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The Effects of Specimen Width on Tensile Properties of Triaxially Braided Textile Composites

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OUTLINE

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- EXPERIMENTAL RESULTS -
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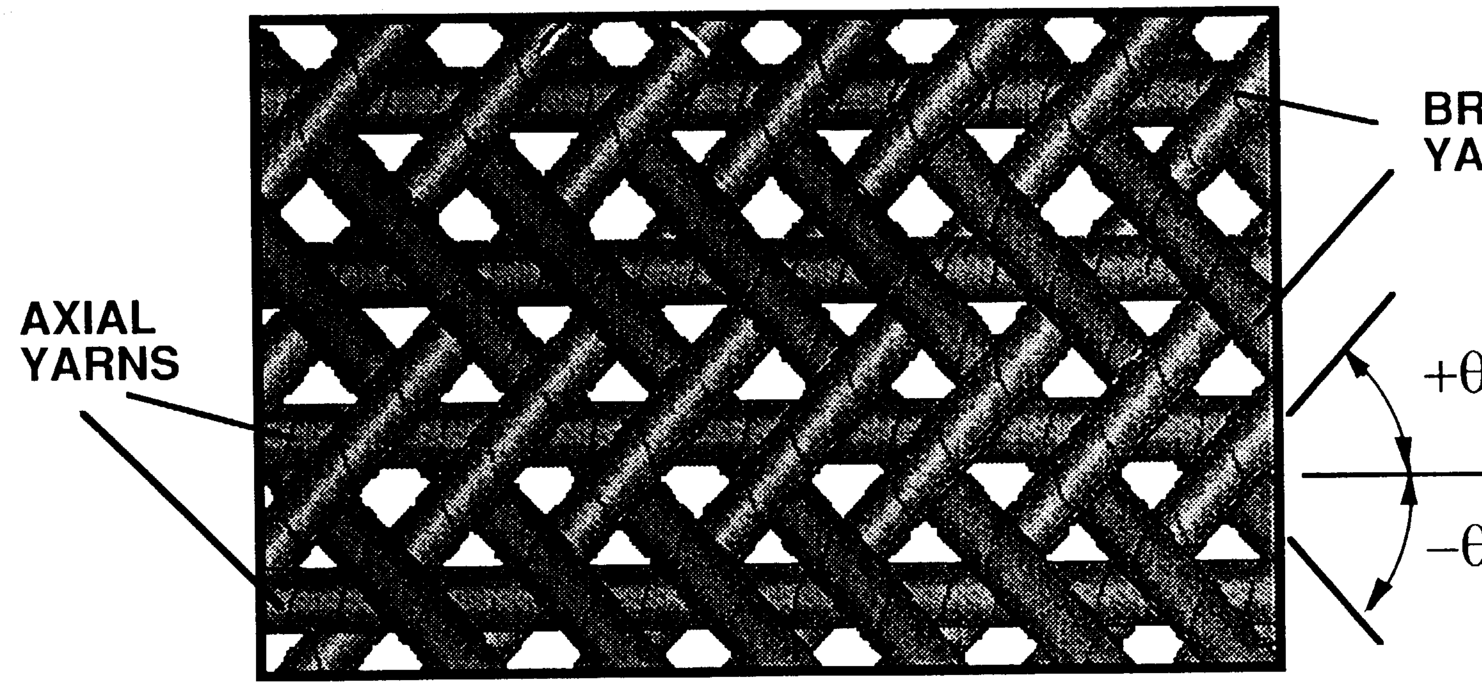
The objective of this study was to examine the effect of the unit cell architecture on the mechanical response of textile reinforced composite materials. Specifically, the study investigated the effect of unit cell size on the tensile properties of 2-D triaxially braided graphite epoxy laminates.

The figures contained in this paper reflect the presentation given at the conference. They may be divided into four sections as the outline listed above illustrates. A short definition of the material system tested is contained in the next figure. This is followed by a statement of the problem and a review of the experimental results. The experimental results consist of a Moire interferometry study of the strain distribution in the material plus modulus and strength measurements. Finally, a short summary and a description of future work will close the paper.

TRIAXIAL BRAID PATTERN



The specimens studied in this investigation featured 2-D triaxially braided AS4 graphite fiber preform impregnated with Shell 1895 epoxy resin. In a triaxially braided preform, three yarns are intertwined to form a single layer of $0/\pm\Theta$ material. In this case, the braided yarns are intertwined in a 2X2 pattern. Each $+\Theta$ yarn crosses alternatively over and under two $-\Theta$ yarns and vise verse. The 0° yarns were inserted between the braided yarns. This yields a two dimensional material; there are no through-the-thickness fibers.

The yarns were braided over a cylindrical mandrel to a nominal thickness of .125 in. The desired preform thickness was achieved by overbraiding layers. 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.

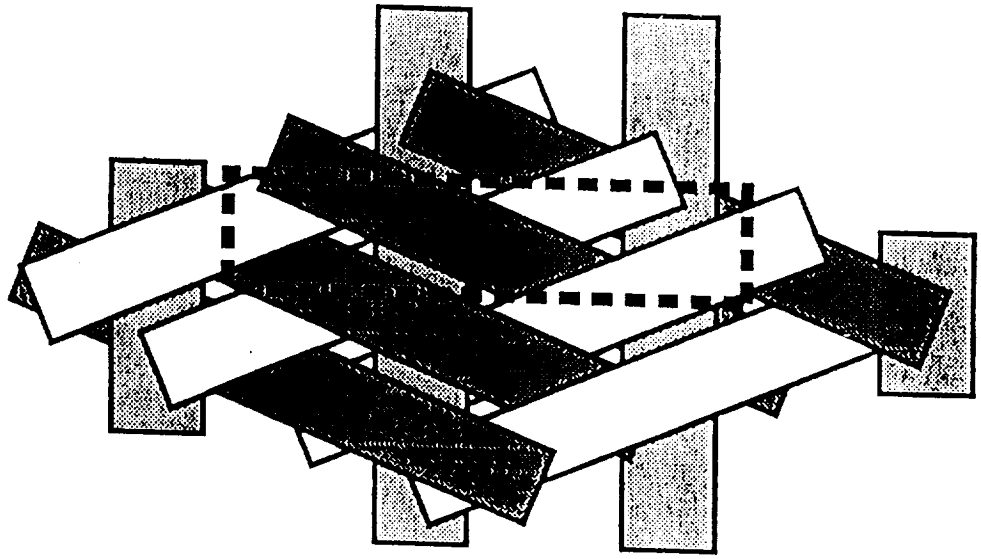
TRIAXIAL BRAID CONFIGURATIONS

MATERIAL	BRAID PATTERN	BRAIDER YARN SIZE (K)	0° YARN SIZE (K)	PERCENT 0° YARNS (%)	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

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 yarns 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.

The increased 0° yarn content, increased 0° yarn spacing, and decreased braid angle of the B1 architecture compared to the B2 architecture are of note. These factors, cumulatively, may aid in interpreting the experimental results.



SMALLEST UNIT CELL

UNIT CELL DIMENSIONS

MATERIAL	WIDTH (in.)	HEIGHT (in.)
A 1	0.48	0.12
B 1	0.42	0.09
B 2	0.46	0.08

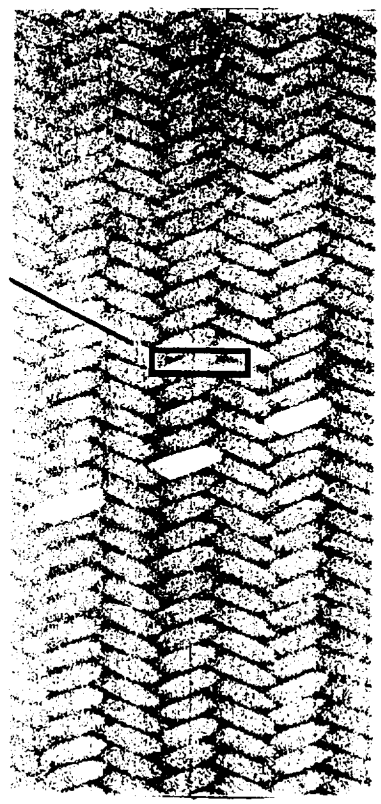
A convenient way to describe textile preforms is to identify a unit cell of material - a repeatable unit of fabric geometry. The unit cell represents the complete yarn intertwinement pattern. The unit cell approach has become the foundation of textile analysis and serves as a convenient framework in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

The table shown above 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 cell width and the braid angle.

Although three architectures are being investigated by NASA and Boeing, this study featured specimens made from the B2 architecture only.

MATERIAL ARCHITECTURE AND TEST COUPON GEOMETRY

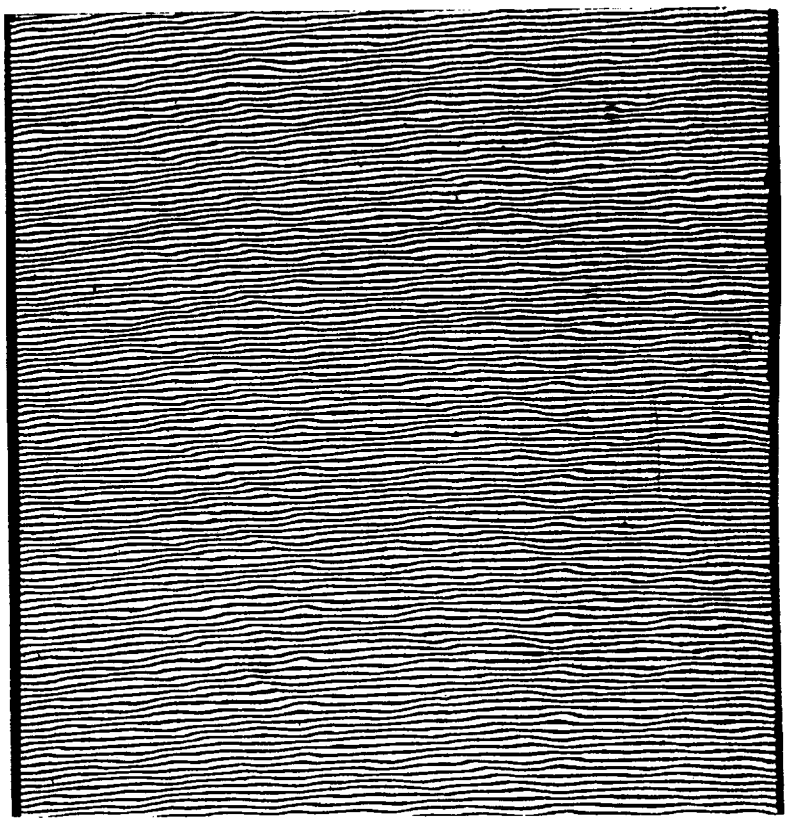


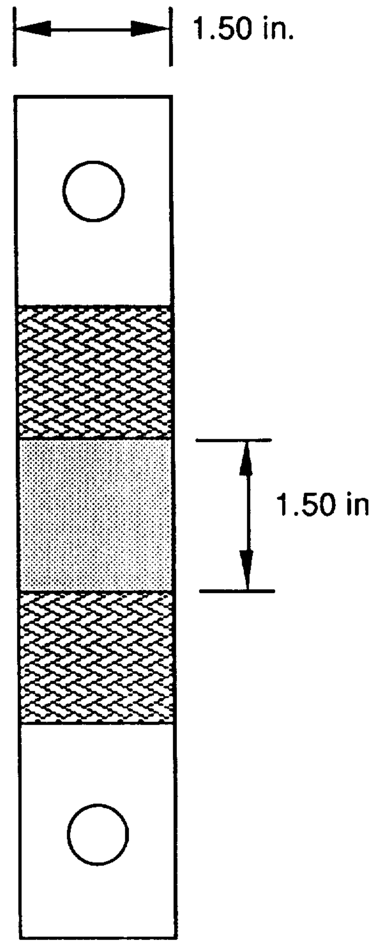
Having defined the unit cell, the question then becomes one of defining degree of heterogeneity within the unit cell. Moire interferometry provided insight into the magnitude of the strain variation in these braided materials. The next three figures summarize the results of the Moire investigation. These slides were also reported in a previous study presented at the conference (Experimental and Analytical Characterization of Triaxially Braided Textile Composites by Masters et. al.).

The strain field inhomogeneity will define the specimen design and the instrumentation used. Determining the effect of this inhomogeneity on experimental results was the subject of this paper.

As an example, consider the tensile coupons used to measure the strength and modulus. The specimen, which is shown in the figure, is 9.5 in. long and 1.5 in. wide. The rectangular section shown in the figure represents the unit cell of the B2 material. As the figure illustrates, the specimen is three unit cells wide. The specific objective of the study was to determine if the specimen width affected the tensile property measurements.

MOIRE INTERFEROMETRY
2-D Triaxial Braid - 1200 Microstrain



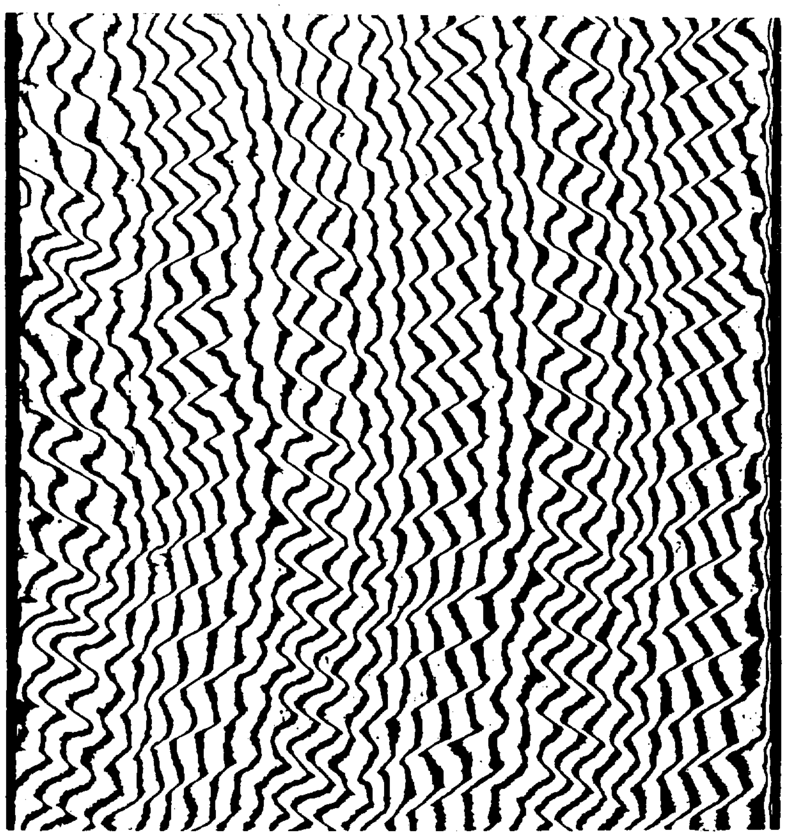


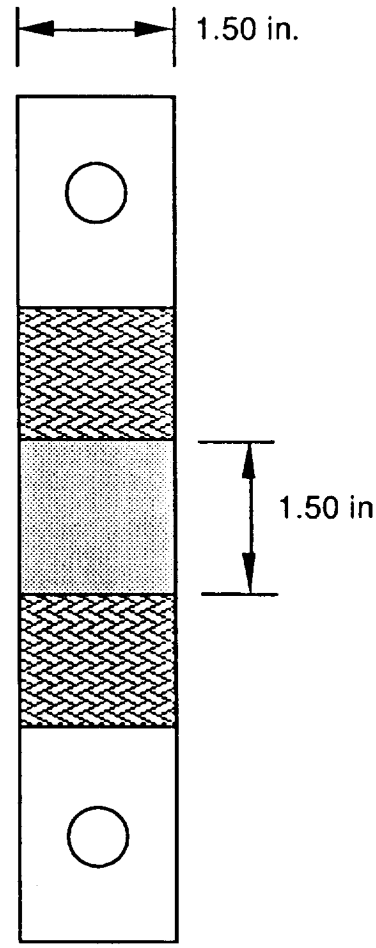
V DISPLACEMENT FIELD

As indicated earlier, Moire 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. These results are shown in this and the following 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.

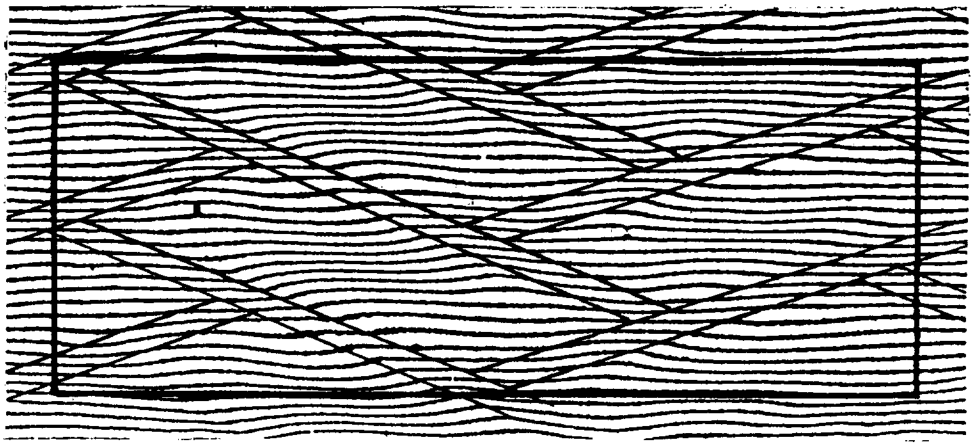
MOIRE INTERFEROMETRY
2-D Triaxial Braid - 2400 Microstrain



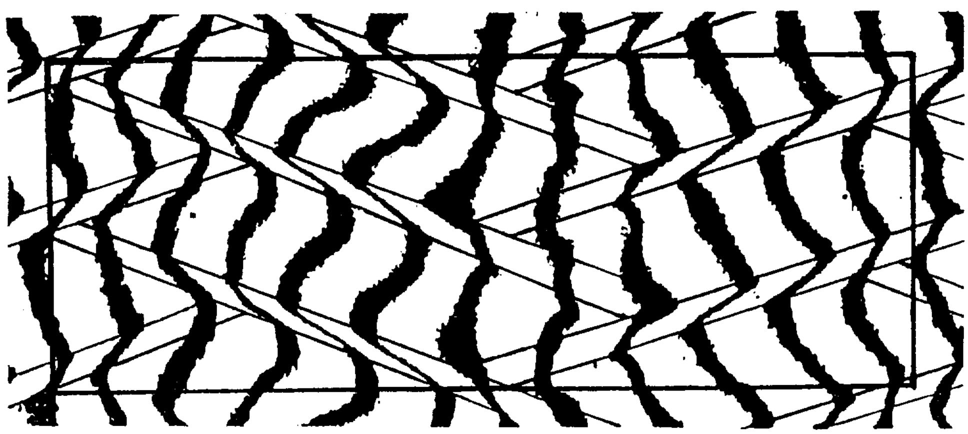


U DISPLACEMENT FIELD

The horizontal displacement patterns (U fields) consist of zigzag vertical fringes that display the Poisson 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 weave geometry. The sharp kinks in the U field fringes reveal the presence of shear strains between the fiber bundles.



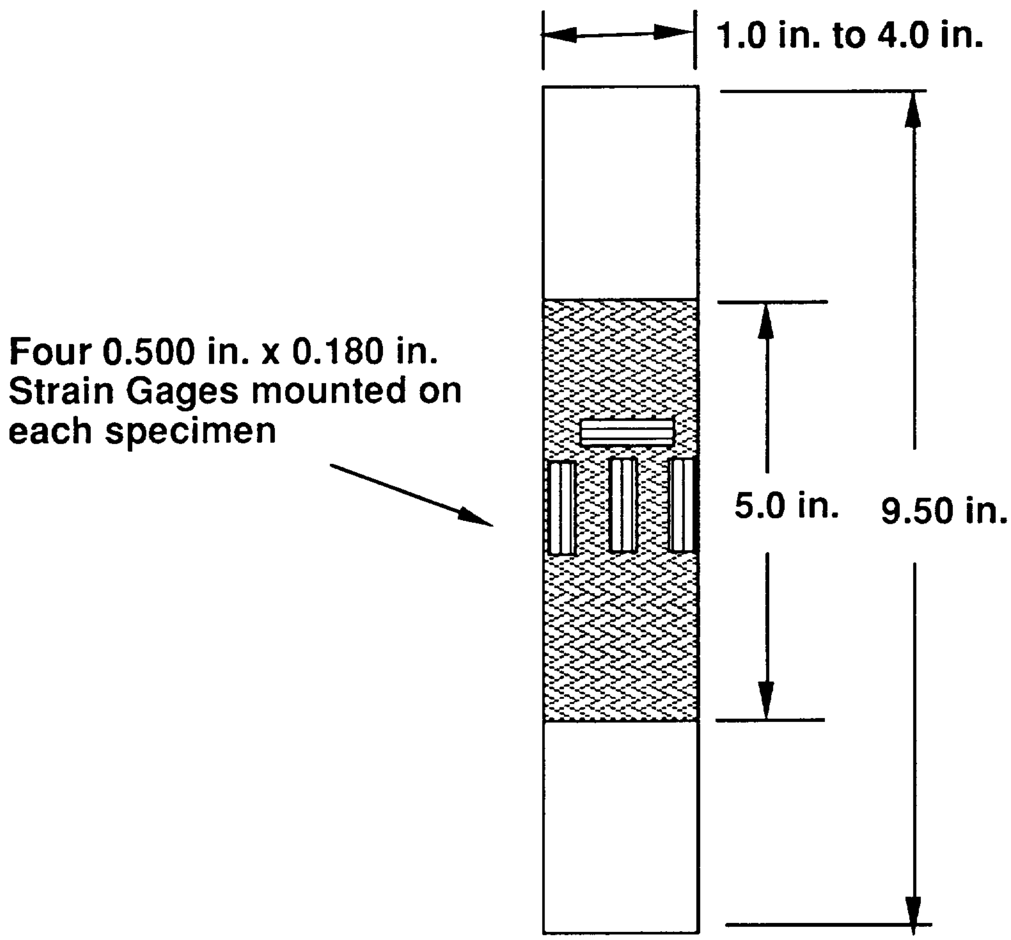
ENLARGED VIEW OF TWO UNIT CELLS - V FIELD



ENLARGED VIEW OF TWO UNIT CELLS - U FIELD

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 2.1. The normal strain varies on top of the fiber bundles and is nearly constant throughout all of the resin rich zones.

Test Specimen Configuration

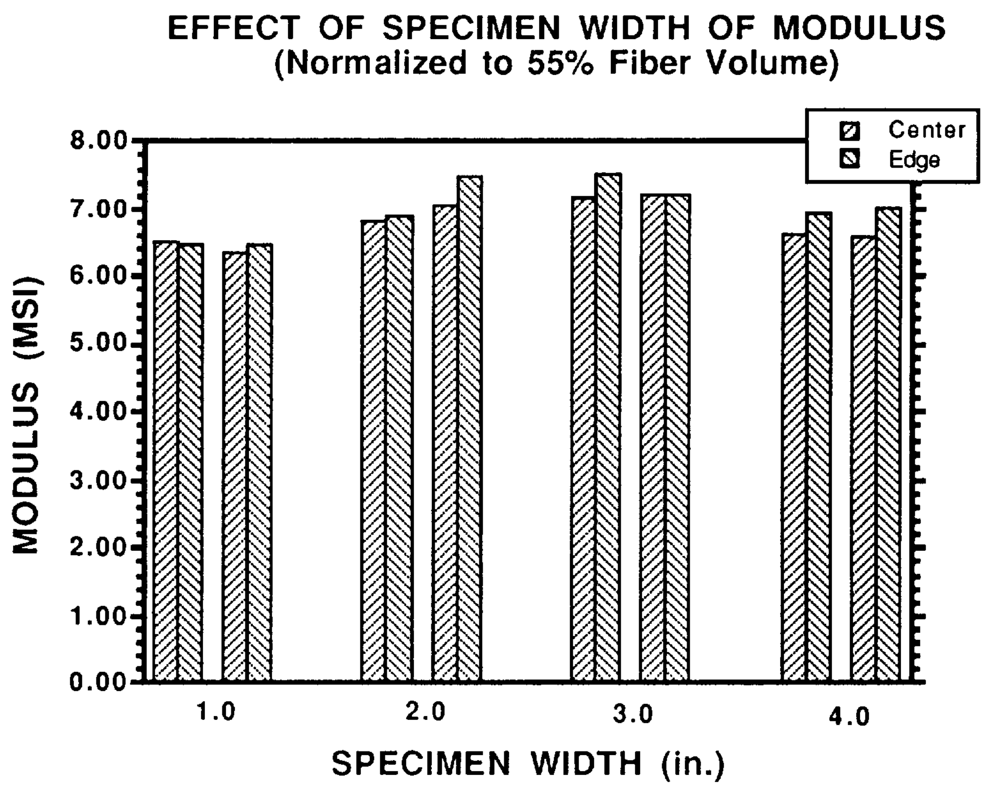


A series of tensile tests were conducted to experimentally determine the effect of specimen width of modulus and strength. The coupons used in this study are shown in the figure. Specimen width was fixed at 9.5 in. Length, however, varied from 1.0 in. to 4.0 in. in one inch increments. All specimens featured the B2 triaxial braid described in the previous table. They were loaded in the 0°, or longitudinal direction.

Each specimen was instrumented with five 0.500 in. long strain gages as shown in the figure. The strain gages effectively spanned five unit cells in this direction.

WIDTH EFFECTS ON TENSILE PROPERTY MEASUREMENT
(Strength and Modulus)

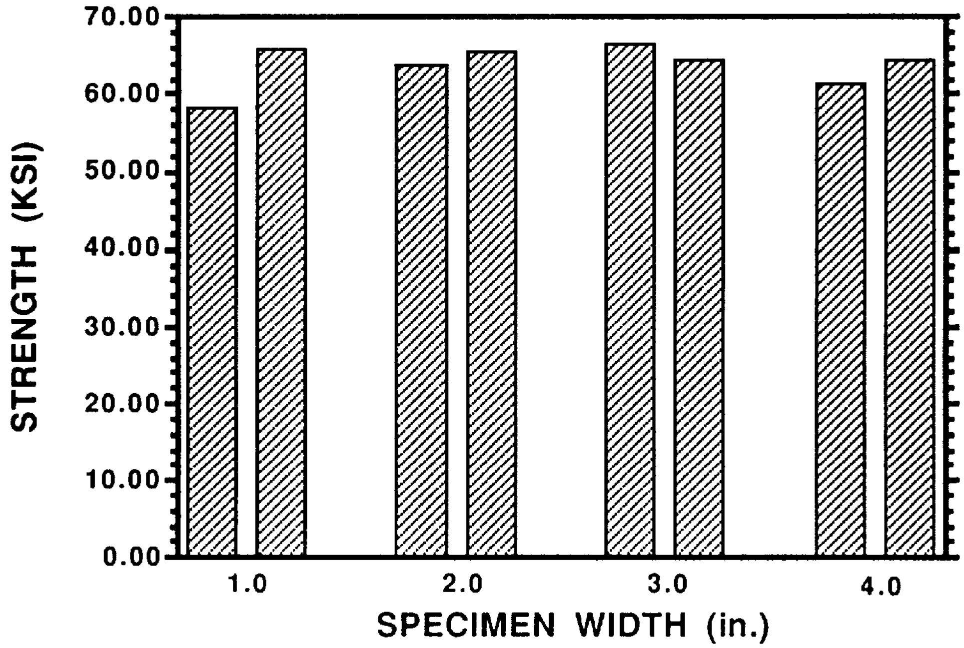
SPECIMEN NUMBER	WIDTH (In.)	THICK. (In.)	FIBER VOLUME (%)	MAX STRESS (KSI)	MODULI (MSI)			
					Left	Center	Center	Right
B2-13-1	1.01	.125	55.2	58.3	6.87	6.50	6.97	6.06
B2-13-2	1.01	.124	55.2	66.0	6.39	6.34	6.77	6.58
B2-13-4	2.01	.121	54.4	63.1	6.48	6.73	6.78	7.15
B2-13-6	2.00	.141	46.1	54.8	5.87	5.90	5.94	6.62
B2-13-7	3.01	.140	46.1	55.7	6.26	5.99	6.24	6.33
B2-13-8	3.01	.141	46.1	53.9	6.14	6.02	5.98	5.92
B2-13-10	4.01	.124	55.2	61.3	6.98	6.65	6.60	6.91
B2-13-12	4.01	.141	46.1	54.0	5.90	5.53	5.89	5.73



The results of the longitudinal modulus measurements are shown in the figure. A total of eight specimens, two at each width, were tested. The moduli measured at the specimen edges were averaged and are compared to the average moduli measured at the center of the specimen. Specimens were machined from several different panels whose fiber volume content varied. The data, which was shown in tabular form in the previous slide, was normalized to 55% fiber volume to isolate width effects.

The data indicate little edge to center variation in modulus. They also demonstrate no significant variation with specimen width.

EFFECT OF SPECIMEN WIDTH OF STRENGTH
(Normalized to 55% Fiber Volume)



The tensile strength results are shown in this figure. Like the moduli data, they too have been normalized to 55% fiber volume to isolate the effect of specimen width. The results, again, reflect no effect of width on mechanical response.

SUMMARY

- **EXPERIMENTAL RESULTS INDICATE NO WIDTH EFFECT ON TENSILE PROPERTIES**

  <u>FOR THIS ARCHITECTURE</u>

- **MOIRE INTERFEROMETRY IDENTIFIED LARGE STRAIN GRADIENT WITHIN THE UNIT CELL**

The results of this short experimental investigation demonstrate that the specimen width did not affect the tensile response of the the 2-D triaxial braids tested. It must be noted, however, that these results are relevant to these architectures only. These results cannot be extended to other textile preform types. We are developing the analytical and experimental data base required to make these assessments.

The Moire interferometry results succeeded in identifying the nature of the inhomogeneity in the strain field. The technique will be applied to additional textile architectures to guide our instrumentation and analysis.

FUTURE WORK

- ➤ **INVESTIGATE SIZE EFFECTS IN OTHER TEXTILE COMPOSITES**

- ➤ **DEVELOP ANALYSES TO PREDICT MATERIAL RESPONSE**

NASA is in the process of initiating an analytical and experimental program to develop standard test methods for textile composites. This program will develop tension, open-hole tension, compression, open-hole compression, and shear test methods for woven, braided, and stitched textiles. The results of this investigation will be applied to that program.

Specifically, this study has identified the magnitude of the strain inhomogeneities within the unit cell and has demonstrated the effectiveness of Moire interferometry in defining the full field strain distribution in these textile composites. Interferometry will be applied to all material forms investigated in the test methods development program to guide specimen design and instrumentation. One objective of the program is to develop sets of criteria to be applied to all textiles.

This study also identified that width effects did not exist for these particular architectures. An experimental data base will be developed to determine if this is true for other architectures.