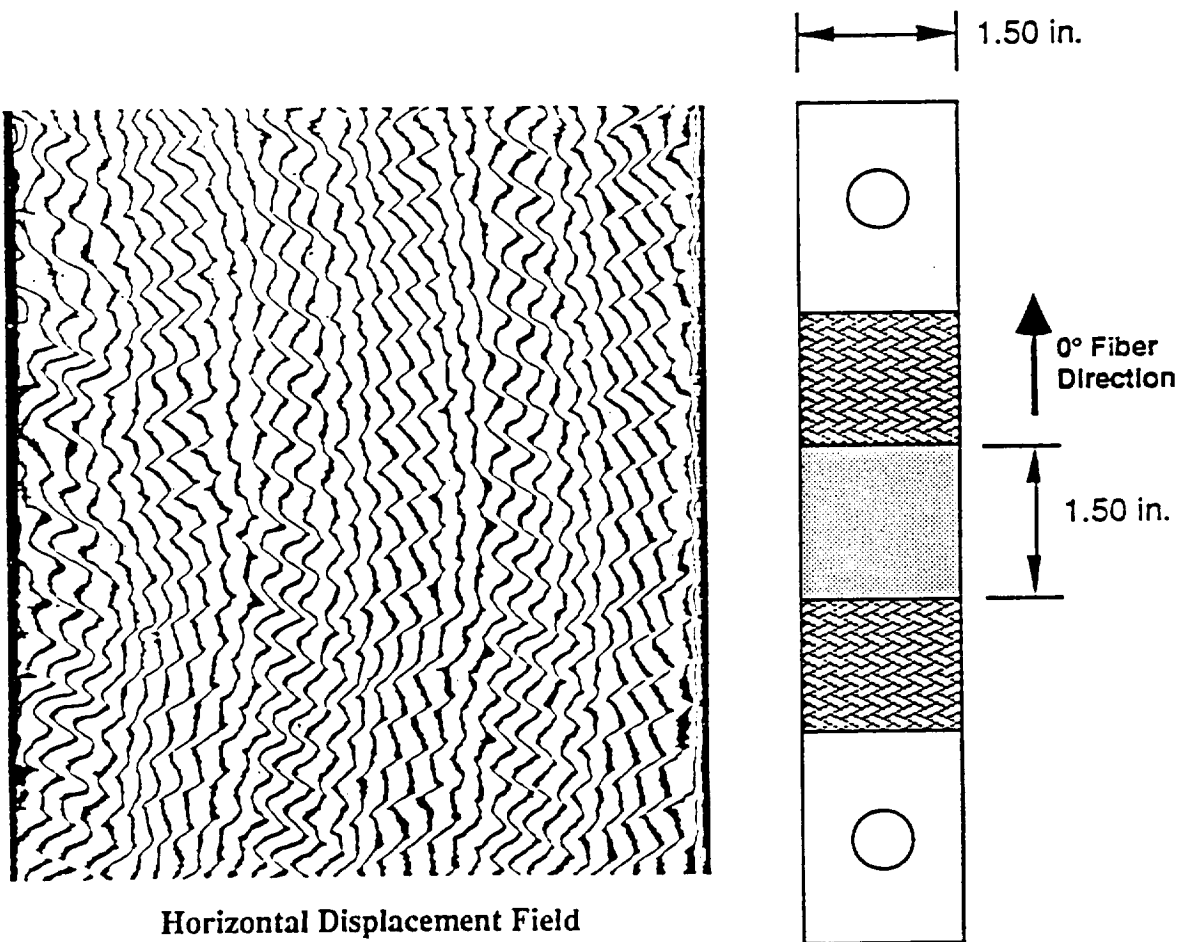
The figure below illustrates the specimen geometry and highlights the section studied. The vertical displacement field that resulted when a specimen was loaded to 1200 micro-strain along the 0° fiber direction is also shown in the figure.

The vertical displacement fields (V fields) consist of basically horizontal fringes; this indicates specimen extension where points along one fringe have been displaced vertically with respect to points along a neighboring fringe. For a uniform extension the fringes should be evenly spaced and straight. The fringes for the specimens tested, however, are wavy and the spacing between them varies. The variation is cyclic and coincides with the repeated unit of the textile architecture.



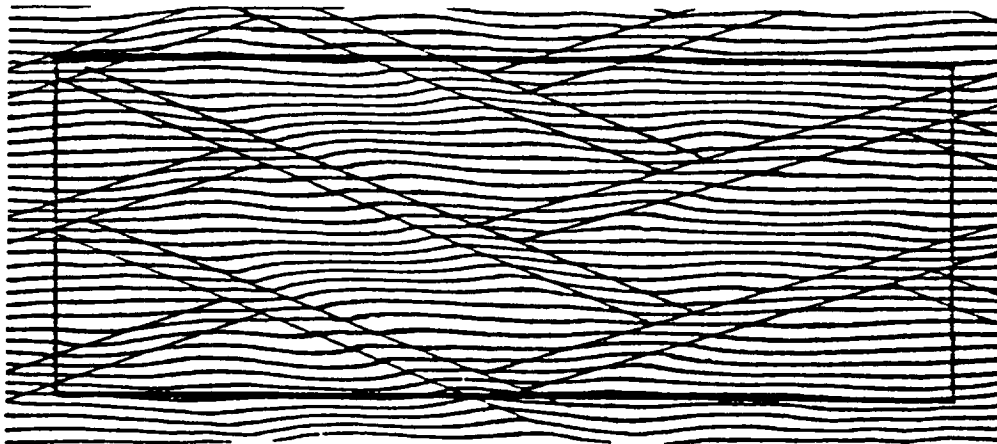
MOIRÉ INTERFEROMETRY Axial Load - Horizontal Displacement Field

The horizontal displacement patterns (U fields) consist of zigzag vertical fringes that display the Poisson's effect. For uniform contraction the fringes should be straight and the spacing constant. The fringes however display a variation which is cyclic, and matches that of the braid geometry. The sharp kinks in the U field fringes reveal the presence of shear strains between the fiber bundles.

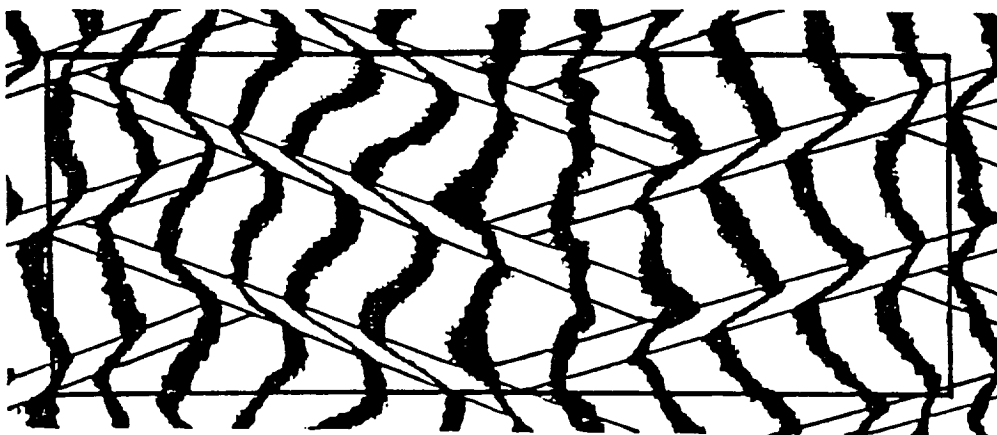


ENLARGED VIEW OF TWO UNIT CELLS OF SPECIMEN (Axial Loading)

The figure shows the V and U fields of a highly magnified region of specimen that consists of two unit cells. The boundaries between adjacent fiber bundles and the outline of the cells are marked. It was revealed that the shear deformation at interfaces between the fiber bundles occurred over a finite width. This width is illustrated in the patterns as the distance between the closely spaced lines. This is consistent with the presence of the resin rich areas between the fiber bundles, which was on the order of one fifth of the width of the fiber bundle itself. The U field shows that the shear strain γ_{xy} in the resin rich zones was on the order of 0.5 times that of the average applied normal strain ϵ_y . Additionally, the U field shows that the Poisson effect was nearly constant across the unit cell. The V displacement pattern clearly shows that the strain ϵ_y varies significantly within each unit cell as can be seen by the nonuniform fringe spacing. The ratio of maximum strain ϵ_y to minimum strain was about 2 to 1. The normal strain varies on top of the fiber bundles and is nearly constant throughout all of the resin rich zones.



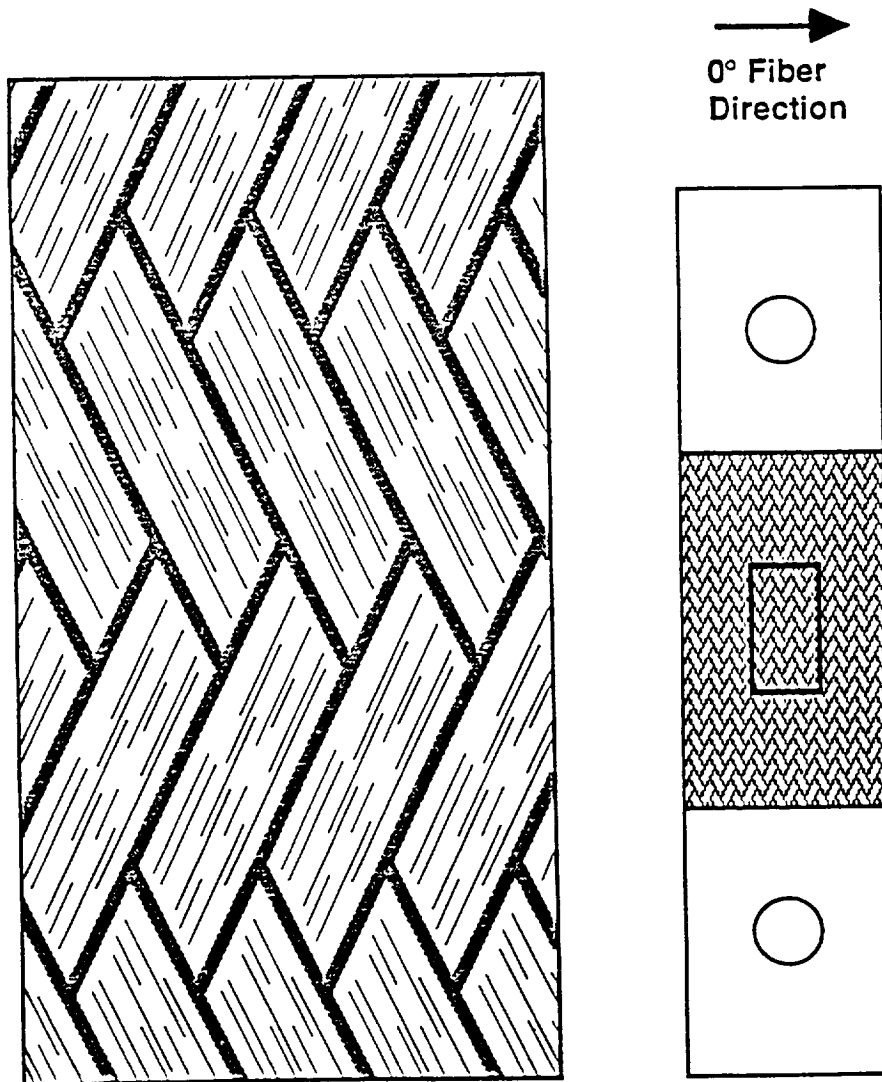
Vertical Displacement Field



Horizontal Displacement Field

**SPECIMEN SECTION COINCIDING WITH
MOIRÉ FRINGE PATTERNS
(Transverse Loading)**

Interferometry was also performed on specimens loaded in the transverse direction (i.e. at 90° to the axial direction). This figure shows the region investigated in these specimens. The pattern of the surface braided yarns is shown schematically in the figure. The deformation fields that developed in these coupons are shown in the next two figures.

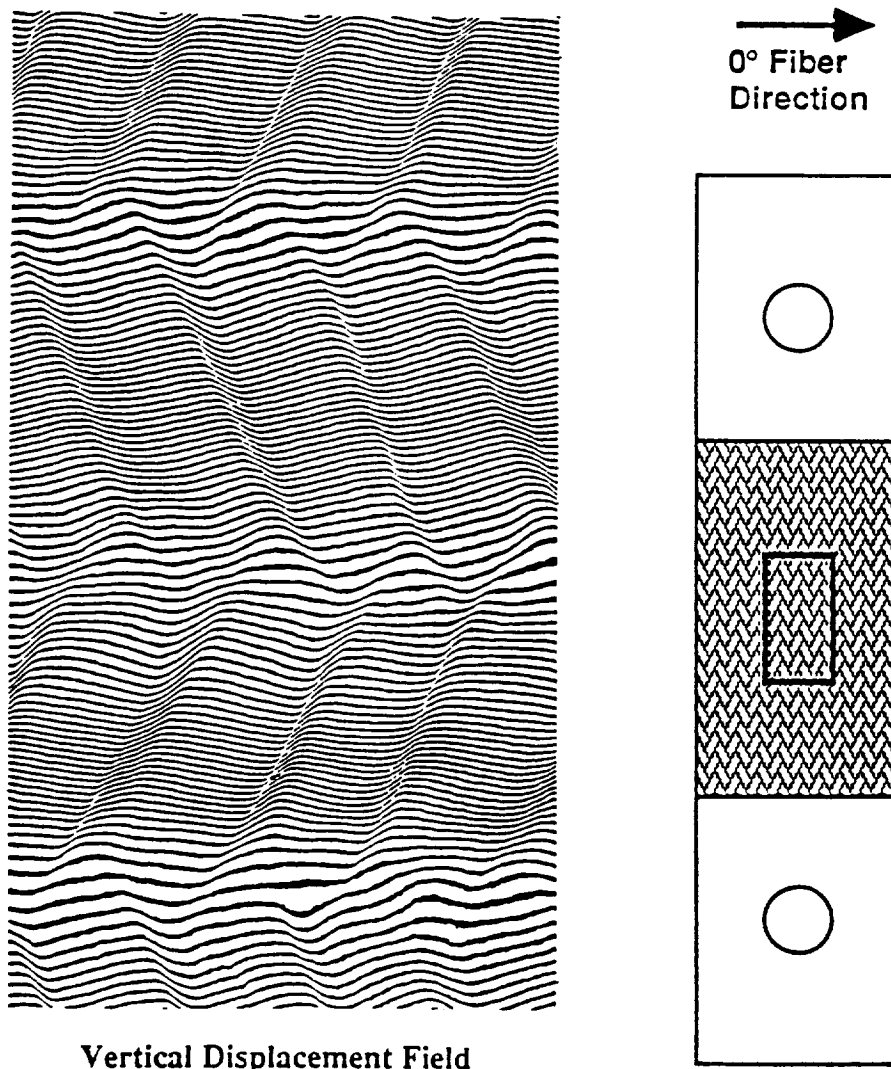


MOIRÉ INTERFEROMETRY Transverse Load - Vertical Displacement Field

In general, the interferometry results indicate that greater variations in normal and shear strains existed in specimens loaded in the transverse direction than in the axial direction.

This figure displays the vertical displacement field for a coupon loaded in the transverse direction. The location of the yarns is evident in the vertical displacement fringe patterns, where sudden jogs in the fringes represent strong shear strains in the resin rich regions between the yarns. From the V displacement pattern, the spacing of the fringes in the vertical direction displays a cyclic variation. The strains are highest over the region where there are 90° fibers under the braider yarns. They are lowest over the regions where the braider yarns cross. The difference between the average strains in these areas is on the order of 3 times.

Unlike the axial loading case, the cyclic variation is not confined to the dimensions of the unit cell. The variation breaches the unit cell to form a global material response that covers the entire specimen. This is illustrated by the horizontal bands seen in the figure. They span several unit cells and extend across the specimen width.



Vertical Displacement Field

Development of Test Methods for Textile Composites

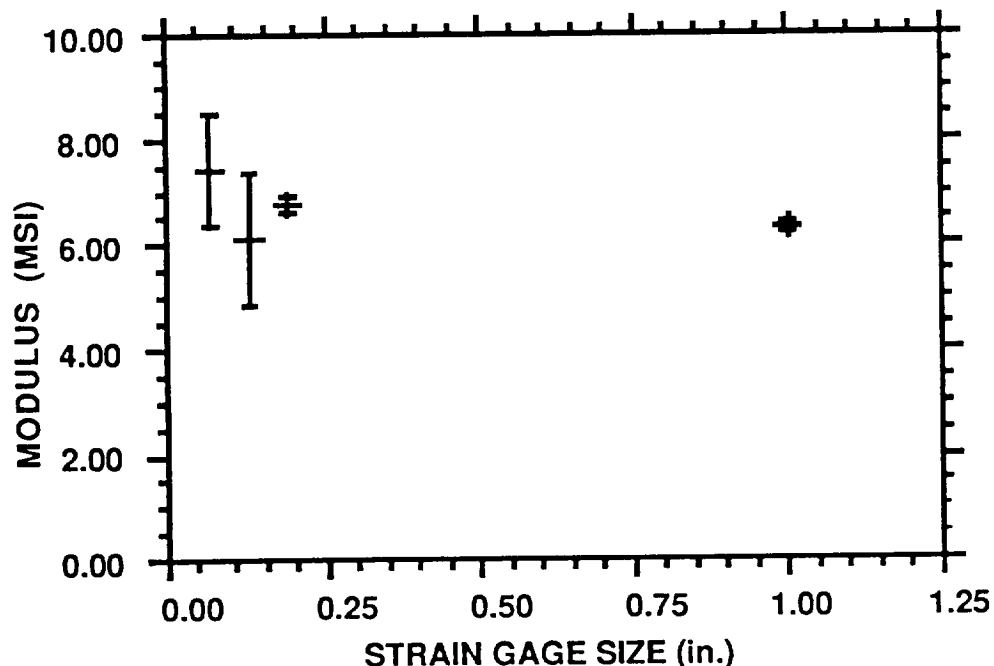
Effect of Strain Gage Size on Modulus :

The inhomogeneity in the strain fields demonstrated in the Moiré interferometric results discussed in the previous slides has significant implications with regard to specimen instrumentation. The large strain gradients seen within the unit cell graphically illustrate the need to measure strain over a truly representative volume of material to get an accurate determination of the global material response. Local strain readings can be misleading and confusing.

The data shown in the figure below demonstrate these points. The figure plots the measured transverse modulus of several B1 laminates vs. the size of the gages used to measure the strain. The gages ranged in length from 0.062 in. to 1.0 in.; the preform's unit cell measures 0.42 in. in this direction. The average modulus and the standard deviation of the data are shown in the figure. As the figure indicates, significant scatter was evident in the results obtained using the small gages. These effects are reduced as the length of the gage increased. The results also indicate that average value also decreased as strain gage size increased.

The results illustrate the need to consider the textile architecture when choosing instrumentation for a specimen.

Transverse Modulus vs Strain Gage Size



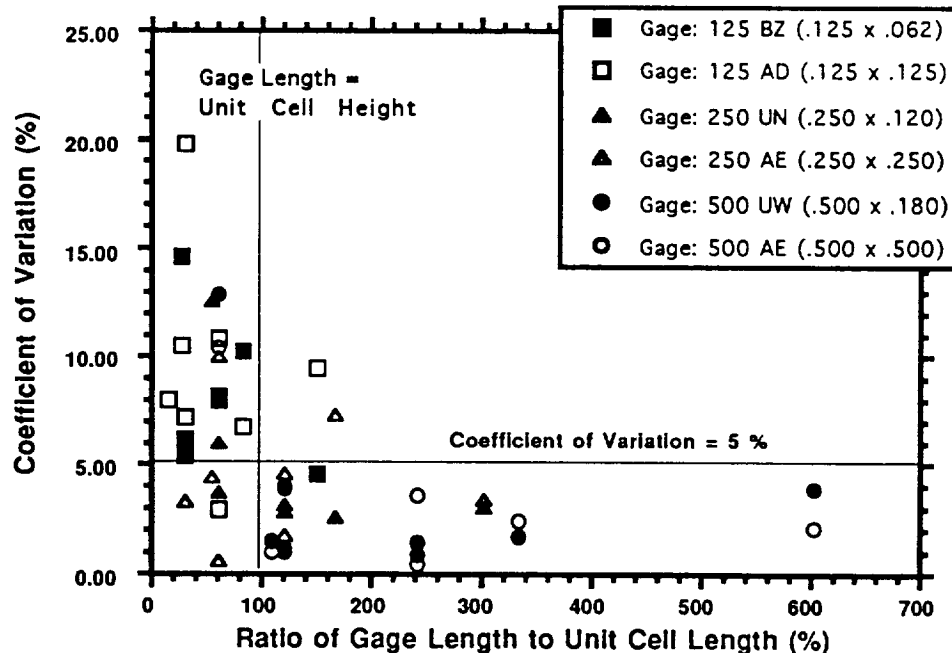
Development of Test Methods for Textile Composites

Effect of Strain Gage Size on Modulus :

The figure shown below presents results of a second evaluation of the effect of strain gage size on modulus measurements. The figure plots the coefficient of variation in the computed modulus measurements versus strain gage size (normalized to the dimension of the unit cell in the direction of loading). Six strain gage types were examined in these measurements. Their dimensions are indicated in the legend in the figure. A line indicating the point where the strain gage length equals the unit cell dimension has been added to the figure to aid in interpreting the data. Similarly, a line marking the point where the coefficient of variation equals 5% has also been added to the figure.

The figure again illustrates the need to consider the textile architecture when choosing instrumentation for a specimen.

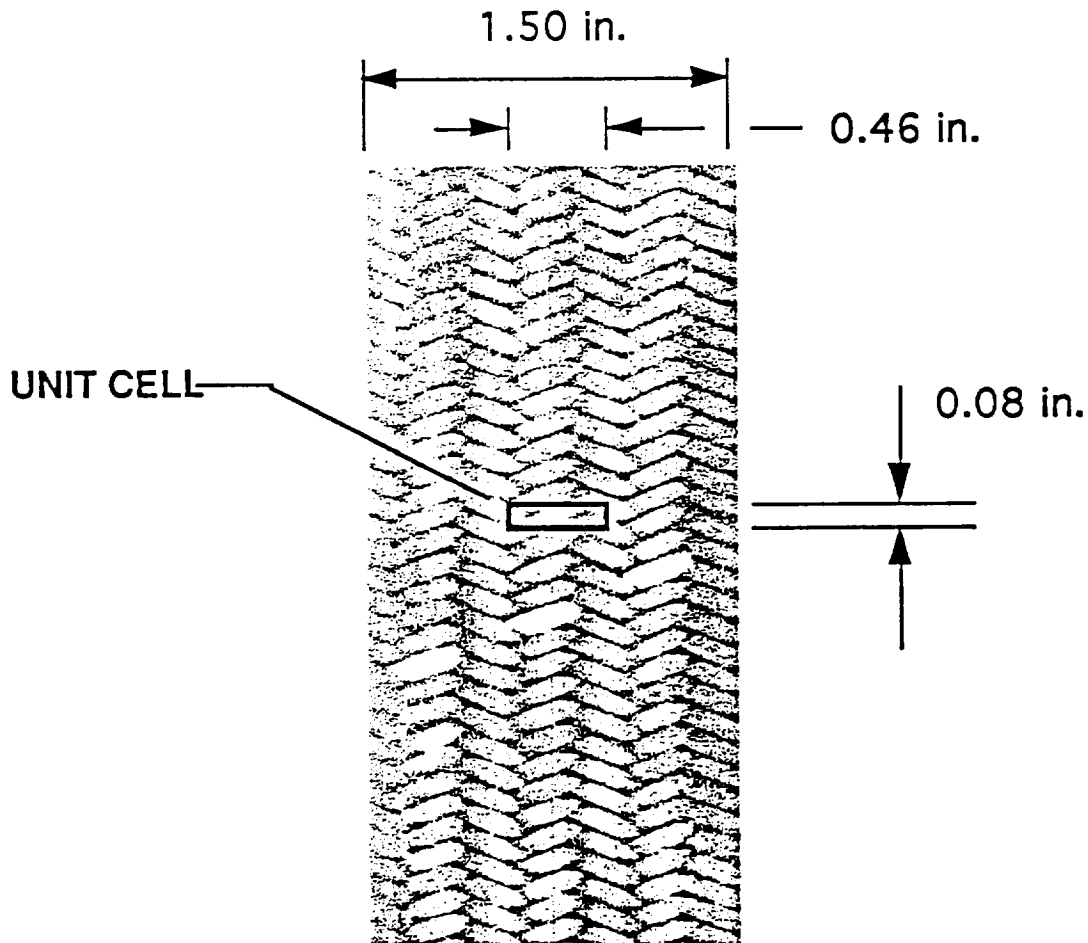
**Effect of Strain Gage Length on Modulus Measurements
(2-D Triaxial Braided Laminates)**



MATERIAL ARCHITECTURE AND TEST COUPON GEOMETRY

The preform architecture must also be considered when designing test specimens. The figure below contains a photograph of a tensile test coupon. The specimen, which is typical of those commonly used in screening and evaluation test programs, is 1.5 in. wide and 10 in. long. Superposed on the photograph are the B2 architecture's unit cell dimensions. As the figure illustrates, when oriented in this direction, the specimen is only three unit cells wide. This again raises the question of whether a representative volume of material is being sampled in the test.

Specimen width and thickness must be considered when designing test specimens to attain true measures of modulus and strength. Unfortunately, design criteria have not yet been established for these materials.



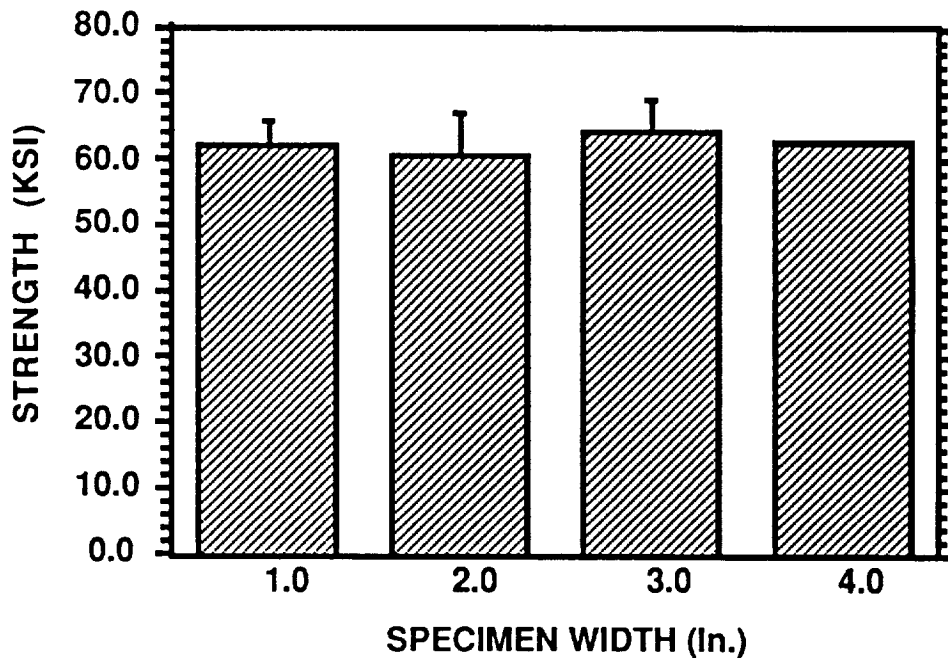
Development of Test Methods for Textile Composites

Effect of Specimen Width on Strength :

A series of longitudinal tensile tests were conducted to judge cursorily the effect of specimen width on strength of the B2 type 2-D triaxially braided laminates defined in an earlier figure. In these tests specimen width was varied from 1.0 in. (2 unit cells wide) to 4.0 in. (8 unit cells wide).

The results of these tests are shown in the figure below. The data, which have been normalized to 55% fiber volume to simplify the comparison, indicate that specimen width had no apparent effect on the test results for this architecture. The average strengths and the standard deviations of the results (indicated by the bars in the figure) were comparable for each group of tests (note: the 4.0 in. data represents the average of two tests; the standard deviation was not computed).

A larger, more complete, examination of the interaction of textile architecture and test laminate geometry is underway as a part of an effort to develop test methods for textile composites. This effort will be outlined in the following pages.



Development of Test Methods for Textile Composites

Summary Investigation of 2-D Braids:

A brief summary of the technical results reviewed in the presentation is given below. The experimental investigation conducted on 2-D braided materials indicated that significant strain gradients existed within the materials unit cell as a result of the braid architecture. This inhomogeneity in the strain field is an important factor that must be considered when choosing instrumentation for a test specimen. Although the 2-D braided laminates tested did not demonstrate a width effect, the size of the unit cell must also be considered when designing a test specimen.

Finally, the concerns discussed above and others listed in an earlier figure will be addressed in an on-going test method development effort.

- **MOIRÉ INTERFEROMETRY IDENTIFIED LARGE STRAIN GRADIENTS WITHIN THE UNIT CELL**
- **INHOMOGENEITY IN STRAIN FIELD EFFECTS INSTRUMENTATION**
- **UNIT CELL SIZE MAY AFFECT TEST RESULTS**
- **ON-GOING INVESTIGATION TO DEFINE TEXTILE TEST METHODS UNDERWAY**

