NASA Contractor Report 4610

A Comparison of Graphite/Epoxy Tape Laminates and 2-D Braided Composites Mechanical Properties

Pierre J. Minguet and Christian K. Gunther

Contract NAS1-19247
Prepared for Langley Research Center

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Abstract

A comparison of the in-plane mechanical properties of unidirectional composite tape laminates and of 2-dimensional triaxially braided composite was conducted. The tape laminate layups were designed to match the percentage of axial fibers and the angle of the bias tows in the braided composite. The material system used for the laminates is AS4/3501-6 which was chosen as the closest available match to AS4/1895 used for the braids. This report documents the results of the testing of the laminates and compares these results with data previously obtained for the braided composite. The strength and stiffness properties measured here include tension, open-hole tension, filled-hole tension, compression and open-hole compression, all of these in both the longitudinal and transverse direction, in-plane shear and bearing.

Results show that the longitudinal modulus of both material forms is quite similar, but that the transverse modulus of the braids is lower. In terms of strength, the longitudinal unnotched strength of the braids is lower than that of the laminates, while the transverse strength is significantly lower. Similarly, the shear strength of the braids was much lower. For both strength and stiffness, the crimp in the bias tows of the braid is probably the main cause for reduced properties. On the other hand, a very significant increase in open-hole and filled-hole tension strength was observed for the braids compared to the tape laminates. However,this was not observed in compression where all the braid properties are lower than for the laminates. Bolt-bearing strength of the braids was also lower.

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1. Introduction

Carbon/Epoxy composites made from textile fiber preforms manufactured with a Resin-Transfer-Molding (RTM) process have some potential for reducing costs and increasing damage tolerance of aerospace structures. One form of textile preform which is under consideration is a 2-dimensional triaxially braided fabric. A large amount of test data has been generated recently to quantify the mechanical properties of various 2-D braided configurations loaded in tension, with and without holes, compression, with and without holes, shear and bolt bearing [1].

The key question is then to determine and quantify the benefits and drawbacks of this material form. Because of the nature of the triaxial fabric (e.g., no 90° fibers), little data which could be used for a direct comparison of mechanical performance is available for more conventional material forms (i.e. tape or biaxial fabric laminates). Therefore, tape laminates with the same ply orientation and percentage of 0° fibers as the previously tested braided composites were manufactured and tested. The objectives of this report are to summarize all the strength and stiffness properties measured for the tape laminates investigated and to compare these properties with those previously determined for 2-D braided composites.

This report describes work accomplished under Contract NAS1-19247 from the National Aeronautics and Space Administration, Langley Research Center, Hampton VA. Mr Clarence C. Poe Jr., NASA LaRC, was the NASA Technical Monitor. The Structures Technology organization of the Boeing Defense & Space Group, Helicopters Division was responsible for completing this task. All specimen manufacturing and material testing was conducted at Integrated Technologies, Inc. (Intec, Bothell, WA)

2. Test Program Description

2.1 *Test Matrix*

Four configurations of 2-D braided composite were extensively tested in a previous investigation as reported in Reference 1. The 2-D braided fabric contains two types of tows, the longitudinal (axial, or 0°) tow and the braided (or bias) tows oriented at angle θ of the axial tow as illustrated in Figure 2.1. The braid pattern used is 2X2 pattern, meaning that each braided tow goes over and under two tows at a time. As shown in Table 2.1, the first three architectures contain a large percentage of axial fiber typical of a composite optimized for a predominantly longitudinal loading. The first architecture, SLL, was braided with small tows to provide a fine architecture, while the third one, LLL, was braided with 2.5 times larger tows, thus allowing one to examine the influence of tow sizes. The second architecture, LLS was braided with a 45° bias angle, thus allowing one to examine the influence of braid angles. For practical applications, braid angles will often be limited to the 45° to 70° range, and the comparison of LLS and LLL allows one to examine both upper and lower bounds on that parameter. Finally, the fourth architecture, LSS, contains a larger amount of ±45° tows more typical of a composite optimized for shear loading. In addition, a fifth configuration, B1, is considered which is used in the fuselage frame for NASA/Boeing ATCAS crown panel. Only limited data were available for this material system in Reference 2. Results from this Reference were scaled up to the common 60% fiber volume fraction used in this report.

Four laminates were designed to match the bias angle and percentage of axial fibers of these braids. Two of the braids, SLL and LLL, have the same layup with different tow sizes and thus will be compared with the same laminate. The material system used is AS4/3501-6 (4.4 oz/yd^2) which closely matches the AS4/1895 system used for the braids. The following four laminates were used:

Laminate 1: $[(45/0/-45/0)_2/45/0/-45]_s$
22 Plies Total, 10 0° Plies (45.4%), 12 45° Plies, to match LLS.

Laminate 2: $[(70/0/-70/0)_2/70/0/-70]_s$
22 Plies Total, 10 0° Plies (45.4%), 12 70° Plies, to match SLL and LLL.

Laminate 3: $[(\pm45)_2/0/(\pm45)_3/0(\pm45)_3/0/(\pm45)_2]_t$
23 Plies Total, 3 0° Plies (13.0%), 20 45° Plies, to match LSS.

Laminate 4: $[(66/0/-66)_4/0]_s$
26 Plies Total, 10 0° Plies (38.5%), 16 66° Plies, to match B1.

Table 2.1 Description of 2-D braid architectures.

Name	Longitudinal Tow Size	Braided Tow Size	% Longitudinal Tow	Braid Angle [°]	Unit Cell Width [in]	Unit Cell Length [in]
SLL	30 K	6 K	46	70	0.458	0.083
LLS	36 K	15 K	46	45	0.415	0.207
LLL	75 K	15 K	46	70	0.829	0.151
LSS	6 K	15 K	12	45	0.415	0.207
B1	18 K	6 K	37	66	0.105	0.046

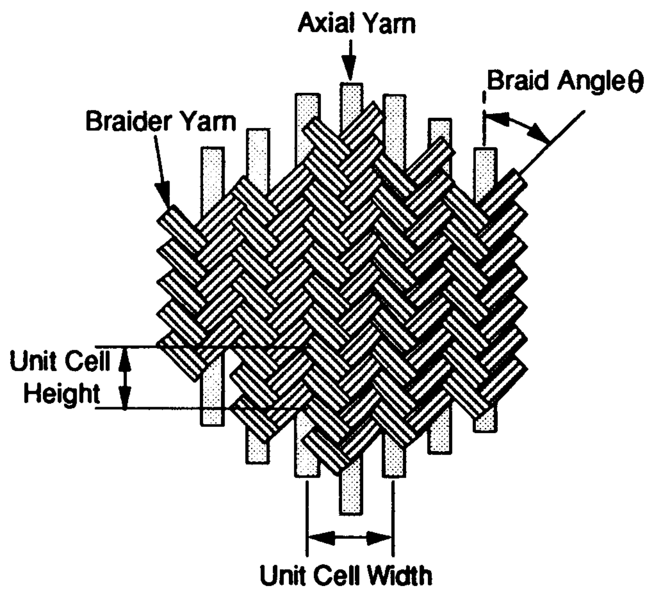

Figure 2.1 Illustration of 2-D Triaxial Braid Configuration.

2.2 *Test Matrix*

The complete test matrix for this program is shown in Table 2.2. A total of 180 specimens were used. All the in-plane material properties considered in Ref. 1 were considered here. Standard size specimen, 12″ long and 1.5″ wide, were used for the tension tests. Modified IITRI specimens, 1.5″ long by 1.5″ wide test section, were used for the compression tests. The laminate thickness was doubled for the compression specimen to insure specimen stability. A hole diameter of 0.188″ was mistakenly used in the compresssion test instead of the standard 0.250″.

Table 2.2 Tape Laminates Test Program

	Laminate Type			
Test Type	**1**	**2**	**3**	**4**
Tension				
Longitudinal	3	3	3	3
Transverse	3	3	3	3
Open-Hole Tension				
Longitudinal (D = 0.188", 0.250")	6	6	6	6
Transverse (D = 0.188", 0.250")	6	6	6	6
Compression				
Longitudinal	3	3	3	3
Transverse	3	3	3	3
Open-Hole Compression				
Longitudinal (D = 0.188")	3	3	3	3
Transverse (D = 0.188")	3	3	3	3
In-Plane Shear				
Boeing Rail Shear	3	3	3	3
Bolt Bearing & Bypass				
Filled-Hole Longitudinal Tension	3	3	3	3
Filled-Hole Transverse Tension	3	3	3	3
Single Shear Bearing	3	3	3	3
Double Shear Bearing	3	3	3	3
TOTALS	**45**	**45**	**45**	**45**

2.3 Data Reduction Techniques

The same approach used in Reference 1 was used here to make all results directly comparable. **All results are normalized to a 60% fiber volume fraction**. Fiber volume fraction and thickness were measured on all manufactured panels. After averaging these data over all panels, a nominal ply thickness of **0.0054"** was calculated. All stiffness moduli and Poisson's coefficients are the initial value of these properties and were measured with a linear regression between 0.001 and 0.003 strain levels. Wherever a nominal strain is reported, it is equal to the strength divided by the initial modulus. Actual strain is the last reading obtained from a strain gage prior to failure. Strength is always calculated as load divided by actual width and nominal thickness.

Open-hole and filled-hole strength results were corrected to infinite plate width with the following formula for a hole diameter d and a plate width w :

$$\sigma_{\infty} = \left[\frac{2 + \left(1 - \frac{d}{w}\right)^3}{3\left(1 - \frac{d}{w}\right)} \right] \cdot \frac{P}{w\ t_{nom}}$$

3. Tension Properties

Tension properties for all four laminates were measured in both the longitudinal (0°) and transverse (90°) directions. Properties included stiffness modulus, Poisson's coefficient, open-hole strength (01.88" and 0.250" diameters) and filled-hole strength using a fully-torqued 0.25" titanium hilock fastener.

3.1 Laminate Results

All the tension properties measured in the longitudinal (0°) direction are shown in Table 3.1, while all the properties measured in the transverse (90°) direction are shown in Table 3.2. Individual test results and typical stress-strain curves can be found in Appendix A and B respectively.

Table 3.1 Laminate Longitudinal Tension Properties

Property	Laminate 1	Laminate 2	Laminate 3	Laminate 4
Modulus [msi]	10.33	9.63	4.92	8.23
CoV [%]	0.8	2.8	0.5	2.0
Poisson's Coefficient	0.663	0.157	0.713	0.190
CoV [%]	2.3	3.7	0.8	0.1
Unnotched Strength [ksi]	131	132	63	105
Nominal Strain [μs]	12,690	13,750	12,840	12,720
CoV [%]	12.5	6.3	1.8	5.3
Actual Strain [μs]	12,300	13,400	15,200	12,800
0.188" OHT Strength [ksi]	72	66	42	61
OHT Nom. Strain [μs]	6,960	6,860	8,460	7,450
CoV [%]	4.4	1.0	2.0	3.7
0.250" OHT Strength [ksi]	69	66	40	60
OHT Nom. Strain [μs]	6,640	6,820	8,080	7,340
CoV [%]	3.8	3.6	1.2	1.7
0.250" FHT Strength [ksi]	60	49	42	47
FHT Strain [μs]	5,820	5,090	8,560	5,710
CoV [%]	2.1	1.8	2.7	3.6

Note: Laminate 1 $[(45/0/-45/0)_2/45/0/-45]_s$
Laminate 2 $[(70/0/-70/0)_2/70/0/-70]_s$
Laminate 3 $[(\pm45)_2/0/(\pm45)_3/0/(\pm45)_3/0/(\pm45)_2]_t$
Laminate 4 $[(66/0/-66)_4/0]_s$

Coefficients of variation were generally quite low and well within the typical values obtained when testing composites. The only exception was the unnotched 0° strength of L1 for which one specimen failed prematurely. If that data point was excluded, L1 strength would be 141 ksi (13,600 μs). Laminate 1, 2 and 4 were linear to failure, as indicated by the fact that actual and nominal strains are virtually equal, while laminate 3 (with a high percentage of ±45° plies) had a softening behavior with the actual strain much higher than nominal. Failure for L1 and L2 occured close to the tabs, and for L4 occured under the tabs. L3 exhibited a large amount of delamination.

Somewhat different failure modes were observed in the 90° unnotched tension tests. Laminates 1 and 2 exhibited a clean straigth break well inside the test section. Laminate 3 also failed inside the test section and showed mostly an in-plane shear failure mode, along with some visible edge delaminations. Laminate 4 exhibited a large amount of delamination initiating from the edges. Laminate 1 and 3 had a softening behavior because of their 45° ply angle. The strain levels in L2 and L4 were much below that in the 0° tests, indicating that pure fiber fracture was not the dominant failure mode.

All laminates but L3 show a strong sensitivity to the presence of a fully torque fastener in the longitudinal tension test. Strength reductions were 13% for L1, 26% for L2, 22% for L4. In the transverse direction, the influence of the fastener was quite different. A strength increase was observed for L1 (+18%) and L2 (+3%), while a strength decrease was observed for L2 (-10%) and L4 (-7%). Note that the strength increase was observed for the two laminates with a low transverse modulus.

Table 3.2 Laminate Transverse Tension Properties

Property	Laminate 1	Laminate 2	Laminate 3	Laminate 4
Modulus [msi]	3.37	8.96	3.48	8.88
CoV [%]	0.9	0.6	1.5	1.9
Poisson's Coefficient	0.225	0.147	0.513	0.223
CoV [%]	9.4	3.9	1.1	2.6
Unnotched Strength [ksi]	35	72	35	73
Nominal Strain [μs]	10,480	8,020	10,030	8,180
CoV [%]	1.8	3.3	0.9	4.6
Actual Strain [μs]	15,600	8,300	14,800	8,600
0.188" OHT Strength [ksi]	31	59	33	58
OHT Nom. Strain [μs]	9,210	6,580	9,520	6,550
CoV [%]	1.2	3.5	0.6	3.6
0.250" OHT Strength [ksi]	28	53	32	54
OHT Nom. Strain [μs]	8,359	5,910	9,140	6,110
CoV [%]	2.7	3.4	0.8	0.5
0.250" FHT Strength [ksi]	33	50	33	52
FHT Strain [μs]	9,660	5,580	9,430	5,810
CoV [%]	2.3	3.1	0.5	3.1

Note: Laminate 1 $[(45/0/-45/0)_2/45/0/-45]_s$
Laminate 2 $[(70/0/-70/0)_2/70/0/-70]_s$
Laminate 3 $[(\pm45)_2/0/(\pm45)_3/0/(\pm45)_3/0/(\pm45)_2]_t$
Laminate 4 $[(66/0/-66)_4/0]_s$

3.2 Comparison with Braided Composite

The first comparison, shown in Figure 3.1, is for longitudinal modulus. Minimal differences were found between braids and tape laminates: +0.4% for SLL, -4.6% for LLL, -0.9% for LLS, and -0.6% for LSS. Considering experimental scatter and the slight differences in percentage of 0°, it is fair to say that there is no difference between longitudinal moduli for the two material forms. The slight reduction for LLL is probably due to the additional tow waviness introduced by the use of large tow sizes.

The comparison is quite different for the transverse modulus. As shown in Figure 3.1, the braided material is substantially less stiff: -19% for SLL, -24% for LLL, -22% for LLS, and -16% for LSS. The primary cause for this reduction is the crimp in the bias tows.

The comparison for unnotched longitudinal tension strength is show in Figure 3.2.a to 3.2.d. A notably lower strength was obtained for all the braids: -17% for SLL, -34% for LLL, -31% for LLS, and -16% for LSS. Once again, the tow waviness is a probable contributor to this loss of strength. However, it is somewhat surprising that there was so little difference in modulus and such difference in strength. Another possible contributor is the matrix material. Although 1895 and 3501-6 are rather similar epoxys, it is possible that 1895 is more brittle or has a lower strain to failure than 3501-6.

The open-hole tension strength comparison is based on the standard 1/4" diameter hole which is often used in developing material allowables. In Reference 1, several hole diameters were tested for each braided material. A log-log best fir curve of strength versus hole diameter was then calculated. This procedure showed that the data at some of the hole diameters did not follow the overall trend due to experimental scatter. This was the case for the 1/4" hole in the SLL and LLS architecture. Thus, instead of using the data for the 1/4" hole, the strength is calculated with the following best fit equations:

SLL: $\sigma = 72.2 * d^{-.165}$ LLL: $\sigma = 53.0 * d^{-.315}$

LLS: $\sigma = 61.3 * d^{-.208}$ LLS: $\sigma = 28.8 * d^{-.265}$

Results in Figure 3.2 show a clear strength advantage for the braided materials. The relative differences between braid and laminate strength were +37% for SLL, +24% for LLL, +20% for LLS, and +4% for LSS. Since moduli are quite similar for each braid and equivalent laminate, the differences in term of nominal strain are about the same.

This strength difference is further magnified in the filled-hole tension test. As mentioned above, the laminated material was quite sensitive to the presence of a fastener, while the data in Ref. 1 showed that the braids were not. The relative differences in term of strength were: +72% for SLL, +47% for LLL, and +19% for LLS (no data is available for LSS).

Post-failure examination of the braided specimens revealed extensive matrix failure between the axial and bias tows which would tend to reduce the stress concentration for axial yarns. On the other hand, examination of the laminated specimen showed a fairly clean fracture surface across the specimen net section. Thus, 2D braids may have advantages over tape laminates with regard to open- and filled-hole tension strengths.

Strength measured along the transverse direction for these materials is shown in Figure 3.3.a to 3.3.d. For the unnotched case, the braided material show a severe strength reduction compared to the tape laminates: -51% for SLL, -57% for LLL, -57% for LLS, and -29% for LSS. Once again, the crimp in the bias tows is the likely cause for the strength reduction.

Only a limited set of data is available for the transverse open-hole tension strength of the braided material. A single hole size of 1/4" was tested and is used for comparison. Somewhat surprisingly, these materials exhibited no notch sensitivity, and in some cases, the strength was slightly higher than that for the unnotched case. The data is probably too limited at this point to draw any definite conclusion. The tape laminates did show some notch sensitivity, and thus the differences in strength between the two material forms are reduced compared to the unnotched case: -36% for SLL, -43% for LLL, -46% for LLS, and -16% for LSS.

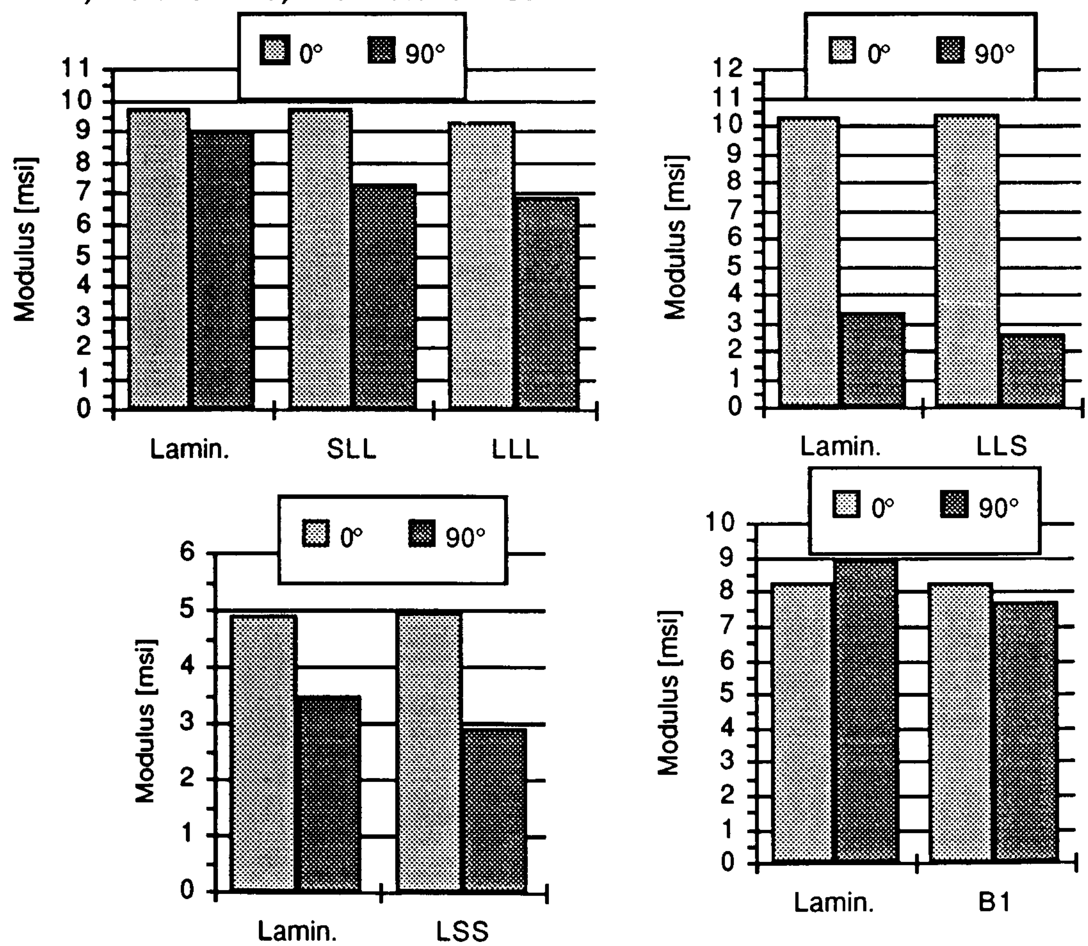

Figure 3.1 Comparison of Longitudinal and Transverse Tension Modulus.

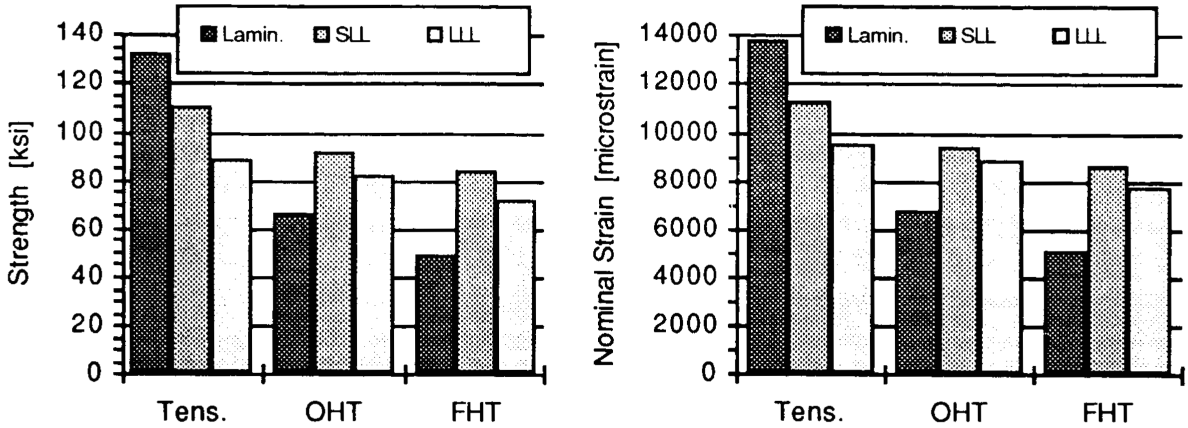

Figure 3.2.a Comparison of 0° Tension Strength for Tape Laminate 1, SLL and LLL.

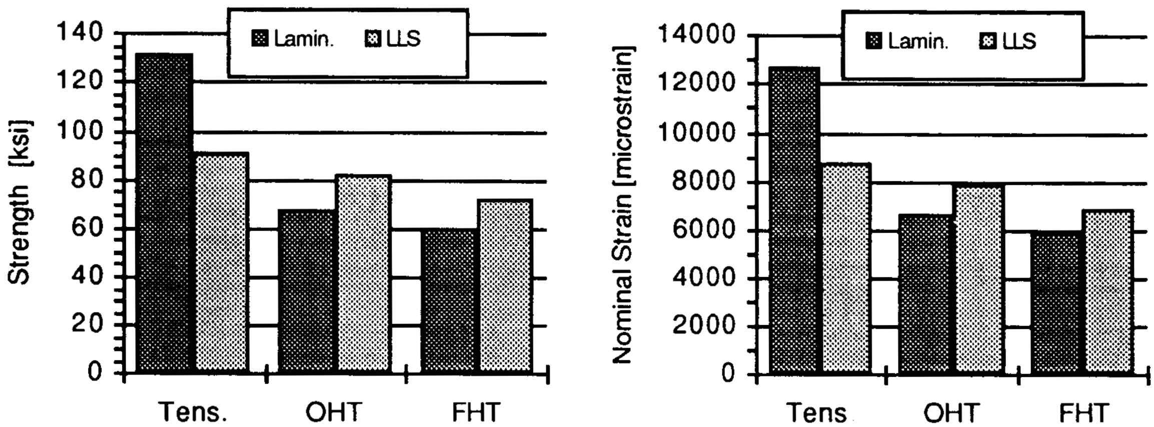

Figure 3.2.b Comparison of 0° Tension Strength for Tape Laminate 2 and LLS.

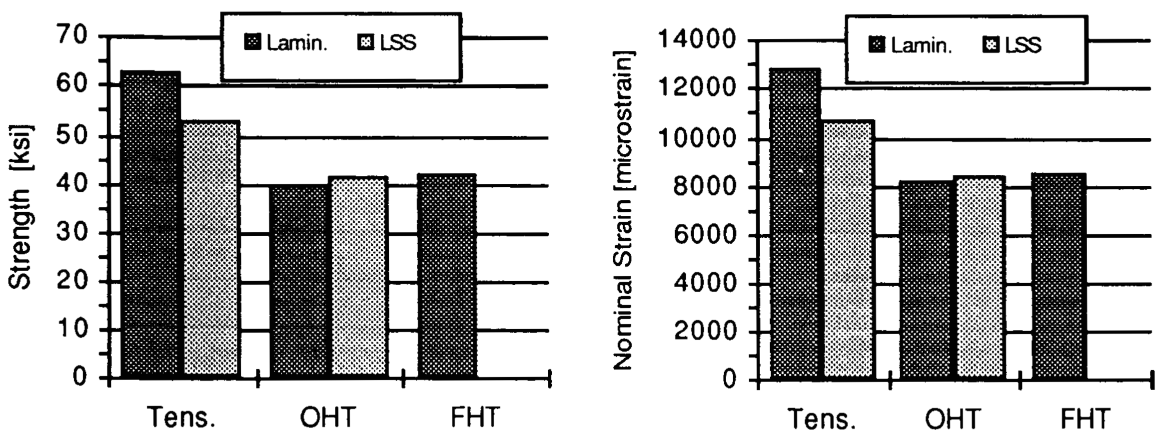

Figure 3.2.c Comparison of 0° Tension Strength for Tape Laminate 3 and LSS.

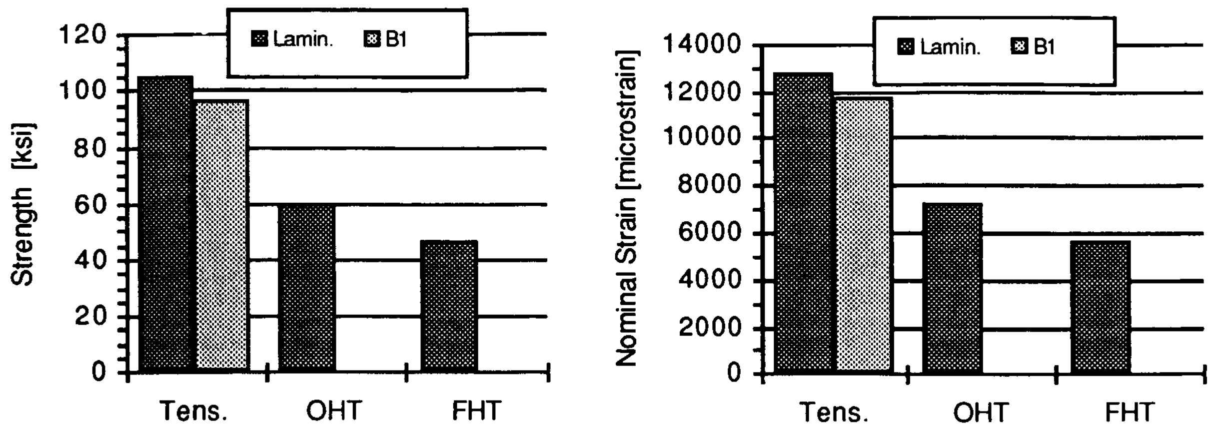

Figure 3.2.d Comparison of 0° Tension Strength for Tape Laminate 4 and B1.

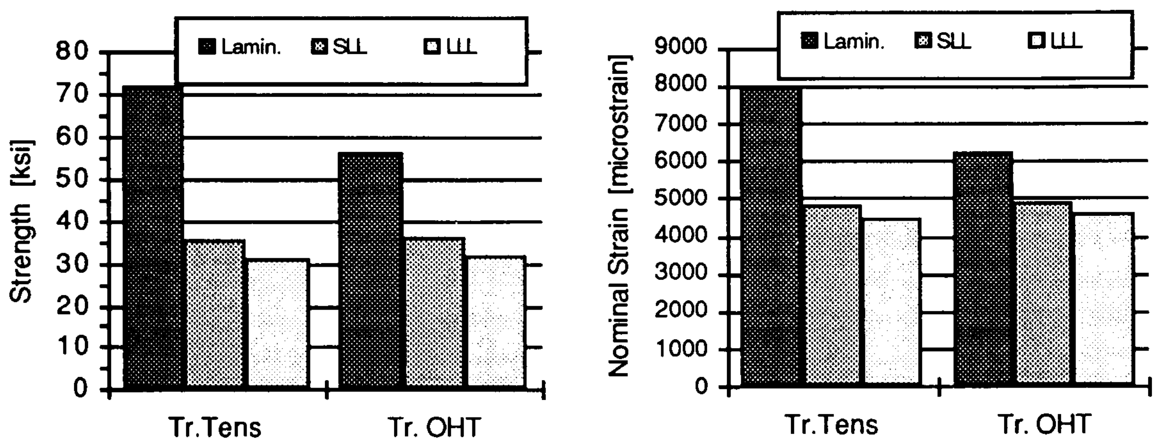

Figure 3.3.a Comparison of 90° Tension Strength for Tape Laminate 1, SLL and LLL.

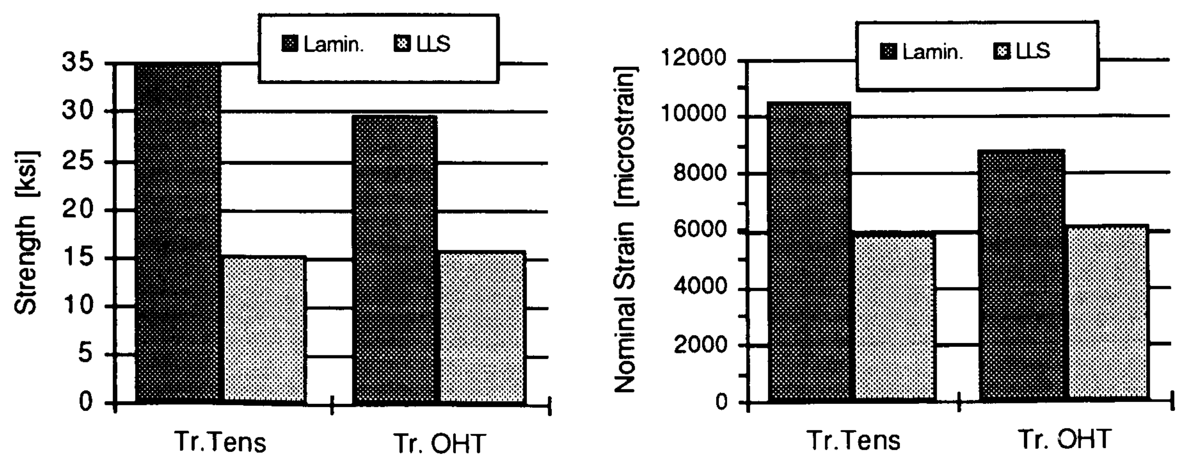

Figure 3.3.b Comparison of 90° Tension Strength for Tape Laminate 2 and LLS.

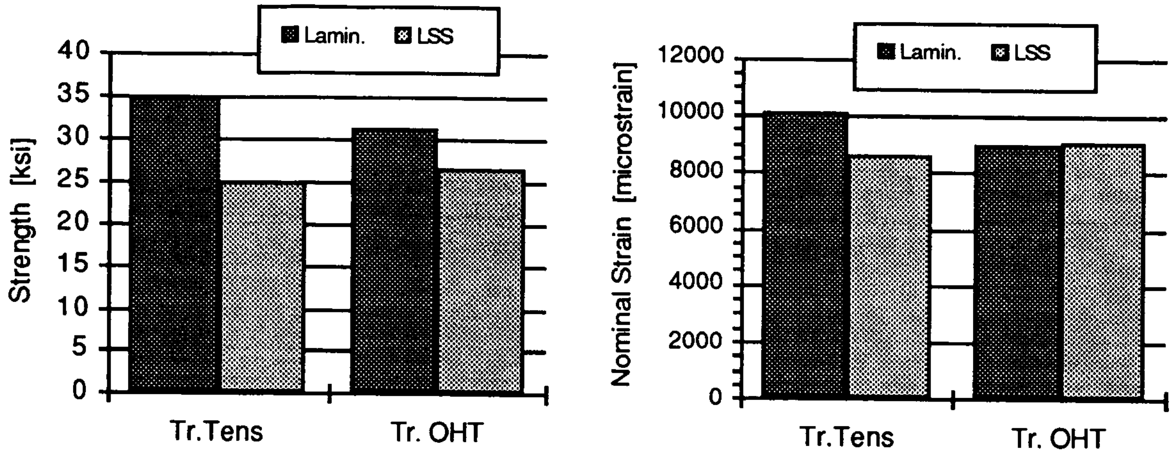

Figure 3.3.c Comparison of 90° Tension Strength for Tape Laminate 3 and LSS.

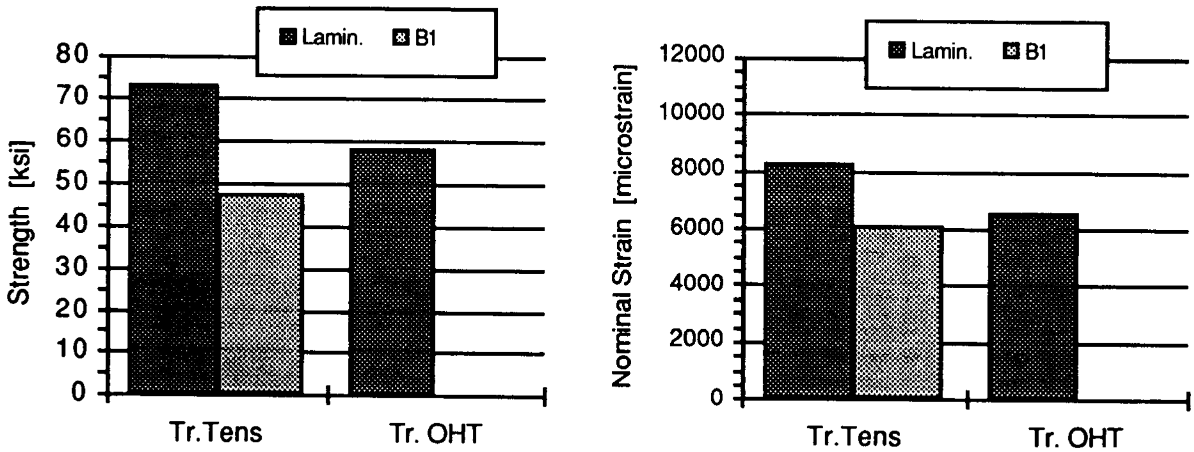

Figure 3.3.d Comparison of 90° Tension Strength for Tape Laminate 4 and B1.

4. Compression Properties

Compression properties for all four laminates were also measured in both the longitudinal (0°) and transverse (90°) directions. Properties included stiffness modulus, Poisson's coefficient and open-hole strength (0.188" diameter). A modified IITRI test specimen [1] with a test section of 1.5" by 1.5" was used for all tests.

4.1 Laminate Results

All the compression properties measured in the longitudinal (0°) direction are shown in Table 4.1, while all the properties measured in the transverse (90°) direction are shown in Table 4.2. Individual test results and typical stress-strain curves can be found in Appendix A and B respectively. Coefficients of variation were generally quite low and well within the typical values obtained when testing composites. Some of the exceptions were the unnotched 0° strength of L1, notched 90° strength of L1 and unotched 90° strength of L2. The nominal strains reported in this section were always calculated with the compression modulus. When comparing the compression moduli to the ones measured in tension, significant differences were observed, 17% lower for L1, 13% for L2, 16% for L3 and 14% L4. A similar observation can me made for the transverse modulus: 8% lower for L1, 14% for L2, 13% for L3 and 18% for L4. Although it is typical for composites to be softer in compression, these differences are slightly higher than expected. The test specimen itself, with a short and wide test section, is believed to be partly responsible for this effect. Longitudinal fiber strains at failure were fairly typical of this type of material, ranging from 0.95% to 1.1%. High strains to failure were measured wherever there was a large percentage ot ±45° fibers, such as in the 0° and 90° test of L3 and in the 90° test of L1.

Table 4.1 Laminate Longitudinal Compression Properties

Property	Laminate 1	Laminate 2	Laminate 3	Laminate 4
Modulus [msi]	8.84	8.53	4.25	7.22
CoV [%]	1.0	2.1	1.6	1.5
Poisson's Coefficient	0.704	0.172	0.712	0.227
CoV [%]	3.0	1.8	3.2	2.9
Unnotched Strength [ksi]	84	82	58	79
Nominal Strain [μs]	9,500	9,640	13,560	10,880
CoV [%]	9.9	5.5	5.1	1.1
0.188" OHT Strength [ksi]	65	75	43	69
OHT Nom. Strain [μs]	7,330	8,770	10,210	9,550
CoV [%]	1.5	2.0	1.4	1.9

Note: Laminate 1 $[(45/0/-45/0)_2/45/0/-45]_s$
Laminate 2 $[(70/0/-70/0)_2/70/0/-70]_s$
Laminate 3 $[(\pm45)_2/0/(\pm45)_3/0/(\pm45)_3/0/(\pm45)_2]_t$
Laminate 4 $[(66/0/-66)_4/0]_s$

Table 4.2 Laminate Transverse Compression Properties

Property	Laminate 1	Laminate 2	Laminate 3	Laminate 4
Modulus [msi]	3.13	7.84	3.08	7.52
CoV [%]	0.6	1.3	1.5	1.9
Poisson's Coefficient	0.237	0.151	0.525	0.226
CoV [%]	2.1	6.7	2.5	4.0
Unnotched Strength [ksi]	50	70	48	74
Nominal Strain [μs]	15,880	8,930	15,720	9,780
CoV [%]	4.9	12.3	1.5	1.4
0.188" OHT Strength [ksi]	42	61	44	59
OHT Nom. Strain [μs]	13,520	7,830	14,220	7,850
CoV [%]	7.6	1.3	0.4	2.6

Note: Laminate 1 $[(45/0/-45/0)_2/45/0/-45]_S$
Laminate 2 $[(70/0/-70/0)_2/70/0/-70]_S$
Laminate 3 $[(\pm45)_2/0/(\pm45)_3/0/(\pm45)_3/0/(\pm45)_2]_t$
Laminate 4 $[(66/0/-66)_4/0]_S$

4.2 Comparison with Braided Composite

The first comparison, shown in Figure 4.1, is for modulus. Small differences were found between braids and tape laminates for the longitudinal modulus, +4.6% for SLL, -1.9% for LLL, -0.2% for LLS, and 3.1% for LSS, and for the transverse modulus, +7.5% for SLL, -5.4% for LLL, -3.2% for LLS, and -1.6% for LSS. The differences for the transverse modulus are less than those observed in the tension case. Based on these observations, it would appear that the modulus measured in the laminated specimen might be somewhat under-estimated, although no precise cause was found for this effect.

The comparison for unnotched longitudinal compression strength is shown in Figure 4.2.a to 4.2.d. As anticipated, a lower strength was obtained for all the braids: -14% for SLL, -28% for LLL, -31% for LLS, and -16% for LSS. Once again, the tow waviness is a probable contributor to this loss of strength.

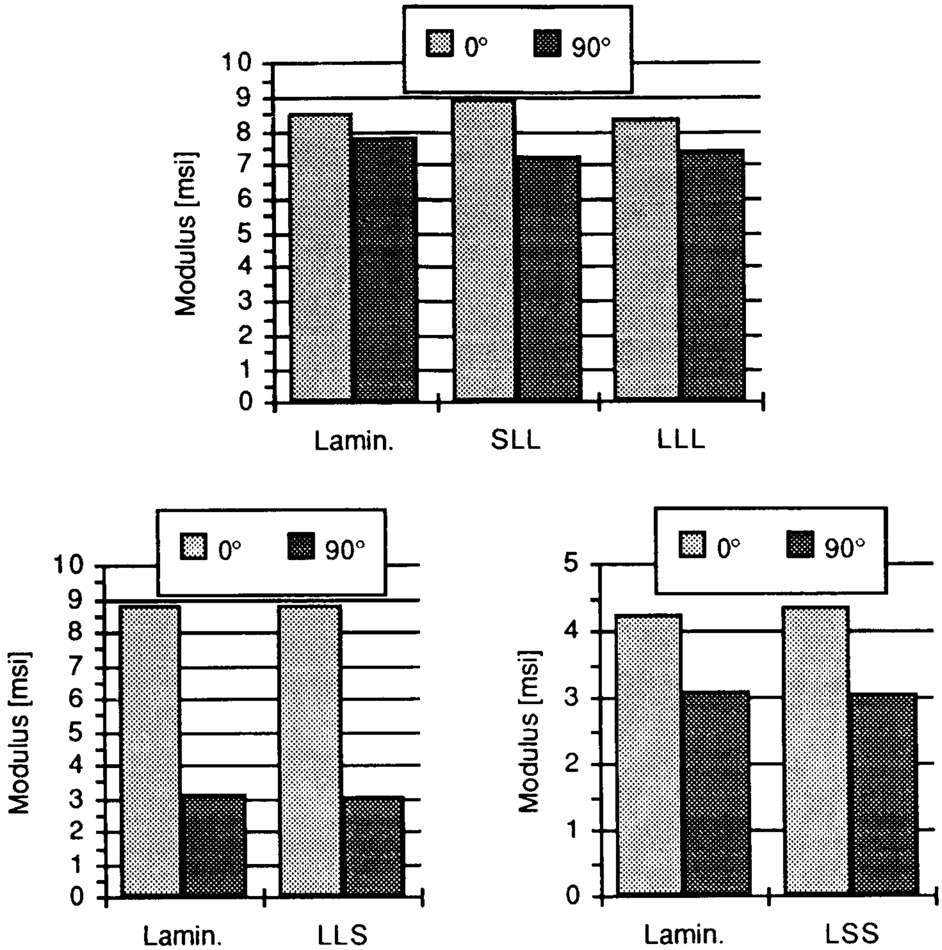

Figure 4.1 Comparison of Longitudinal and Transverse Compression Modulus.

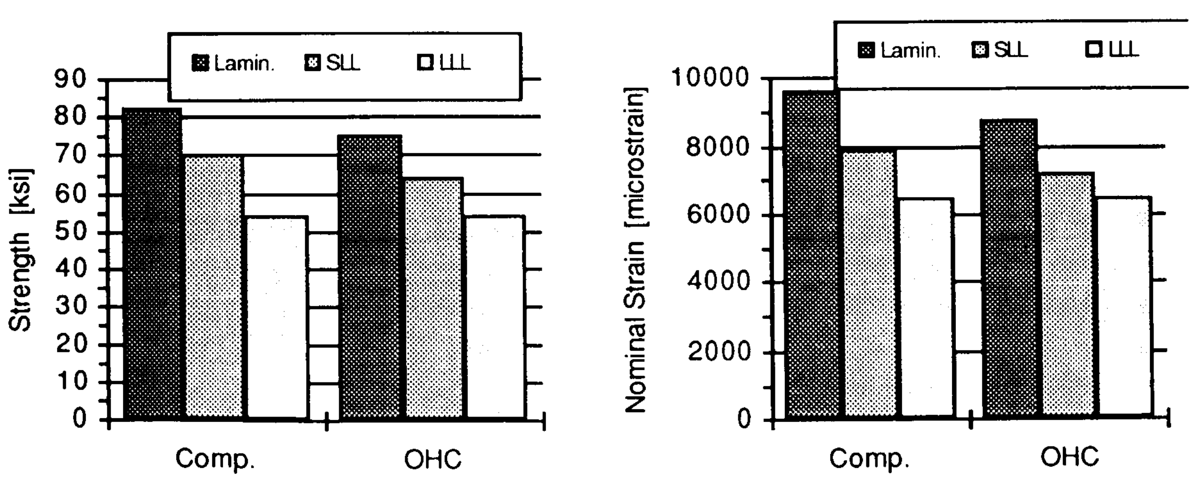

Figure 4.2.a Comparison of 0° Compression Strength for Tape Laminate 1, SLL and LLL.

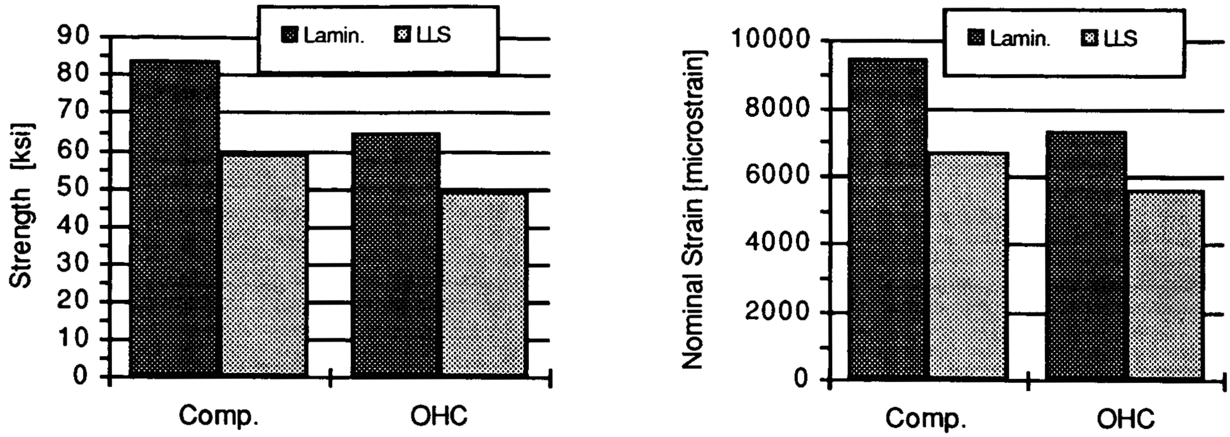

Figure 4.2.b Comparison of 0° Compression Strength for Tape Laminate 2, LLS.

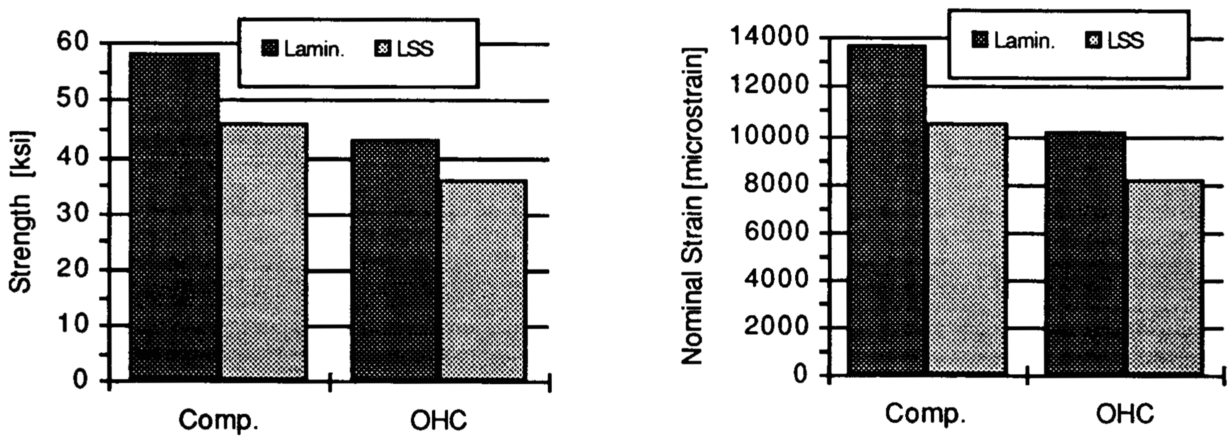

Figure 4.2.c Comparison of 0° Compression Strength for Tape Laminate 3, LSS.

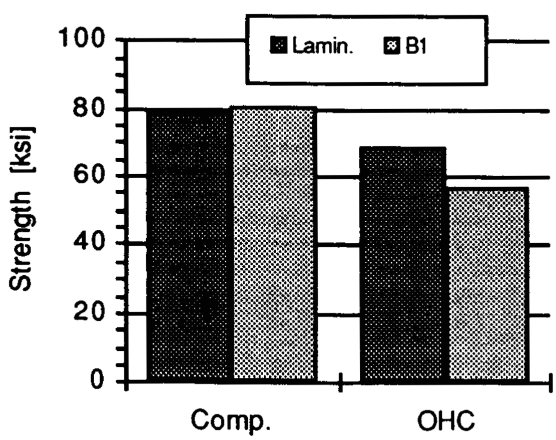

Figure 4.2.d Comparison of 0° Compression Strength for Tape Laminate 4, B1.

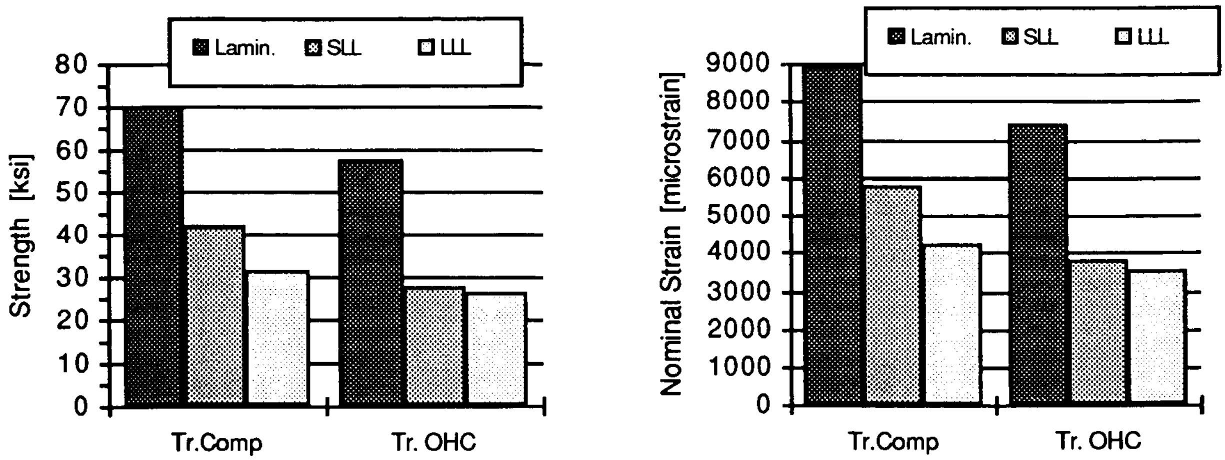

Figure 4.3.a Comparison of 90° Compression Strength for Tape Laminate 1, SLL and LLL.

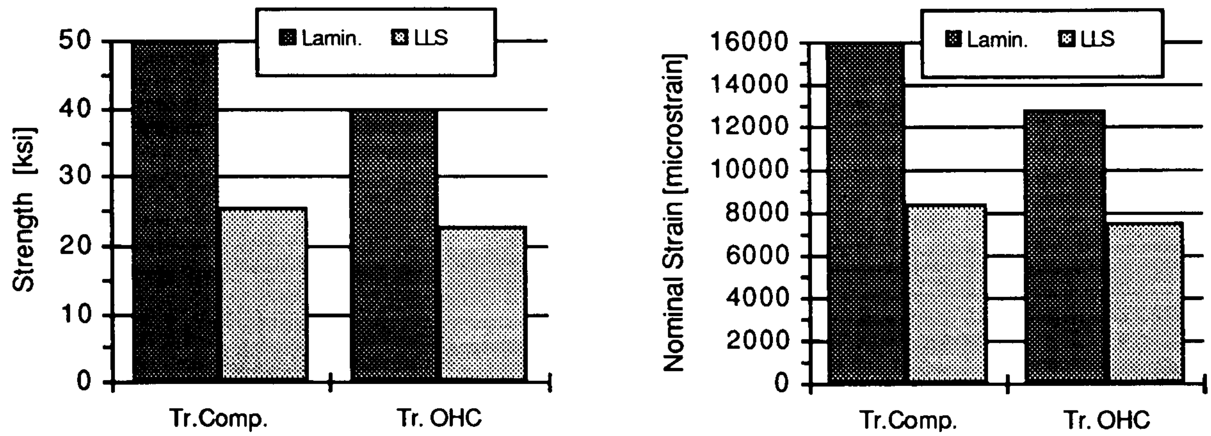

Figure 4.3.b Comparison of 90° Compression Strength for Tape Laminate 2, LLS.

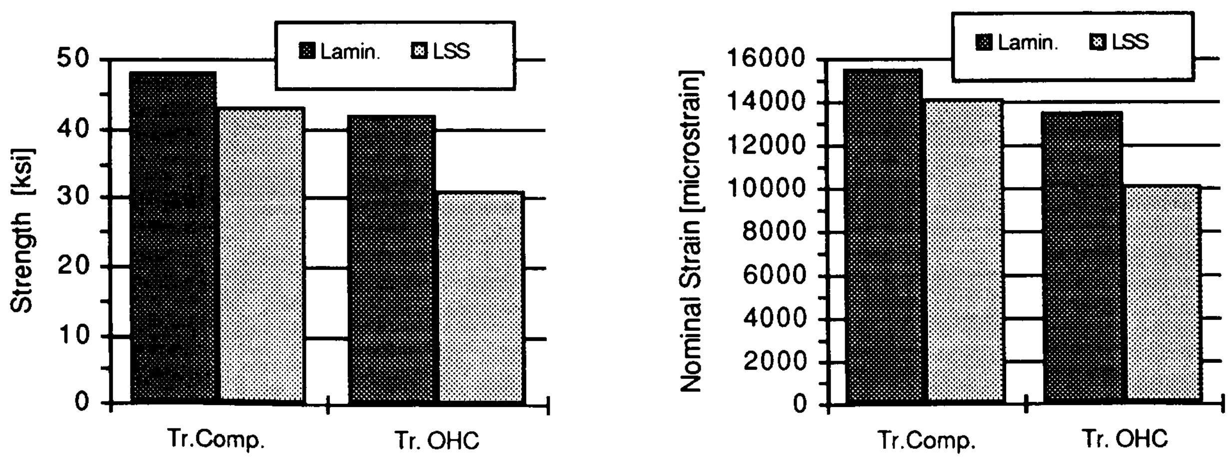

Figure 4.3.c Comparison of 90° Compression Strength for Tape Laminate 3, LSS.

5. Shear Properties

In-plane strength was measured for all four laminates using the rail shear test method. All specimens were tabbed with 0.125" thick quasi-isotropic graphite/epoxy tabs to avoid the bearing failures encountered in Reference 1.

5.1 Laminate Results

Stiffness and strength results are shown in Table 5.1. Individual test results can be found in Appendix A. Unfortunately, bearing failures were experienced in all the laminates except L2. Thus, the reported strength is actually a lower bound to the actual shear strength of these laminates.

Table 5.1 Laminate Shear Properties

Property	Laminate 1	Laminate 2	Laminate 3	Laminate 4
Modulus [msi]	2.74	1.68	4.05	2.13
CoV [%]	3.2	6.5	2.9	2.7
Shear Strength [ksi]	35	36	36	32
CoV [%]	7.1	4.7	4.1	4.8

Note: Laminate 1 [(45/0/-45/0)2/45/0/-45]s
Laminate 2 [(70/0/-70/0)2/70/0/-70]s
Laminate 3 [(±45)2/0/(±45)3/0/(±45)3/0/(±45)2]t
Laminate 4 [(66/0/-66)4/0]s

5.2 Comparison with Braided Composite

The comparison of shear moduli is shown in Figure 5.1, and of the shear strength in Figure 5.2. For the 2-D braids, the results of the rail shear testing in Reference 1 were used in the comparison. Results show that the measured moduli are fairly comparable, but that there is a significant difference in strength. That difference is consistant with the low transverse strength observed in the transverse tension and transverse compression tests. Because of the bearing failures encountered in the tape laminate tests and the LSS tests, it is not possible to put an exact figure on the difference between the two material forms. Based on the results for Laminate 2 (which failed in shear), SLL and LLL, the shear strength reduction could be as high as 50%. However, that layup is not well suited to carry shear loads. Laminate 3 and LSS were optimized for shear. Data show that the fiber strain level was about -8,000 microstrain in L3 when bearing failure occured. If one assumes a compression failure in the 45° plies as the failure mode if no premature bearing failure had occured, results in Section 4 show that at least -9,500 microstrain can be achieved along the fiber direction (see L1 in Table 4.1). This would translate to a minimum shear strength of 43 ksi for L3, or about 33% more than LSS.

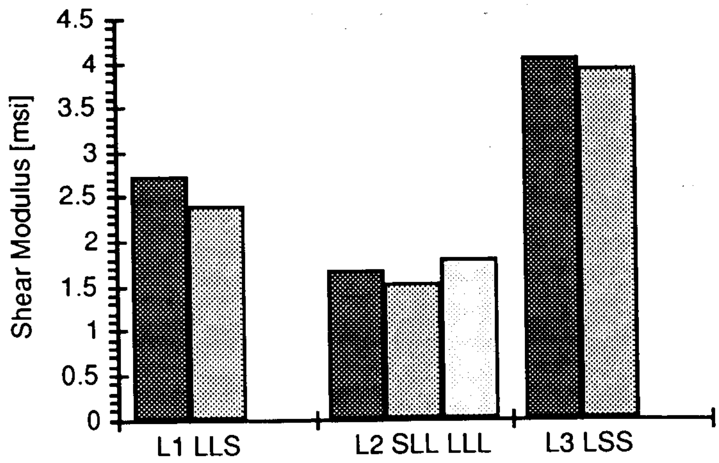

Figure 5.1 Comparison of In-Plane Shear Modulus of Laminates and 2-D Braids.

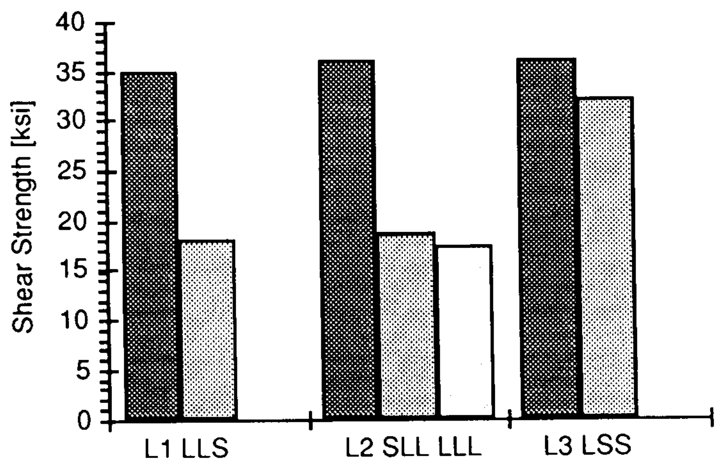

Figure 5.2 Comparison of In-Plane Shear Strength of Laminates and 2-D Braids.

6. Bolt Bearing Properties

Bolt bearing strength was measured for all four laminates using two test configurations, the stabilized single shear specimen and the double shear specimen [1]. A fully torqued 1/4" titanium HiLock fastener was installed in both cases, and the standard values of W/D of 6 and e/D of 3 were used for both configurations.

6.1 Laminate Results

Bolt bearing strength was measured for all four laminates using two test configurations, the stabilized single shear specimen and the double shear specimen. Ultimate bearing strength results are reported in Table 6.1. Individual test results can be found in Appendix A. Interestingly, the strength is almost identical for all four layups in both types of test. As expected, the double shear test always produced higher bearing strength by about 20 to 30%.

Table 6.1 Laminate Bearing Strength Properties

Property	Laminate 1	Laminate 2	Laminate 3	Laminate 4
Single Shear Strength [ksi]	119	122	118	119
CoV [%]	4.1	1.3	2.0	2.5
Double Shear Strength [ksi]	143	154	144	158
CoV [%]	3.9	1.9	5.0	4.5

Note: Laminate 1 [(45/0/-45/0)2/45/0/-45]s
Laminate 2 [(70/0/-70/0)2/70/0/-70]s
Laminate 3 [(±45)2/0/(±45)3/0/(±45)3/0/(±45)2]t
Laminate 4 [(66/0/-66)4/0]s

6.2 Comparison with Braided Composite

The comparison with the braided material is shown in Figure 6.1, but data from Reference 1 or 2 was not available for both test methods and all braids. Lower strength were obtained with the braids in all cases where data was available. In single shear, reductions were -16% for SLL, -25% for LLL and -30% for LLS, while in double shear, the reductions were -12% for SLL and -13% for LLS.

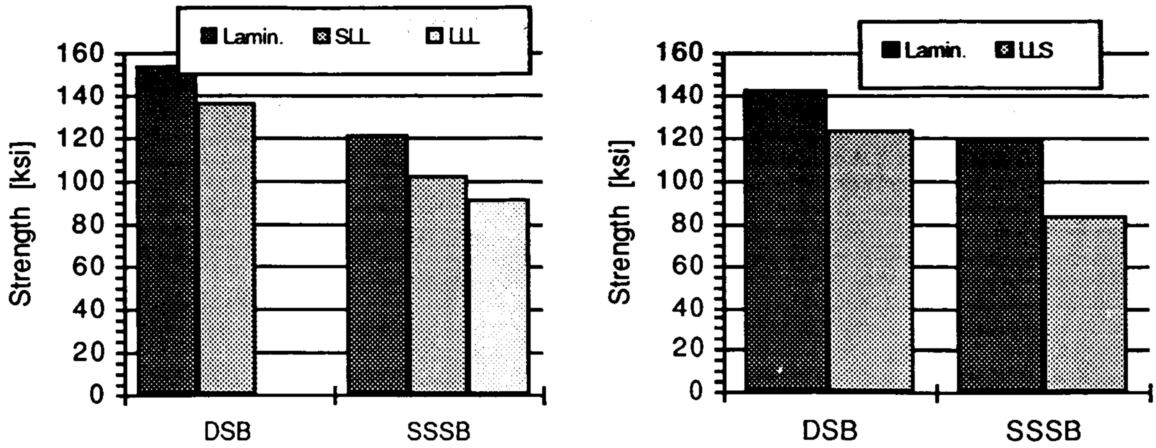

Figure 6.1 Comparison of Bearing Strength for Tape Laminate 1, 2 and braids SLL, LLL and LLS.

References

1. Minguet, P.J., Fedro, M.J., Gunther, C.K., "Test Methods for Textile Composites", NASA CR-4609, 1994.

2 Masters, J.E., Foye, R.L., Pastore, C.M., Gowayed, Y.A., "Mechanical Properties of Triaxially Braided Composites: Experimental and Analytical Results," Proceedings of the Ninth DoD/NASA/FAA Conference on Fibrous Composites in Structural Design, Lake Tahoe, Nevada, November 1991.

Appendix A Test Data

Appendix A Test Data

All the individual test data are included in this appendix as reported by Intec. Note that stresses in these spreadsheets are normalized by the actual specimen thickness.

Intec
Project #: BH0003

Comparison of Laminated Composites to Braided Textiles for Boeing Helicopters

Temperature: RT
intec engineer: Maryann Einarson
Boeing engineer: Pierre Minguet

Tension Results

Specimen ID	Test Type	Mat. Class	Panel ID	Fiber Vol. (%)	Ave Dimensions (in) Width	Thickness	Load at Audible (kips)	Ult. Load (kips)	Ult. Stress (ksi)	Ultimate Ext. Strn (με)	Ultimate Axial Strn (με)	Ultimate Trans. Strn (με)	Exten. Modulus (Mpsi)	Ax. SG Modulus (Mpsi)	Poisson's Ratio	Failure Mode/ Comments
BH3-001	Tens	1	1A	66.3	1.499	0.1083	17.00	25.674	158.168		13,536	-9,966	11.934	11.284	0.660	Failed in gage section
BH3-002	Tens	1	1A	66.3	1.500	0.1083	14.20	24.385	150.142		12,714	-9,549	11.817	11.458	0.680	Failed in gage section
BH3-003	Tens	1	1A	66.3	1.500	0.1097	17.90	20.116	122.196		10,647	-7,507	11.110	11.167	0.650	Failed in gage section
						Average	16.37	**23.39**	**143.50**		**12,299**	**-9,007**	**11.62**	**11.30**	**0.663**	
						Std. Dev		2.91	18.88		1489	1316	0.45	0.15	0.015	
						% COV		12.44	13.16		12.10	-14.61	3.84	1.30	2.303	
BH3-019	Tens	2	2A	65.7	1.501	0.1071	7.40	22.203	138.162		12,867	-1,805	10.447	10.346	0.150	Failed at upper tab edge
BH3-020	Tens	2	2A	65.7	1.500	0.1075	8.00	23.492	145.705		13,267	-1,877	10.631	10.828	0.160	Failed in gage section
BH3-021	Tens	2	2A	65.7	1.500	0.1089	8.70	25.180	154.118		14,161	-1,980	10.480	10.687	0.160	Failed in gage sec.,severe delam
						Average	8.03	**23.63**	**146.00**		**13,432**	**-1,887**	**10.52**	**10.62**	**0.157**	
						Std. Dev		1.49	7.98		663	88	0.10	0.25	0.006	
						% COV		6.32	5.47		4.93	-4.66	0.93	2.33	3.685	
BH3-037	Tens	3	3A	65.8	1.500	0.1117	10.40	11.992	71.580	16196	15,845	na	5.447	5.455	0.710	Failed in gage section
BH3-038	Tens	3	3A	65.8	1.500	0.1145	----	11.618	67.660	15202	15,101	na	5.368	5.310	0.710	Failed in gage section
BH3-039	Tens	3	3A	65.8	1.500	0.1145	9.40	11.653	67.829		14,780	na	5.321	5.362	0.720	Failed in gage section
						Average	9.90	**11.75**	**69.02**	**15699**	**15,242**		**5.38**	**5.38**	**0.713**	
						Std. Dev		0.21	2.22		546		0.06	0.07	0.006	
						% COV		1.76	3.21		3.58		1.18	1.37	0.809	
BH3-055	Tens	4	4A	64.3	1.500	0.1261	15.80	20.903	110.493		12,574	-2,243	9.214	8.953	0.190	Failed at lower tab edge beginnin
BH3-056	Tens	4	4A	64.3	1.499	0.1295	12.40	21.805	112.314		12,552	-2,274	9.003	9.080	0.190	Failed at lower tab edge beginnin
BH3-057	Tens	4	4A	64.3	1.499	0.1299	12.00	23.213	119.222		13,375	-2,424	8.852	8.863	0.190	Failed at lower tab edge beginnin
						Average	13.40	**21.97**	**114.01**		**12,834**	**-2,314**	**9.02**	**8.97**	**0.190**	
						Std. Dev		1.16	4.61		469	97	0.18	0.11		
						% COV		5.30	4.04		3.65	-4.18	2.02	1.22		

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Project #: BH0003

Comparison of Laminated Composites to Braided Textiles for Boeing Helicopters

Temperature: RT
Intec engineer: Maryann Einarson
Boeing engineer: Pierre Minguet

Transverse Tension Results

Specimen ID	Test Type	Mat. Class	Panel ID	Fiber Vol. (%)	Ave Dimensions (in) Width	Thickness	Load at Audible (kips)	Ult. Load (kips)	Ult. Stress (ksi)	Ultimate Ext. Strn ($\mu\varepsilon$)	Ultimate Axial Strn ($\mu\varepsilon$)	Ultimate Trans. Strn ($\mu\varepsilon$)	Exten. Modulus (Mpsi)	Ax. SG Modulus (Mpsi)	Poisson's Ratio	Failure Mode/ Comments
BH3-076	TT	1	1B	66.9	1.502	0.1075	----	6.440	39.864	15614	****		3.790	****		No axial strn data
BH3-077	TT	1	1B	66.9	1.501	0.1085	4.30	6.278	38.545	15773	15,710	-3,870	3.631	3.723	0.240	Failed in gage section and at grip
BH3-078	TT	1	1B	66.9	1.501	0.1087	4.60	6.222	38.129		15,560	-3,362	3.553	3.669	0.210	Failed in gage section
						Average	4.45	**6.31**	**38.85**	**15694**	**15,635**	**-3,616**	**3.66**	**3.70**	**0.225**	
						Std. Dev		0.11	0.91	112	106	359	0.12	0.04	0.021	
						% COV		1.79	2.33	0.72	0.68	-9.93	3.30	1.03	9.428	
BH3-088	TT	2	2B	66.0	1.502	0.1072	11.00	12.370	76.861		8,019	-1,120	9.549	9.885	0.150	Failed in gage section
BH3-089	TT	2	2B	66.0	1.502	0.1063	11.90	12.987	81.334	9524	8,380	-1,156	9.821	10.090	0.150	Failed in gage section
BH3-090	TT	2	2B	66.0	1.502	0.1077	12.10	13.170	81.405		8,597	-926	9.526	9.896	0.140	Failed in gage section
						Average	11.67	**12.84**	**79.87**	**9524**	**8,332**	**-1,067**	**9.63**	**9.96**	**0.147**	
						Std. Dev		0.42	2.60		292	124	0.16	0.12	0.006	
						% COV		3.26	3.26		3.50	-11.59	1.70	1.16	3.936	
BH3-100	TT	3	3B	66.2	1.502	0.1127	6.40	6.556	38.729	14473	15,739	-8,970	3.878	3.809	0.510	Failed in gage section
BH3-101	TT	3	3B	66.2	1.502	0.1125	6.40	6.500	38.465	13024	14,339	-8,659	4.061	3.900	0.520	Failed in gage section
BH3-102	TT	3	3B	66.2	1.501	0.1133	6.20	6.439	37.859	13720	14,267	-8,318	3.965	3.760	0.510	Failed in gage section
						Average	6.33	**6.50**	**38.35**	**13739**	**14,782**	**-8,649**	**3.97**	**3.82**	**0.513**	
						Std. Dev		0.06	0.45	725	830	326	0.09	0.07	0.006	
						% COV		0.90	1.16	5.27	5.61	-3.77	2.31	1.86	1.125	
BH3-112	TT	4	4B	66.4	1.503	0.1304	14.90	15.536	79.269		8,690	-2,009	9.508	9.543	0.220	Failed in gage section
BH3-113	TT	4	4B	66.4	1.503	0.1292	14.50	15.852	81.629		9,039	-1,662	9.419	9.808	0.220	Failed in gage section
BH3-114	TT	4	4B	66.4	1.503	0.1296	13.90	14.497	74.451		8,171	-1,838	9.572	9.413	0.230	Failed at upper grip edge
						Average	14.43	**15.29**	**78.45**		**8,633**	**-1,836**	**9.50**	**9.59**	**0.223**	
						Std. Dev		0.71	3.66		437	174	0.08	0.20	0.006	
						% COV		4.63	4.66		5.06	-9.45	0.81	2.10	2.585	

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Project #: BH0003

Comparison of Laminated Comp. to Braided Textiles for Boeing Helicopters

Temperature: RT

intec Engineer: Maryann Einarson
Boeing engineer: Pierre Minguet

Open Hole Tension Results

Specimen ID	Test Type	Mat. Class	Cell #	Panel ID	Fiber Volume (%)	Average Dimensions (inches) Width	Length	Thick-ness	Hole Dia 1	W/D	Load at Audible *(kips)*	Ultimate Load *(kips)*	Ultimate Stress *(ksi)*	Failure Location/ Comments
Specimen ID	Test Type	Mat. Class	Cell #	Panel ID	Fiber Volume (%)	Average Dimensions (inches) Width	Length	Thick-ness	Hole Dia 1	W/D	Load at Audible *(kips)*	Ultimate Load *(kips)*	Ultimate Stress *(ksi)*	Failure Location/ Comments
BH3-004	OHT	1	3	1A	66.3	1.502	11.5	0.1137	0.1880	8		12.65	74.09	Hole/delamination
BH3-005	OHT	1	3	1A	66.3	1.502	11.5	0.1117	0.1880	8		12.07	71.98	Hole/delamination
BH3-006	OHT	1	3	1A	66.3	1.502	11.5	0.1137	0.1885	8		13.20	77.27	Hole/delamination
									Average			**12.64**	**74.45**	
									Std. Dev.			0.56	2.66	
									% COV			4.44	3.57	
BH3-022	OHT	2	16	2A	65.7	1.502	12.0	0.1084	0.1885	8	9.35	11.51	70.74	Failed at Hole
BH3-023	OHT	2	16	2A	65.7	1.502	12.0	0.1087	0.1885	8	9.20	11.58	70.93	Failed at Hole
BH3-024	OHT	2	16	2A	65.7	1.503	12.0	0.1079	0.1885	8	9.25	11.75	72.43	Failed at Hole
									Average		9.27	**11.61**	**71.36**	
									Std. Dev.			0.12	0.93	
									% COV			1.03	1.30	
BH3-040	OHT	3	29	3A	65.8	1.501	11.5	0.1142	0.1890	8	7.05	7.80	45.50	Failed at Hole
BH3-041	OHT	3	29	3A	65.8	1.502	11.5	0.1135	0.1895	8	6.80	7.58	44.45	Failed at Hole
BH3-042	OHT	3	29	3A	65.8	1.503	11.5	0.1125	0.1185	8	7.05	7.60	44.92	Failed at Hole
									Average		6.97	**7.66**	**44.96**	
									Std. Dev.			0.12	0.52	
									% COV			1.60	1.16	
BH3-058	OHT	4	42	4A	64.3	1.503		0.1293	0.1895	8	8.95	13.07	67.26	Failed at Hole
BH3-059	OHT	4	42	4A	64.3	1.501		0.1297	0.1880	8	10.40	12.14	62.38	Failed at Hole
BH3-060	OHT	4	42	4A	64.3	1.502		0.1297	0.1895	8	10.70	12.80	65.70	Failed at Hole
									Average		10.02	**12.67**	**65.11**	
									Std. Dev.			0.48	2.49	
									% COV			3.79	3.83	

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Temperature: RT

intec Engineer: Maryann Einarson
Boeing engineer: Pierre Minguet

Open Hole Tension Results

Specimen ID	Test Type	Mat. Class	Cell #	Panel ID	Fiber Volume (%)	Average Dimensions (inches)				W/D	Load at Audible *(kips)*	Ultimate Load *(kips)*	Ultimate Stress *(ksi)*	Failure Location/ Comments
						Width	Length	Thick-ness	Hole Dia 1					
BH3-179	OHT	1	48	1A	66.3	1.501	11.5	0.1078	0.2505	6		11.880	73.433	Failed at Hole
BH3-180	OHT	1	48	1A	66.3	1.502	11.5	0.1090	0.2505	6		11.437	69.882	Failed at Hole
BH3-181	OHT	1	48	1A	66.3	1.501	11.5	0.1085	0.2505	6		12.326	75.678	Failed at Hole
									Average			**11.88**	**73.00**	
									Std. Dev.			0.44	2.92	
									% COV			3.74	4.00	
BH3-182	OHT	2	49	2A	65.7	1.501	12.0	0.1109	0.2505	6		11.839	71.103	Failed at Hole
BH3-183	OHT	2	49	2A	65.7	1.501	12.0	0.1100	0.2505	6	9.50	11.110	67.282	Failed at Hole
BH3-184	OHT	2	49	2A	65.7	1.502	12.0	0.1091	0.2510	6	9.40	11.150	68.027	Failed at Hole
									Average		9.45	**11.37**	**68.80**	
									Std. Dev.			0.41	2.03	
									% COV			3.60	2.94	
BH3-185	OHT	3	50	3A	65.8	1.501	11.5	0.1147	0.2510	6	7.40	7.154	41.580	Failed at Hole
BH3-186	OHT	3	50	3A	65.8	1.501	11.0	0.1150	0.2500	6	7.30	7.113	41.214	Failed at Hole
BH3-187	OHT	3	50	3A	65.8	1.501	11.5	0.1147	0.2500	6	6.39	7.277	42.276	Failed at Hole
									Average		7.03	**7.18**	**41.69**	
									Std. Dev.			0.09	0.54	
									% COV			1.19	1.29	
BH3-188	OHT	4	51	4A	64.3	1.500	11.5	0.1320	0.2505	6		12.546	63.339	Failed at Hole
BH3-189	OHT	4	51	4A	64.3	1.502	11.5	0.1305	0.2505	6		12.167	62.073	Failed at Hole
BH3-190	OHT	4	51	4A	64.3	1.501	11.5	0.1315	0.2505	6		12.233	61.947	Failed at Hole
									Average			**12.32**	**62.45**	
									Std. Dev.			0.20	0.77	
									% COV			1.64	1.23	

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Project #: BH0003

Comparison of Laminated Comp. to Braided Textiles for Boeing Helicopters

Temperature: RT

intec Engineer: Maryann Einarson
Boeing engineer: Pierre Minguet

Open Hole Transverse Tension Results

Specimen ID	Test Type	Mat. Class	Cell #	Panel ID	Fiber Volume (%)	Average Dimensions (inches)				W/D	Load at Audible *(kips)*	Ultimate Load *(kips)*	Ultimate Stress *(ksi)*	Failure Location/ Comments
						Width	Length	Thick-ness	Hole Dia 1					
BH3-073	OHTT	1	4	1B	66.9	1.503	12.0	0.1072	0.2515	6	3.00	4.810	29.87	Hole
BH3-074	OHTT	1	4	1B	66.9	1.503	12.0	0.1081	0.2515	6	2.50	5.037	31.00	Hole
BH3-075	OHTT	1	4	1B	66.9	1.503	12.0	0.1087	0.2510	6	3.10	4.811	29.46	Hole
									Average		2.87	**4.89**	**30.11**	
									Std. Dev.			0.13	0.80	
									% COV			2.67	2.65	
BH3-204	OHTT	2	56	2A	65.7	1.500	12.0	0.1079	0.2520	6	none	8.987	55.54	Hole
BH3-205	OHTT	2	56	2A	65.7	1.500	12.0	0.1082	0.2515	6	none	9.519	58.68	Hole
BH3-206	OHTT	2	56	2A	65.7	1.500	12.0	0.1072	0.2520	6	8.60	8.982	55.86	Hole
									Average		8.60	**9.16**	**56.69**	
									Std. Dev.			0.31	1.73	
									% COV			3.37	3.05	
BH3-097	OHTT	3	30	3B	66.2	1.503	12.0	0.1129	0.2510	6		5.719	33.70	Hole
BH3-098	OHTT	3	30	3B	66.2	1.502	12.0	0.1125	0.2515	6		5.716	33.84	Hole
BH3-099	OHTT	3	30	3B	66.2	1.502	12.0	0.1128	0.2510	6		5.795	34.21	Hole
									Average			**5.74**	**33.92**	
									Std. Dev.			0.04	0.26	
									% COV			0.78	0.77	
BH3-109	OHTT	4	43	4B	66.4	1.508	12.0	0.1286	0.2505	6		11.040	56.94	Hole
BH3-110	OHTT	4	43	4B	66.4	1.503	12.0	0.1287	0.2515	6	10.87	11.088	57.33	Hole
BH3-111	OHTT	4	43	4B	66.4	1.502	12.0	0.1316	0.2510	6	11.04	11.099	56.15	Hole
									Average		10.96	**11.08**	**56.80**	
									Std. Dev.			0.03	0.60	
									% COV			0.28	1.06	

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Project #: BH0003

Comparison of Laminated Comp. to Braided Textiles for Boeing Helicopters

Temperature: RT

intec Engineer: Maryann Einarson
Boeing engineer: Pierre Minguet

Open Hole Transverse Tension Results

Specimen ID	Test Type	Mat. Class	Cell #	Panel ID	Fiber Volume (%)	Average Dimensions (inches) Width	Length	Thick-ness	Hole Dia 1	W/D	Load at Audible *(kips)*	Ultimate Load *(kips)*	Ultimate Stress *(ksi)*	Failure Location/ Comments
BH3-121	OHTT	1	53	1A	66.3	1.503	12.0	0.1081	0.1885	6	2.50	5.39	33.18	Hole/ delamination
BH3-122	OHTT	1	53	1A	66.3	1.502	12.0	0.1077	0.1885	6	2.45	5.47	33.79	Hole/ delamination
BH3-123	OHTT	1	53	1A	66.3	1.502	12.0	0.1068	0.1885	6	2.95	5.52	34.40	Hole/ delamination
									Average		2.63	**5.46**	**33.79**	
									Std. Dev.			0.06	0.61	
									% COV			1.18	1.79	
BH3-085	OHTT	2	17	2B	66.0	1.503	12.0	0.1048	0.1885	8	9.20	10.59	67.23	Hole/ delamination
BH3-086	OHTT	2	17	2B	66.0	1.503	12.0	0.1054	0.1890	8	9.35	10.54	66.58	Hole/ delamination
BH3-087	OHTT	2	17	2B	66.0	1.503	12.0	0.1066	0.1890	8	9.75	9.94	62.08	Hole/ delamination
									Average		9.43	**10.36**	**65.30**	
									Std. Dev.			0.36	2.80	
									% COV			3.50	4.29	
BH3-124	OHTT	3	54	3A	65.8	1.501	12.0	0.1129	0.1885	6		6.09	35.93	Hole/ delamination
BH3-125	OHTT	3	54	3A	65.8	1.501	12.0	0.1143	0.1885	6		6.07	35.34	Hole/ delamination
BH3-126	OHTT	3	54	3A	65.8	1.502	12.0	0.1144	0.1885	6		6.02	35.06	Hole/ delamination
									Average			**6.06**	**35.44**	
									Std. Dev.			0.03	0.44	
									% COV			0.51	1.25	
BH3-127	OHTT	4	55	4A	64.3	1.502	12.0	0.1295	0.1885	6	11.75	12.47	64.13	Hole/ delamination
BH3-128	OHTT	4	55	4A	64.3	1.500	12.0	0.1292	0.1885	6	10.15	12.02	61.98	Hole/ delamination
BH3-129	OHTT	4	55	4A	64.3	1.501	12.0	0.1282	0.1885	6	11.05	11.61	60.28	Hole/ delamination
									Average		10.98	**12.03**	**62.13**	
									Std. Dev.			0.43	1.93	
									% COV			3.58	3.10	

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Project #: BH0003

Comparison of Laminated Composites to Braided Textiles for Boeing Helicopters

Temperature: RT
intec Engineer: Maryann Einarson
Boeing engineer: Pierre Minguet

Filled Hole Tension Results

Specimen ID	Test Type	Mat. Class	Cell #	Panel ID	Fiber Volume (%)	Average Dimensions (inches)				Load at Audible *(kips)*	Ultimate Load *(kips)*	Ultimate Stress *(ksi)*	Failure Mode/ Comments
						Width	Length	Thick ness	Hole Dia 1				
Specimen ID	Test Type	Mat. Class	Cell #	Panel ID	Fiber Volume (%)	Average Dimensions (inches)				Load at Audible *(kips)*	Ultimate Load *(kips)*	Ultimate Stress *(ksi)*	Failure Mode/ Comments
						Width	Length	Thick ness	Hole Dia 1				
BH3-007	FHT	1	10	1A	66.3	1.503	11.5	0.1094	0.2515	8.45	10.49	63.82	Fastener/delamination
BH3-008	FHT	1	10	1A	66.3	1.501	11.5	0.1092	0.2510	9.35	10.58	64.57	Fastener/delamination
BH3-009	FHT	1	10	1A	66.3	1.502	11.5	0.1106	0.2495	8.80	10.17	61.26	Fastener/delamination
									Average	8.87	**10.41**	**63.22**	
									Std. Dev.		0.22	1.74	
									% COV		2.07	2.75	
BH3-025	FHT	2	23	2A	65.7	1.501	12.0	0.1067	0.2505	8.00	8.32	51.97	Fastener/delamination
BH3-026	FHT	2	23	2A	65.7	1.502	12.0	0.1078	0.2505	6.75	8.51	52.58	Fastener/delamination
BH3-027	FHT	2	23	2A	65.7	1.501	12.0	0.1085	0.2500	7.80	8.62	52.94	Fastener/delamination
									Average	7.52	**8.48**	**52.50**	
									Std. Dev.		0.15	0.49	
									% COV		1.76	0.94	
BH3-043	FHT	3	36	3A	65.8	1.502	11.5	0.1149	0.2520	5.15	7.45	43.18	Fastener
BH3-044	FHT	3	36	3A	65.8	1.503	11.5	0.1144	0.2515	5.70	7.84	45.64	Fastener
BH3-045	FHT	3	36	3A	65.8	1.503	11.5	0.1149	0.2500	5.90	7.54	43.65	Fastener
									Average	5.58	**7.61**	**44.16**	
									Std. Dev.		0.20	1.31	
									% COV		2.69	2.97	
BH3-061	FHT	4	49	4A	64.3	1.505	11.5	0.1303	0.2505	8.20	9.74	49.67	Fastener
BH3-062	FHT	4	49	4A	64.3	1.502	11.5	0.1304	0.2515	9.23	9.84	50.20	Fastener
BH3-063	FHT	4	49	4A	64.3	1.502	11.5	0.1296	0.2505	8.55	9.19	47.22	Fastener
									Average	8.66	**9.59**	**49.03**	
									Std. Dev.		0.35	1.59	
									% COV		3.64	3.25	

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Project #: BH0003

Comparison of Laminated Composites to Braided Textiles for Boeing Helicopters

Temperature: RT
intec Engineer: Maryann Einarson
Boeing engineer: Pierre Minguet

Filled Hole Transverse Tension Results

Specimen ID	Test Type	Mat. Class	Cell #	Panel ID	Fiber Volume (%)	Average Dimensions (inches)				Load at Audible *(kips)*	Ultimate Load *(kips)*	Ultimate Stress *(ksi)*	Failure Mode/ Comments
						Width	Length	Thick ness	Hole Dia 1				
BH3-079	FHTT	1	11	1B	66.9	1.503	12.0	0.1080	0.2510	3.65	5.73	35.30	Fastener delamination/ spark
BH3-080	FHTT	1	11	1B	66.9	1.502	12.0	0.1083	0.2520	3.40	5.71	35.11	Fastener delamination
BH3-081	FHTT	1	11	1B	66.9	1.503	12.0	0.1061	0.2515	3.15	5.50	34.48	Fastener delamination
									Average	3.40	**5.65**	**34.96**	
									Std. Dev.		0.13	0.43	
									% COV		2.30	1.22	
BH3-091	FHTT	2	24	2B	66.0	1.502	12.0	0.1062	0.2505	7.20	8.35	52.38	Fastener delamination
BH3-092	FHTT	2	24	2B	66.0	1.502	12.0	0.1051	0.2510	5.95	8.80	55.79	Fastener delamination
BH3-093	FHTT	2	24	2B	66.0	1.501	12.0	0.1066	0.2500	7.90	8.83	55.19	Fastener delamination
									Average	7.02	**8.66**	**54.45**	
									Std. Dev.		0.27	1.83	
									% COV		3.10	3.35	
BH3-103	FHTT	3	37	3B	66.2	1.503	12.0	0.1117	0.2515	4.10	5.91	35.19	Fastener delamination
BH3-104	FHTT	3	37	3B	66.2	1.502	12.0	0.1115	0.2515	3.85	5.91	35.27	Fastener delamination
BH3-105	FHTT	3	37	3B	66.2	1.502	12.0	0.1116	0.2520	3.75	5.96	35.52	Fastener delamination
									Average	3.90	**5.92**	**35.32**	
									Std. Dev.		0.03	0.17	
									% COV		0.48	0.49	
BH3-115	FHTT	4	50	4B	66.4	1.502	12.0	0.1296	0.2515	5.62	10.65	54.70	Fastener delamination
BH3-116	FHTT	4	50	4B	66.4	1.503	12.0	0.1283	0.2515	7.85	10.75	55.75	Fastener delamination
BH3-117	FHTT	4	50	4B	66.4	1.502	12.0	0.1283	0.2500	8.60	10.14	52.66	Fastener delamination
									Average	7.36	**10.51**	**54.37**	
									Std. Dev.		0.32	1.57	
									% COV		3.08	2.90	

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Project #: BH0003

Comparison of Laminated Comp. to Braided Textiles for Boeing Helicopters

Temperature: RT

intec Engineer: Maryann Einarson
Boeing Engineer: Pierre Minguet

IITRI Compression Results

Specimen ID	Test Type	Mat. Class	Panel ID	Fiber Vol. (%)	Average Dim. (in) Width	Thickness	Load at Audible *(kips)*	Ultimate Load *(kips)*	Ultimate Stress *(ksi)*	Ult. Axial Strn #1 *(με)*	Ult. Axial Strn#2 *(με)*	Ultimate Trans. Strn *(με)*	Chord Ave. Axial Modulus *(MPSI)*	Poisson's Ratio
Specimen ID	Test Type	Mat. Class	Panel ID	Fiber Vol. (%)	Average Dim. (in) Width	Thickness	Load at Audible *(kips)*	Ultimate Load *(kips)*	Ultimate Stress *(ksi)*	Ult. Axial Strn #1 *(με)*	Ult. Axial Strn#2 *(με)*	Ultimate Trans. Strn *(με)*	Ave. Axial Modulus *(MPSI)*	Poisson's Ratio
BH3-136	IITRI	1	1C	57.5	1.498	0.2502	26.80	27.091	72.302	-8307	-9691	6985	8.37	0.705
BH3-137	IITRI	1	1C	57.5	1.497	0.2496	29.70	30.083	80.518	-8226	-11229	7242	8.46	0.724
BH3-138	IITRI	1	1C	57.5	1.499	0.2488	30.40	33.089	88.742	-11541	-12158	8498	8.58	0.682
						Average	28.97	**30.09**	**80.52**	**-9,358**	**-11,026**	**7,575**	**8.47**	**0.703**
						Std. Dev.		3.00	8.22				0.11	0.021
						% COV		9.97	10.21				1.24	2.98
BH3-148	IITRI	2	2C	57.9	1.498	0.2469	27.60	27.708	74.939	-9210	-9347	1678	8.33	0.173
BH3-149	IITRI	2	2C	57.9	1.497	0.2455	30.40	30.632	83.338	-11204	-11799	1910	8.15	0.169
BH3-150	IITRI	2	2C	57.9	1.498	0.2462	29.40	30.396	82.417	-9774	-12147	1726	8.48	0.175
						Average	29.13	**29.58**	**80.23**	**-10,063**	**-11,098**	**1,771**	**8.32**	**0.173**
						Std. Dev.		1.62	4.61				0.17	0.003
						% COV		5.49	5.74				1.99	1.71
BH3-198	IITRI	3	3D	59.6	1.500	0.2469	none	21.804	58.860	-23890	-21199	18937	4.25	0.686
BH3-199	IITRI	3	3D	59.6	1.499	0.2471	19.10	19.930	53.818	-20553	-17429	16287	4.14	0.726
BH3-200	IITRI	3	3D	59.6	1.498	0.2490	none	21.804	58.454	na	na	na	4.23	0.725
						Average	19.10	**21.18**	**57.04**	**-22,222**	**-19,314**	**17,612**	**4.21**	**0.713**
						Std. Dev.		1.08	2.80				0.06	0.023
						% COV		5.11	4.91				1.39	3.19
BH3-172	IITRI	4	4C	58.3	1.498	0.2974	32.90	34.065	76.481	-12396	-12539	2469	7.07	0.225
BH3-173	IITRI	4	4C	58.3	1.497	0.2968	28.90	33.727	75.909	-12226	-12313	2406	7.14	0.221
BH3-174	IITRI	4	4C	58.3	1.499	0.2982	29.30	34.515	77.206	-11437	-12881	2885	6.90	0.234
						Average	30.37	**34.10**	**76.53**	**-12,020**	**-12,578**	**2,587**	**7.04**	**0.226**
						Std. Dev.		0.40	0.65				0.12	0.007
						% COV		1.16	0.85				1.75	2.89

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Project #: BH0003

Comparison of Laminated Comp. to Braided Textiles for Boeing Helicopters

Temperature: RT

intec Engineer: Maryann Einarson
Boeing Engineer: Pierre Minguet

IITRI Transverse Compression Results

Specimen ID	Test Type	Mat. Class	Panel ID	Fiber Vol. (%)	Average Dim. (in) Width	Thickness	Load at Audible (kips)	Ultimate Load (kips)	Ultimate Stress (ksi)	Ult. Axial Strn #1 (με)	Ult. Axial Strn#2 (με)	Ultimate Trans. Strn (με)	Chord Ave. Axial Modulus (MPSI)	Poisson's Ratio
BH3-133	IITRI-T	1	1C	57.5	1.500	0.2474	none	18.613	50.176	-18137	-17984	3838	3.04	0.232
BH3-134	IITRI-T	1	1C	57.5	1.499	0.2496	none	16.872	45.112	-14689	-17507	3759	2.98	0.242
BH3-135	IITRI-T	1	1C	57.5	1.498	0.2477	none	17.972	48.444	-16199	-17699	3953	3.03	0.238
						Average		**17.82**	**47.91**	**-16,342**	**-17,730**	**3,850**	**3.02**	**0.237**
						Std. Dev.		0.88	2.57				0.03	0.005
						% COV		4.94	5.37				1.07	2.20
BH3-145	IITRI-T	2	2C	57.9	1.499	0.2489	20.80	21.866	58.607	-10144	-11437	1388	7.65	0.146
BH3-146	IITRI-T	2	2C	57.9	1.498	0.2476	26.30	27.947	75.383	-8868	-10035	1290	7.62	0.145
BH3-147	IITRI-T	2	2C	57.9	1.498	0.2474	24.00	25.694	69.333	-7645	-9715	1281	7.50	0.163
						Average	23.70	**25.17**	**67.77**	**-8,886**	**-10,396**	**1,320**	**7.59**	**0.151**
						Std. Dev.		3.07	8.50				0.08	0.010
						% COV		12.21	12.54				1.05	6.39
BH3-192	IITRI-T	3	3D	59.6	1.498	0.2484	none	17.744	47.697	-19194	na	11401	3.05	0.540
BH3-193	IITRI-T	3	3D	59.6	1.494	0.2497	17.50	17.998	48.257	na	-17402	na	3.06	0.518
BH3-194	IITRI-T	3	3D	59.6	1.498	0.2463	none	17.506	47.452	-19188	na	na	3.01	0.517
						Average	17.50	**17.75**	**47.80**	**-19,191**	**-17,402**	**11,401**	**3.04**	**0.525**
						Std. Dev.		0.25	0.41				0.03	0.013
						% COV		1.39	0.86				0.87	2.47
BH3-169	IITRI-T	4	4C	58.3	1.498	0.2989	29.60	31.792	71.004	-10442	-10473	2113	7.21	0.216
BH3-170	IITRI-T	4	4C	58.3	1.498	0.2985	none	31.630	70.756	-10107	-10651	2173	7.24	0.232
BH3-171	IITRI-T	4	4C	58.3	1.497	0.3000	29.80	32.468	72.284	-10059	-11142	2255	7.43	0.231
						Average	29.70	**31.96**	**71.35**	**-10,203**	**-10,755**	**2,180**	**7.29**	**0.227**
						Std. Dev.		0.44	0.82				0.12	0.009
						% COV		1.39	1.15				1.64	3.90

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Project #: BH0003

Comparison of Laminated Comp. to Braided Textiles for Boeing Helicopters

Temperature: RT

intec Engineer: Maryann Einarson

Boeing engineer: Pierre Minguet

Open Hole Compression Results (Modified IITRI)

Specimen ID	Test Type	Mat. Class	Cell #	Panel ID	Fiber Volume (%)	Average Dimensions (in) Width	Thickness	Hole Dia 1	Load at Audible *(kips)*	Ultimate Load *(kips)*	Gross Ult. Stress *(ksi)*	Failure Location/ Comments
BH3-139	OHC	1	7	1C	57.5	1.497	0.2503	0.1875	22.40	22.501	60.079	Failure through hole @ 45 ang
BH3-140	OHC	1	7	1C	57.5	1.496	0.2510	0.1875	21.40	23.142	61.647	Failure through hole @ 45 ang
BH3-141	OHC	1	7	1C	57.5	1.499	0.2494	0.1875	22.70	22.766	60.907	Failure through hole @ 45 ang
								Average	22.17	**22.80**	**60.88**	
								Std. Dev.		0.32	0.78	
								% COV		1.41	1.29	
BH3-151	OHC	2	20	2C	57.9	1.498	0.2495	0.1875	26.00	26.360	70.558	Failure through hole
BH3-152	OHC	2	20	2C	57.9	1.498	0.2501	0.1870	25.50	25.989	69.372	Failure through hole
BH3-153	OHC	2	20	2C	57.9	1.499	0.2482	0.1870	none	27.040	72.681	Failure through hole
								Average	25.75	**26.46**	**70.87**	
								Std. Dev.		0.53	1.68	
								% COV		2.01	2.37	
BH3-201	OHC	3	33	3D	59.6	1.498	0.2481	0.1895	15.60	15.925	42.855	Failure through hole
BH3-202	OHC	3	33	3D	59.6	1.500	0.2479	0.1885	15.30	15.587	41.937	Failure through hole
BH3-203	OHC	3	33	3D	59.6	1.496	0.2468	0.1885	15.40	15.488	41.952	Failure through hole
								Average	15.43	**15.67**	**42.25**	
								Std. Dev.		0.23	0.53	
								% COV		1.46	1.24	
BH3-175	OHC	4	46	4C	58.3	1.499	0.2996	0.1890	29.60	29.932	66.638	Failure through hole
BH3-176	OHC	4	46	4C	58.3	1.499	0.2971	0.1895	27.70	29.614	66.514	Failure through hole
BH3-177	OHC	4	46	4C	58.3	1.498	0.2986	0.1895	28.00	28.822	64.428	Failure through hole
								Average	28.43	**29.46**	**65.86**	
								Std. Dev.		0.57	1.24	
								% COV		1.94	1.89	

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Project #: BH0003

Comparison of Laminated Comp. to Braided Textiles for Boeing Helicopters

Temperature: RT

intec Engineer: Maryann Einarson
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Open Hole Transverse Compression Results (Modified IITRI)

Specimen ID	Test Type	Mat. Class	Cell #	Panel ID	Fiber Volume (%)	Average Dimensions (in) Width	Thickness	Hole Dia 1	Load at Audible *(kips)*	Ultimate Load *(kips)*	Gross Ult. Stress *(ksi)*	Failure Location/ Comments
BH3-130	OHC-T	1	8	1C	57.5	1.499	0.2482	0.1895	13.02	13.664	36.730	Failure through hole
BH3-131	OHC-T	1	8	1C	57.5	1.498	0.2465	0.1870	15.30	15.893	43.061	Failure through hole
BH3-132	OHC-T	1	8	1C	57.5	1.499	0.2499	0.1870	14.90	15.173	40.513	Failure through hole
								Average	14.41	**14.91**	**40.10**	
								Std. Dev.		1.14	3.19	
								% COV		7.63	7.94	
BH3-142	OHC-T	2	21	2C	57.9	1.500	0.2475	0.1870	19.80	21.378	57.603	Failure through hole
BH3-143	OHC-T	2	21	2C	57.9	1.498	0.2525	0.1870	20.80	21.841	57.746	Failure through hole
BH3-144	OHC-T	2	21	2C	57.9	1.497	0.2486	0.1870	20.80	21.866	58.738	Failure through hole
								Average	20.47	**21.70**	**58.03**	
								Std. Dev.		0.27	0.62	
								% COV		1.27	1.07	
BH3-195	OHC-T	3	34	3D	59.6	1.500	0.2447	0.1885	none	15.807	43.069	Failure through hole
BH3-196	OHC-T	3	34	3D	59.6	1.499	0.2453	0.1885	none	15.868	43.174	Failure through hole
BH3-197	OHC-T	3	34	3D	59.6	1.499	0.2387	0.1890	none	15.750	44.038	Failure through hole
								Average		**15.81**	**43.43**	
								Std. Dev.		0.06	0.53	
								% COV		0.37	1.23	
BH3-166	OHC-T	4	47	4C	58.3	1.498	0.2985	0.1895	23.60	25.971	58.087	Failure through hole
BH3-167	OHC-T	4	47	4C	58.3	1.498	0.2959	0.1895	24.40	24.754	55.867	Failure through hole
BH3-168	OHC-T	4	47	4C	58.3	1.496	0.2990	0.1890	23.00	24.916	55.700	Failure through hole
								Average	23.67	**25.21**	**56.55**	
								Std. Dev.		0.66	1.33	
								% COV		2.62	2.36	

intec

Project #: BH0003

Comparison of Laminated Composites to Braided Textiles for Boeing Helicopters

Temperature: RT
intec engineer: Maryann Einarson
Boeing engineer: Pierre Minguet

Rail Shear Results

Specimen ID	Test Type	Mat. Class	Panel ID	Fiber Vol. (%)	Average Dimensions Width	Thickness	Load at Audible *(kips)*	Ultimate Load *(kips)*	Ultimate Stress *(ksi)*	Ultimate +45° Strn *(με)*	Ultimate -45° Strn *(με)*	Ultimate 90° Strn *(με)*	Chord Ax. SG Modulus *(MPSI)*	Failure mode
BH3-082	RS	1	1B	66.9	3.005	0.1057	11.14	11.510	36.232	5950	-6530	672	3.05	bearing
BH3-083	RS	1	1B	66.9	3.023	0.1063	12.18	12.340	38.419	5973	-6998	923	3.00	bearing
BH3-084	RS	1	1B	66.9	3.015	0.1051	13.20	13.305	42.008	6494	-6966	750	3.22	bearing
						Average	**12.17**	**12.38**	**38.89**	**6139**	**-6831**	**782**	**3.09**	
						Std. Dev.		0.90	2.92				0.12	
						% COV		7.25	7.50				3.73	
BH3-094	RS	2	2B	66.0	3.013	0.1076	12.66	12.770	39.396	12275	-13322	-302	1.80	shear
BH3-095	RS	2	2B	66.0	3.004	0.1086	12.18	12.236	37.502	11854	-12363	-12	1.77	shear
BH3-096	RS	2	2B	66.0	3.002	0.1083		13.434	41.321	13412	-14739	-354	1.99	shear
						Average	**12.42**	**12.81**	**39.41**	**12514**	**-13475**	**-223**	**1.85**	
						Std. Dev.		0.60	1.91				0.12	
						% COV		4.68	4.85				6.44	
BH3-106	RS	3	3B	66.2	3.012	0.1113	13.30	13.916	41.537	5050	-5408	na	4.37	bearing
BH3-107	RS	3	3B	66.2	3.014	0.1114	11.40	12.900	38.438	4239	-4726	1548	4.53	bearing
BH3-108	RS	3	3B	66.2	3.003	0.1103	12.50	13.748	41.500	4379	-4960	na	4.67	bearing
						Average	**12.40**	**13.52**	**40.49**	**4556**	**-5031**	**1548**	**4.52**	
						Std. Dev.		0.54	1.78				0.15	
						% COV		4.03	4.39				3.32	
BH3-118	RS	4	4B	66.4	2.996	0.1250	11.70	12.632	33.749	7219	-7708	324	2.33	bearing
BH3-119	RS	4	4B	66.4	2.985	0.1285	13.80	13.868	36.159	7960	-8303	84	2.39	bearing
BH3-120	RS	4	4B	66.4	3.006	0.1247	11.40	13.306	35.497	7729	-8165	744	2.39	bearing
						Average	**12.30**	**13.27**	**35.14**	**7636**	**-8059**	**384**	**2.37**	
						Std. Dev.		0.62	1.24				0.03	
						% COV		4.66	3.54				1.46	

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Project #: BH0003

Comparison of Laminated Composites to Braided Textiles for Boeing Helicopters

Temperature: RT
intec engineer: Maryann Einarson
Boeing engineer: Pierre Minguet

Double Shear Bearing Results

Specimen ID	Test Type	Mat. Class	Panel ID	Fiber Volume (%)	Average Dimensions Width	Thickness	Hole Dia 1	Edge Dist 1	Load at Audible (kips)	Failure Load Limit (kips)	Ult (kips)	Bearing Stress Limit (ksi)	Ultimate (ksi)	Failure Mode/ Comments
BH3-016	DSB	1	1A	66.3	1.503	0.1066	0.2505	0.6285	3.90	3.668	4.361	137.59	163.59	Shear out
BH3-017	DSB	1	1A	66.3	1.502	0.1078	0.2505	0.6295	3.65	3.667	4.079	136.07	151.35	Shear out
BH3-018	DSB	1	1A	66.3	1.500	0.1090	0.2505	0.6265	3.35	4.008	4.372	147.04	160.39	Shear out
								Average	**3.63**	**3.781**	**4.271**	**140.23**	**158.44**	
								Std. Dev.	0.28	0.20	0.17	5.94	6.35	
								% COV	7.58	5.20	3.89	4.24	4.00	
BH3-034	DSB	2	2A	65.7	1.501	0.1081	0.2510	0.6200	3.65	3.362	4.612	124.40	170.66	Shear out
BH3-035	DSB	2	2A	65.7	1.501	0.1077	0.2515	0.6245	3.90	3.955	4.470	146.93	166.07	Shear out
BH3-036	DSB	2	2A	65.7	1.501	0.1065	0.2510	0.6260	3.80	3.874	4.628	145.46	173.77	Shear out
								Average	**3.78**	**3.730**	**4.570**	**138.93**	**170.16**	
								Std. Dev.	0.13	0.32	0.09	12.60	3.87	
								% COV	3.33	8.62	1.90	9.07	2.28	
BH3-052	DSB	3	3A	65.8	1.502	0.1134	0.2510	0.6300	3.30	3.912	4.661	137.95	164.36	Bearing
BH3-053	DSB	3	3A	65.8	1.502	0.1134	0.2510	0.6295	3.20	3.825	4.567	134.88	161.05	Bearing
BH3-054	DSB	3	3A	65.8	1.500	0.1125	0.2510	0.6295	3.15	3.487	4.234	124.02	150.59	Bearing
								Average	**3.22**	**3.741**	**4.487**	**132.28**	**158.66**	
								Std. Dev.	0.08	0.22	0.22	7.32	7.19	
								% COV	2.37	6.00	5.00	5.53	4.53	
BH3-070	DSB	4	4A	64.3	1.500	0.1288	0.2510	0.6280	4.30	4.427	5.719	137.45	177.56	Bearing
BH3-071	DSB	4	4A	64.3	1.501	0.1288	0.2510	0.6295	4.30	4.667	5.647	144.98	175.42	Bearing
BH3-072	DSB	4	4A	64.3	1.502	0.1269	0.2510	0.6310	3.55	4.299	5.258	135.54	165.78	Bearing
								Average	**4.05**	**4.464**	**5.541**	**139.32**	**172.92**	
								Std. Dev.	0.43	0.19	0.25	4.99	6.28	
								% COV	10.69	4.18	4.48	3.58	3.63	

Notes: Bearing stress calculated from: Load/actual thickness/nominal hole diameter
Hole 1: First specimen, fastener head side. Hole 2: First specimen, Hilok side. Hole 3: Second specimen, Hilok side. Hole 4: Second specimen, fastener heac
Limit load and stress represent 2% hole diameter offset or load at first zero slope, whichever occurred first.

Intec

Project #: BH0003

Comparison of Laminated Composites to Braided Textiles for Boeing Helicopters

Temperature: RT
intec engineer: Maryann Einarson
Boeing engineer: Pierre Minguet

Stabilized Single Shear Bearing Results

Specimen ID	Test Type	Mat. Class	Panel ID	Fiber Vol. (%)	Average Dimensions: Width	Thickness	Hole Dia 1	Hole Dia 2	Edge Dist 1	Edge Dist 2	Load at Audible *(kips)*	Failure Load: Limit *(kips)*	Ult *(kips)*	Bearing Stress: Limit *(ksi)*	Ultimate *(ksi)*	Failure Mode/ Comments
BH3-010	SSSB	1	1A	66.3	1.501	0.1089	0.2510	0.2510	0.6310	0.6300	6.25	5.855	6.917	107.53	127.03	Bearing hole 1&4
BH3-011	SSSB	1	1A	66.3	1.501	0.1064	0.2510	0.2505	0.6310	0.6310	6.25	5.855	6.917	110.09	130.06	
BH3-012	SSSB	1	1A	66.3	1.502	0.1088	0.2510	0.2510	0.6320	0.6310	6.35	6.176	6.989	113.56	128.51	Bearing hole 1&4
BH3-013	SSSB	1	1A	66.3	1.501	0.1093	0.2510	0.2505	0.6310	0.6310	6.35	6.176	6.989	113.04	127.93	
BH3-014	SSSB	1	1A	66.3	1.501	0.1063	0.2510	0.2510	0.6310	0.6315	7.00	6.761	7.455	127.25	140.31	Bearing holes 1&4
BH3-015	SSSB	1	1A	66.3	1.501	0.1072	0.2505	0.2510	0.6270	0.6300	7.00	6.761	7.455	126.14	139.09	
										Average	**6.53**	**6.264**	**7.120**	**116.11**	**131.95**	
										Std. Dev.		0.46	0.29	10.10	7.27	
										% COV		7.33	4.10	8.70	5.51	
BH3-028	SSSB	2	2A	65.7	1.502	0.1068	0.2515	0.2510	0.6250	0.6260	5.50	5.930	7.211	111.01	135.00	Bearing holes 1&4
BH3-029	SSSB	2	2A	65.7	1.501	0.1066	0.2510	0.2515	0.6235	0.6250	5.50	5.930	7.211	111.28	135.33	
BH3-030	SSSB	2	2A	65.7	1.501	0.1079	0.2510	0.2510	0.6240	0.6210	5.10	5.161	7.384	95.69	136.91	Bearing holes 1&4
BH3-031	SSSB	2	2A	65.7	1.502	0.1066	0.2505	0.2510	0.6235	0.6250	5.10	5.161	7.384	96.80	138.49	
BH3-032	SSSB	2	2A	65.7	1.501	0.1058	0.2500	0.2510	0.6240	0.6255	6.10	6.293	7.295	118.92	137.86	Bearing holes 1&4
BH3-033	SSSB	2	2A	65.7	1.502	0.1072	0.2505	0.2510	0.6250	0.6270	6.10	6.293	7.295	117.41	136.10	
										Average	**5.57**	**5.795**	**7.297**	**108.54**	**136.59**	
										Std. Dev.		0.58	0.09	11.81	1.46	
										% COV		9.97	1.19	10.88	1.07	
BH3-046	SSSB	3	3A	65.8	1.504	0.1103	0.2510	0.2510	0.6305	0.6315	4.10	6.500	7.191	117.84	130.37	Bearing holes 1&4
BH3-047	SSSB	3	3A	65.8	1.503	0.1116	0.2505	0.2510	0.6305	0.6310	4.10	6.500	7.191	116.47	128.85	
BH3-048	SSSB	3	3A	65.8	1.502	0.1136	0.2510	0.2505	0.6315	0.6300	4.30	5.537	7.478	97.52	131.71	Bearing holes 1&4
BH3-049	SSSB	3	3A	65.8	1.503	0.1109	0.2510	0.2510	0.6320	0.6340	4.30	5.537	7.478	99.85	134.86	(Partial bearing hole 3)
BH3-050	SSSB	3	3A	65.8	1.503	0.1126	0.2510	0.2515	0.6315	0.6345	5.00	6.282	7.313	111.60	129.91	Bearing holes 1&4
BH3-051	SSSB	3	3A	65.8	1.503	0.1130	0.2510	0.2505	0.6320	0.6315	5.00	6.282	7.313	111.15	129.40	
										Average	**4.47**	**6.106**	**7.327**	**108.99**	**130.67**	
										Std. Dev.		0.51	0.14	10.41	0.94	
										% COV		8.27	1.97	9.55	0.72	

Notes: Bearing stress calculated from: Load/actual thickness/nominal hole diameter
Hole 1: First specimen, fastener head side. Hole 2: First specimen, Hilok side. Hole 3: Second specimen, Hilok side. Hole 4: Second specimen, fastener head side.
Limit load and stress represent 2% hole diameter offset or load at first zero slope, whichever occurred first.

Intec

Project #: BH0003

Comparison of Laminated Composites to Braided Textiles for Boeing Helicopters

Temperature: RT
intec engineer: Maryann Einarson
Boeing engineer: Pierre Minguet

Stabilized Single Shear Bearing Results

Specimen ID	Test Type	Mat. Class	Panel ID	Fiber Vol. (%)	Average Dimensions						Load at Audible (kips)	Failure Load		Bearing Stress		Failure Mode/ Comments
					Width	Thickness	Hole Dia 1	Hole Dia 2	Edge Dist 1	Edge Dist 2		Limit (kips)	Ult (kips)	Limit (ksi)	Ultimate (ksi)	
BH3-064	SSSB	4	4A	64.3	1.503	0.1251	0.2515	0.2510	0.6320	0.6330	6.90	6.938	8.594	110.92	137.39	Bearing holes 1&4
BH3-065	SSSB	4	4A	64.3	1.502	0.1275	0.2510	0.2505	0.6320	0.6330	6.90	6.938	8.594	108.82	134.79	
BH3-066	SSSB	4	4A	64.3	1.501	0.1281	0.2510	0.2500	0.6315	0.6325	6.50	7.020	8.254	109.59	128.85	Bearing holes 1&4
BH3-067	SSSB	4	4A	64.3	1.503	0.1229	0.2515	0.2515	0.6300	0.6310	6.50	7.020	8.254	114.28	134.36	
BH3-068	SSSB	4	4A	64.3	1.502	0.1258	0.2515	0.2515	0.6300	0.6310	6.75	6.931	8.208	110.23	130.54	Bearing holes 1&4
BH3-069	SSSB	4	4A	64.3	1.500	0.1276	0.2500	0.2515	0.6335	0.6320	6.75	6.931	8.208	108.65	128.67	
										Average	**6.72**	**6.963**	**8.352**	**110.25**	**132.26**	
										Std. Dev.		0.05	0.21	0.66	4.52	
										% COV		0.71	2.52	0.60	3.42	

Notes: Bearing stress calculated from: Load/actual thickness/nominal hole diameter
Hole 1: First specimen, fastener head side. Hole 2: First specimen, Hilok side. Hole 3: Second specimen, Hilok side. Hole 4: Second specimen, fastener head side.
Limit load and stress represent 2% hole diameter offset or load at first zero slope, whichever occurred first.

Appendix B Typical Stress-Strain Curves

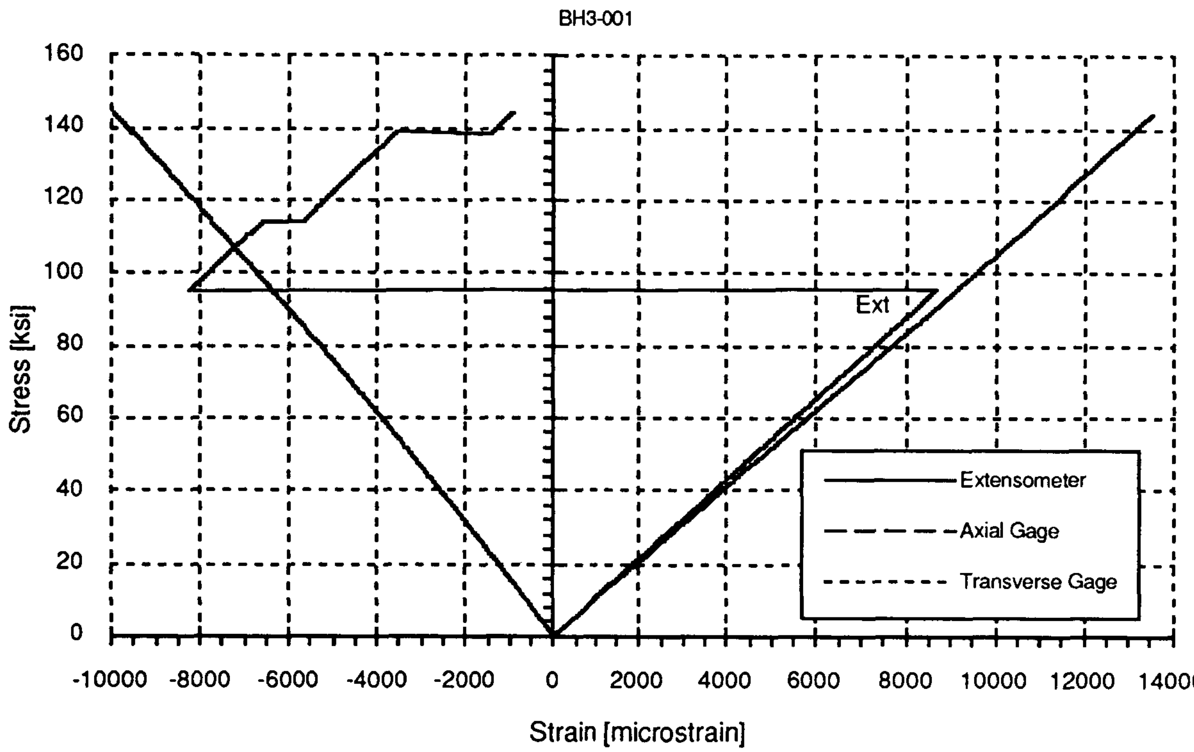

Figure B.1 Typical Longitudinal Tension Test Strain Data for Laminate L1.

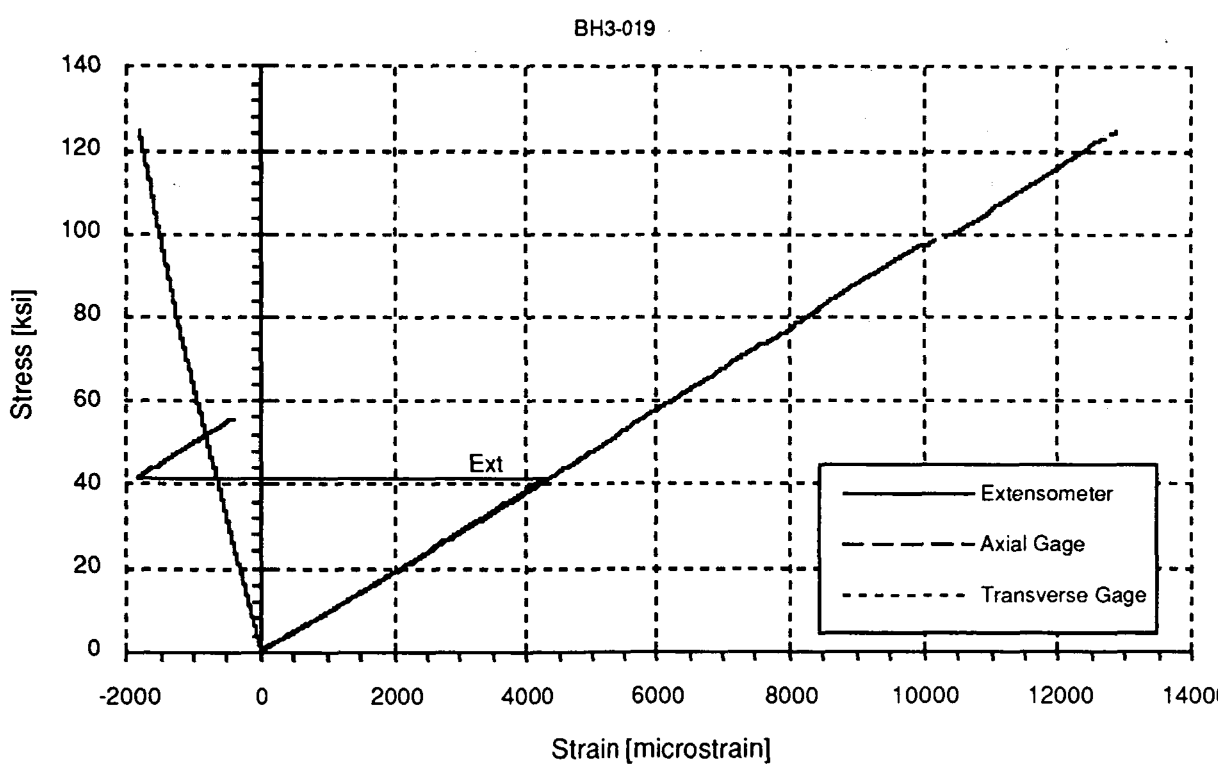

Figure B.2 Typical Longitudinal Tension Test Strain Data for Laminate L2.

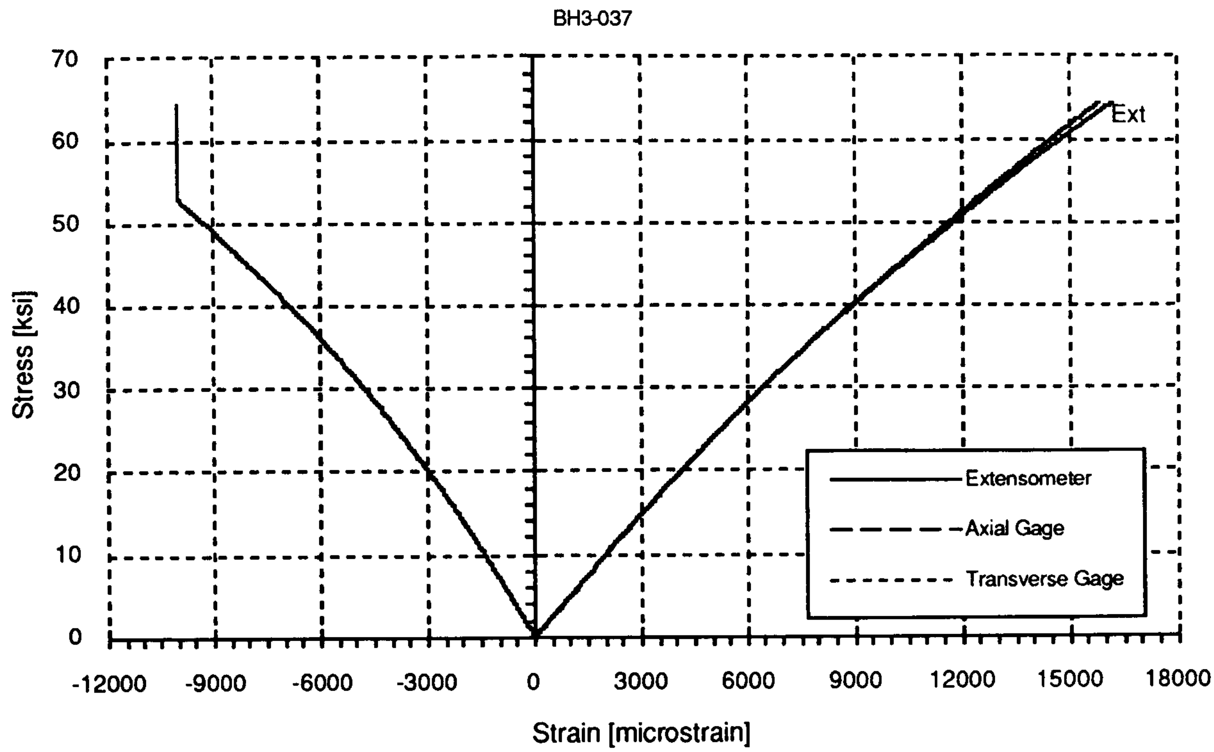

Figure B.3 Typical Longitudinal Tension Test Strain Data for Laminate L3.

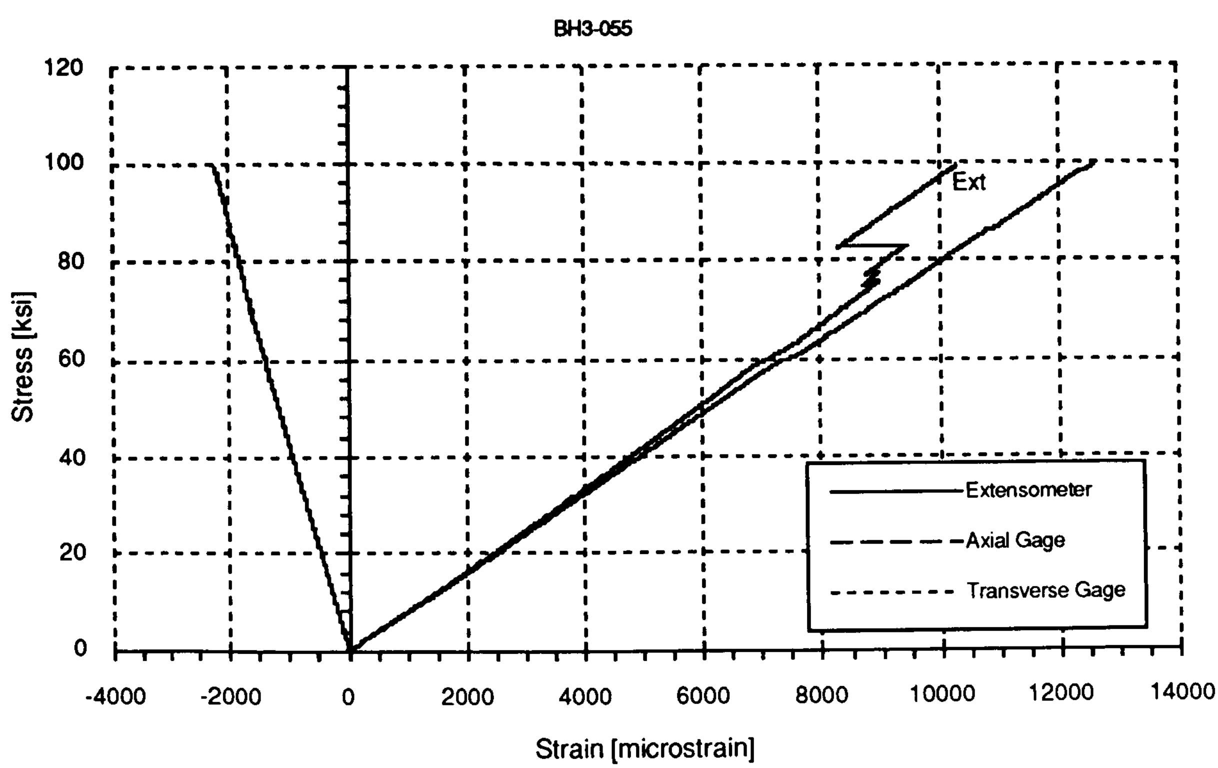

Figure B.4 Typical Longitudinal Tension Test Strain Data for Laminate L4.

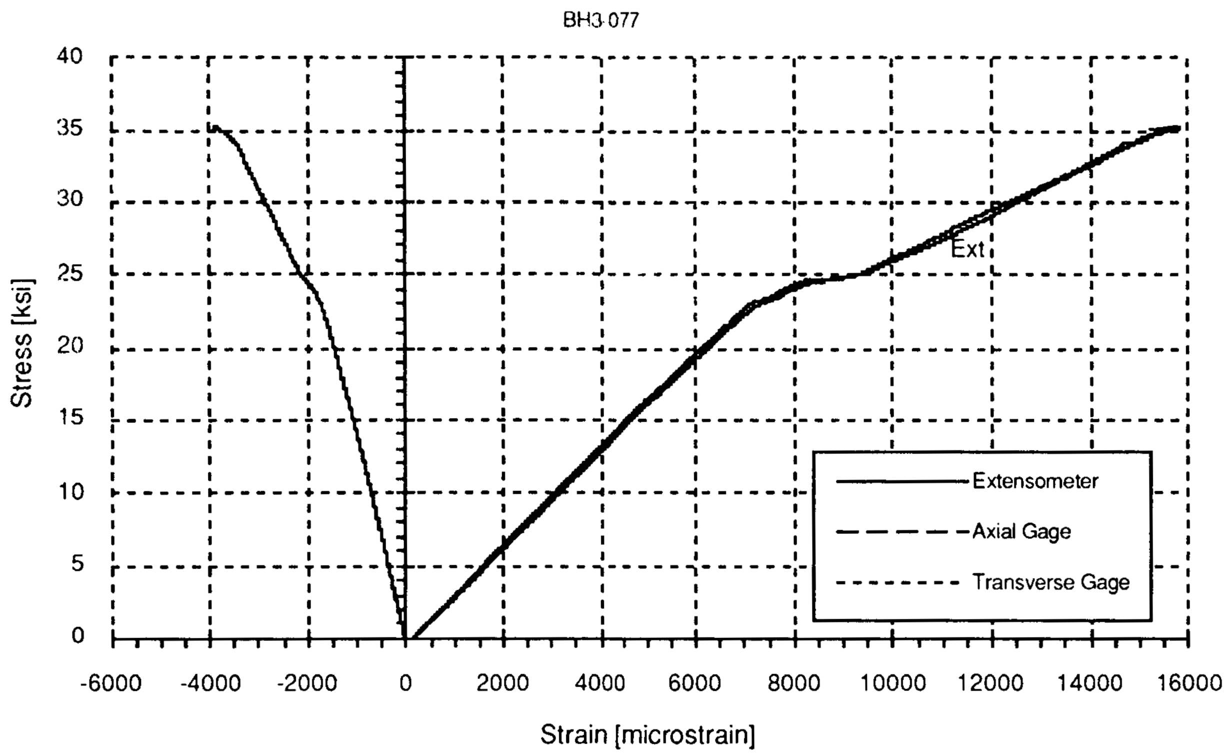

Figure B.5 Typical Transverse Tension Test Strain Data for Laminate L1.

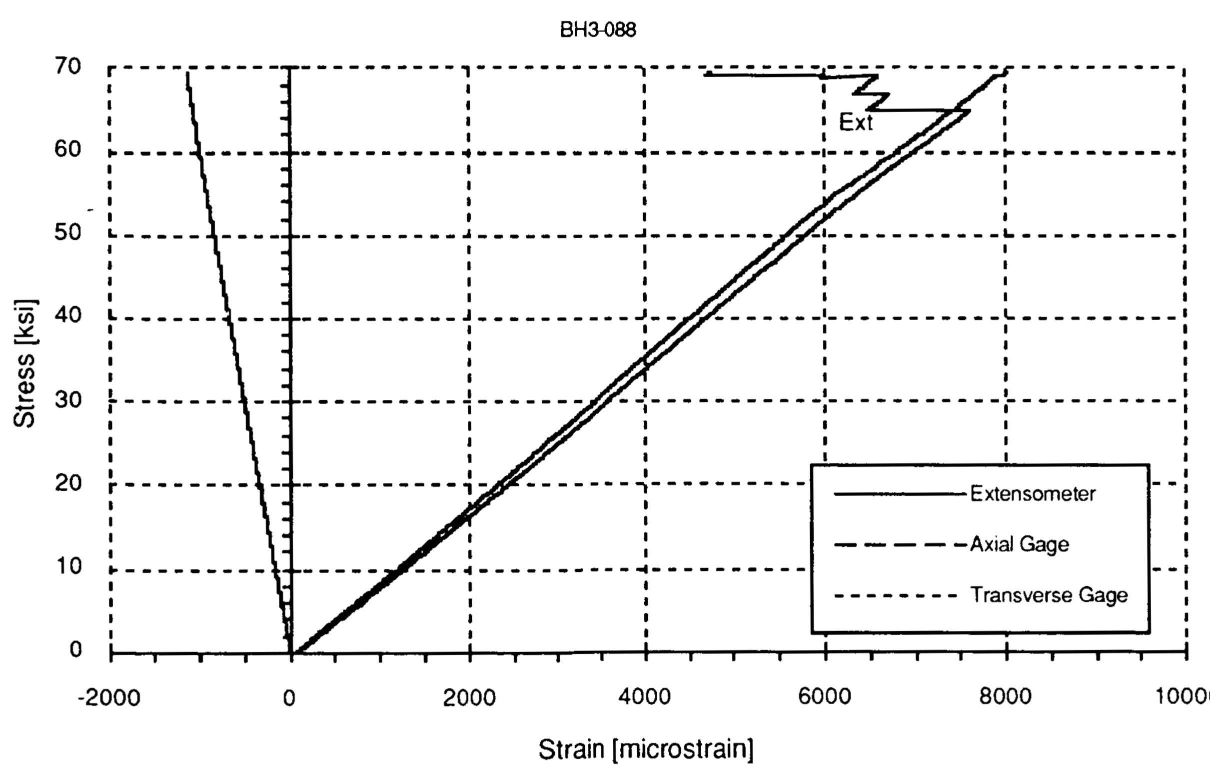

Figure B.6 Typical Transverse Tension Test Strain Data for Laminate L2.

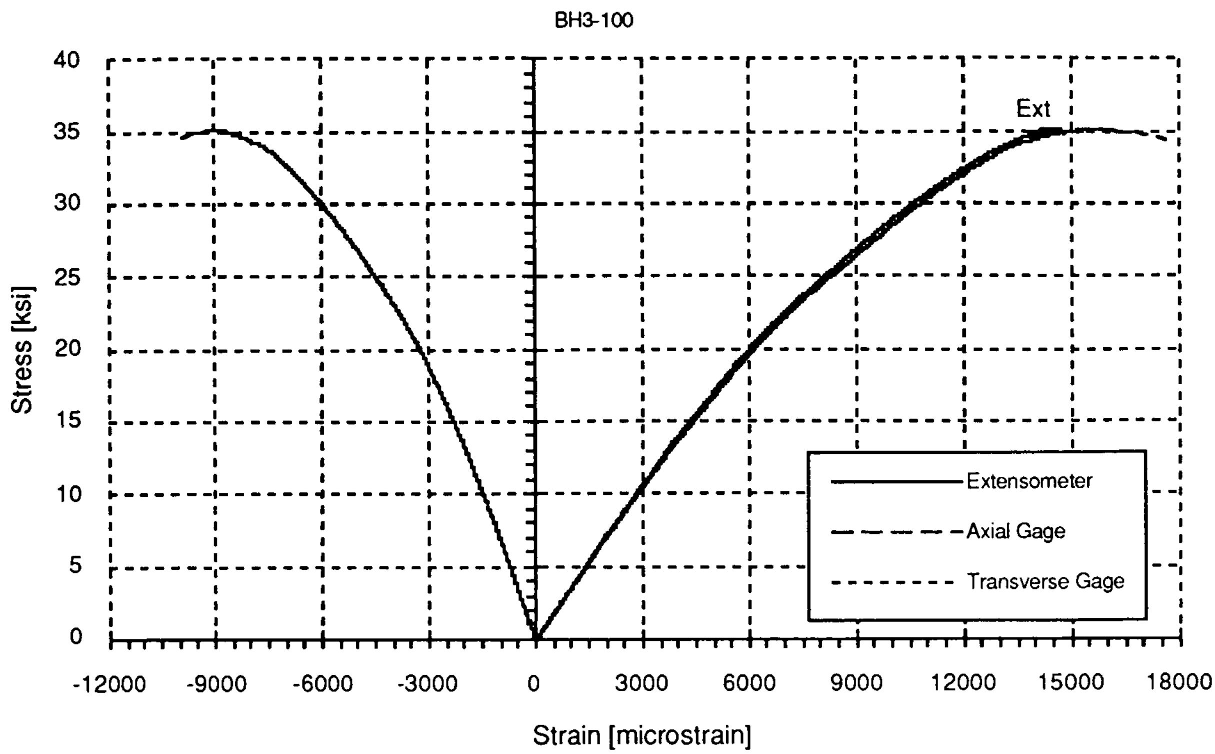

Figure B.7 Typical Transverse Tension Test Strain Data for Laminate L3.

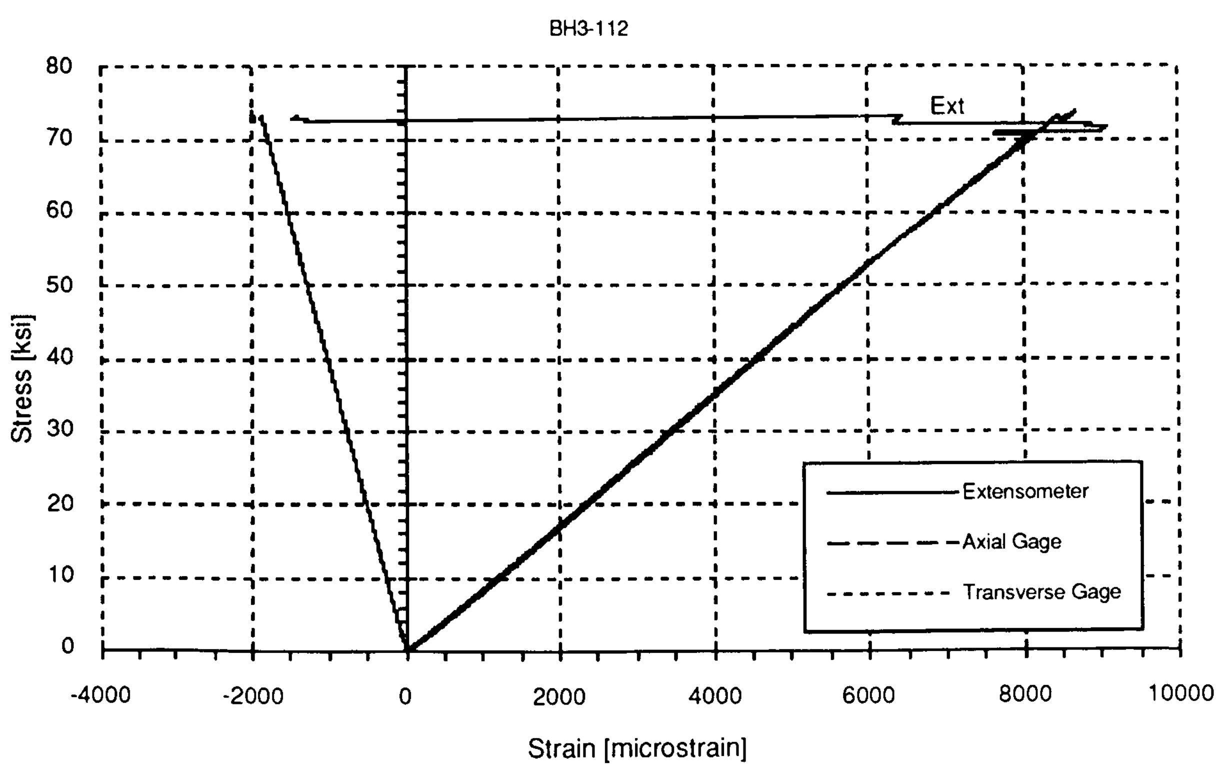

Figure B.8 Typical Transverse Tension Test Strain Data for Laminate L4.

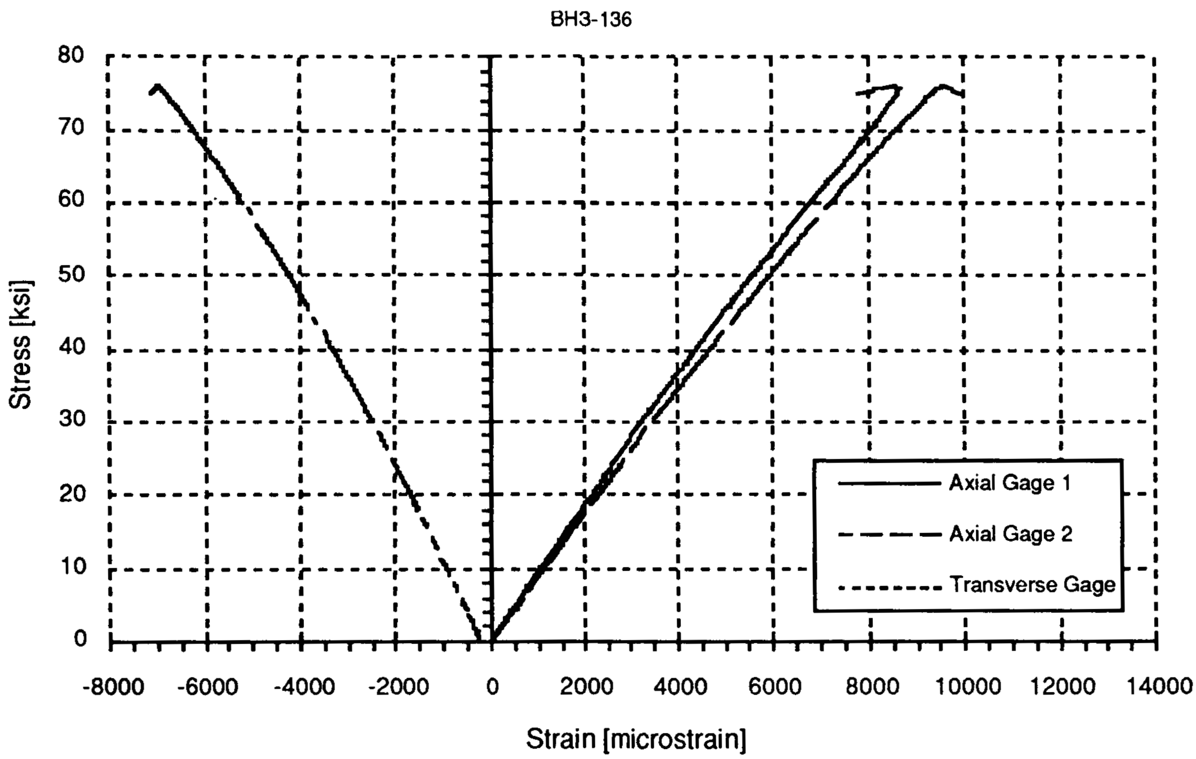

Figure B.9 Typical Longitudinal Compression Test Strain Data for Laminate L1.

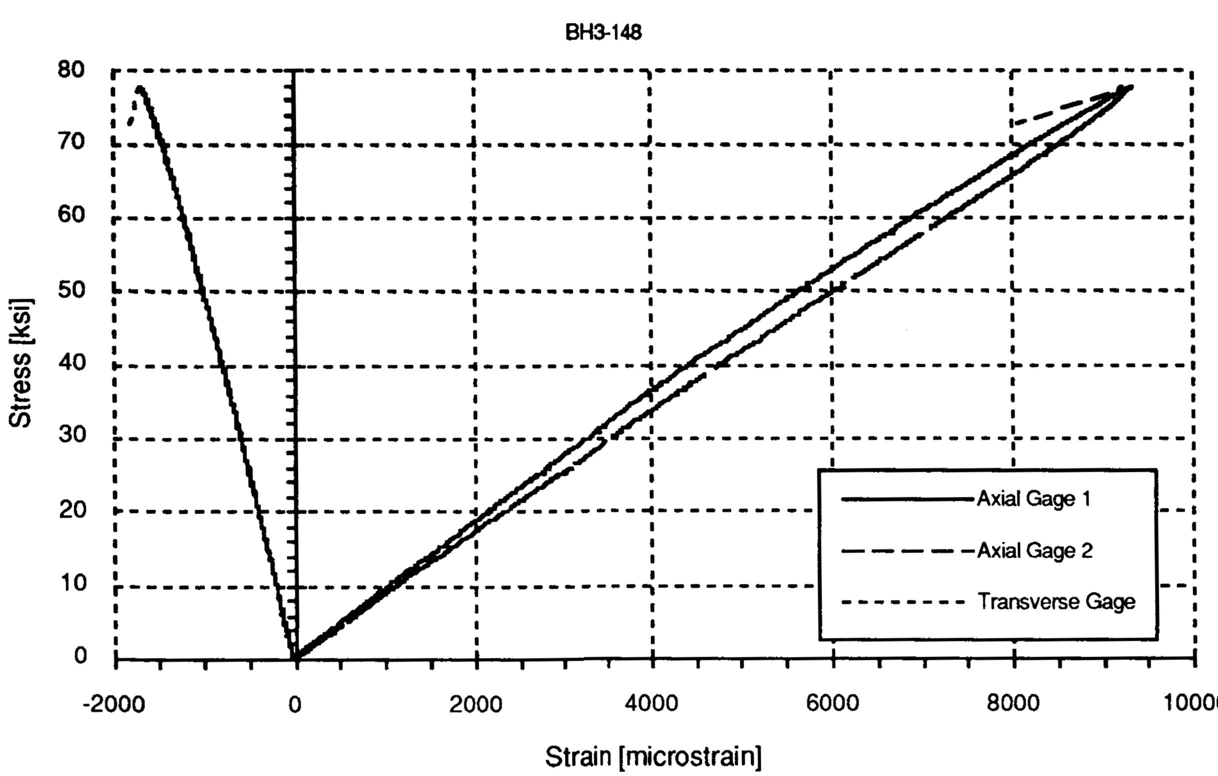

Figure B.10 Typical Longitudinal Compression Test Strain Data for Laminate L2.

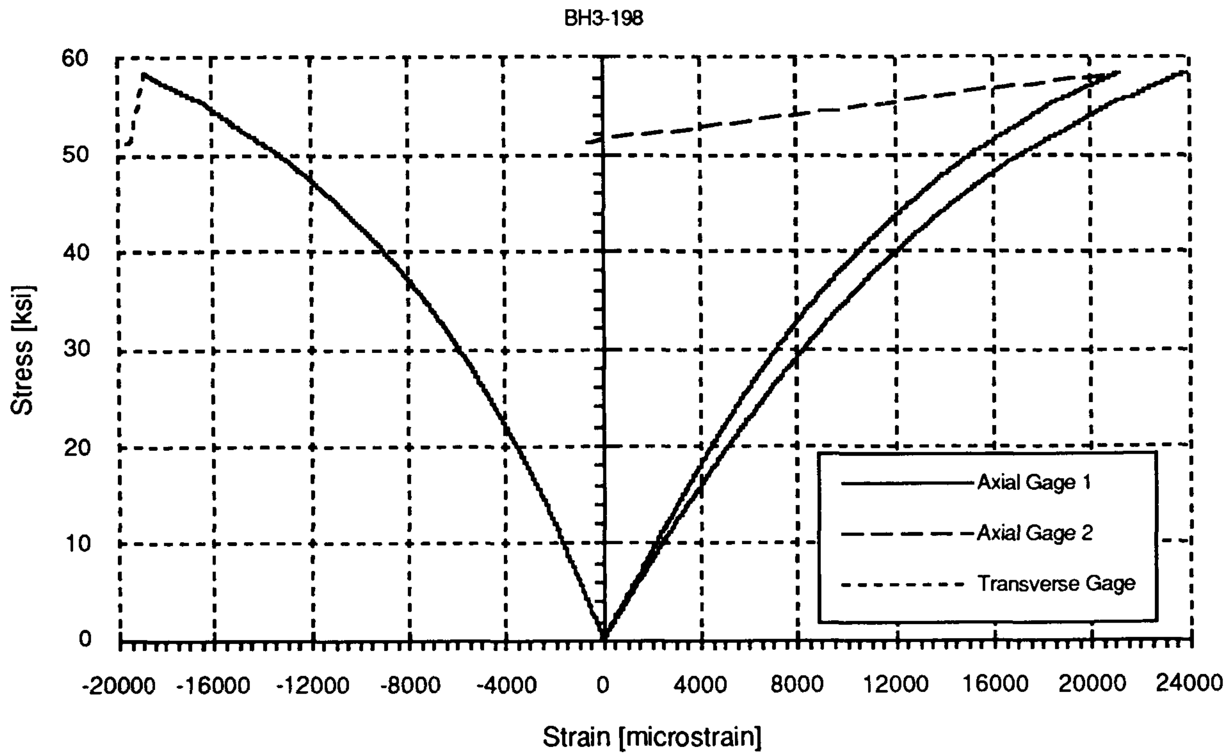

Figure B.11 Typical Longitudinal Compression Test Strain Data for Laminate L3.

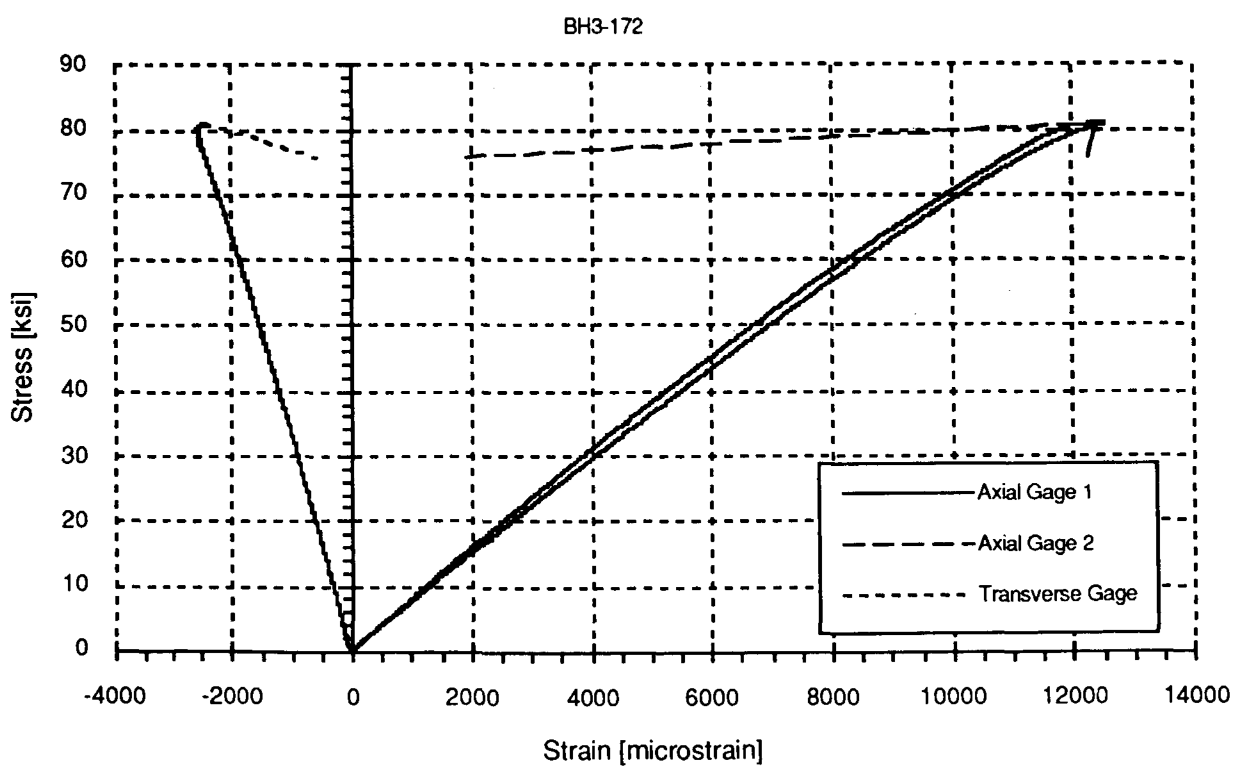

Figure B.12 Typical Longitudinal Compression Test Strain Data for Laminate L4.

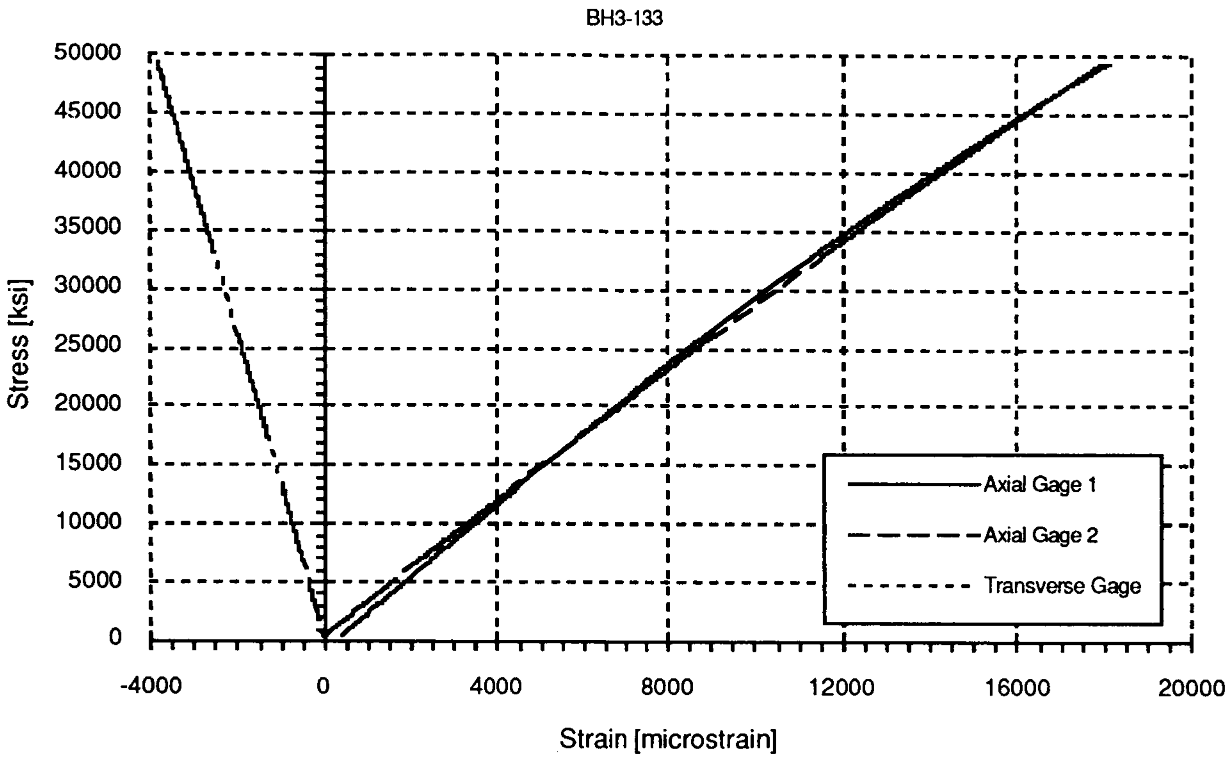

Figure B.13 Typical Transverse Compression Test Strain Data for Laminate L1.

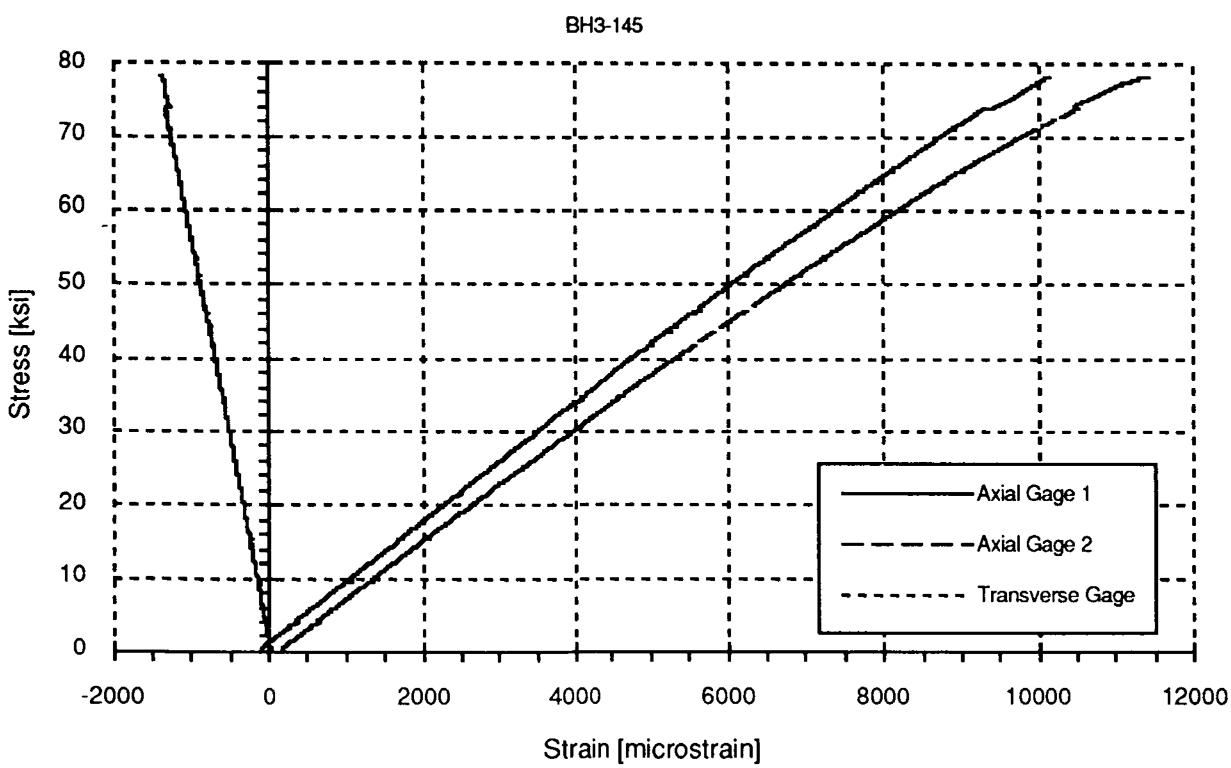

Figure B.14 Typical Transverse Compression Test Strain Data for Laminate L2.

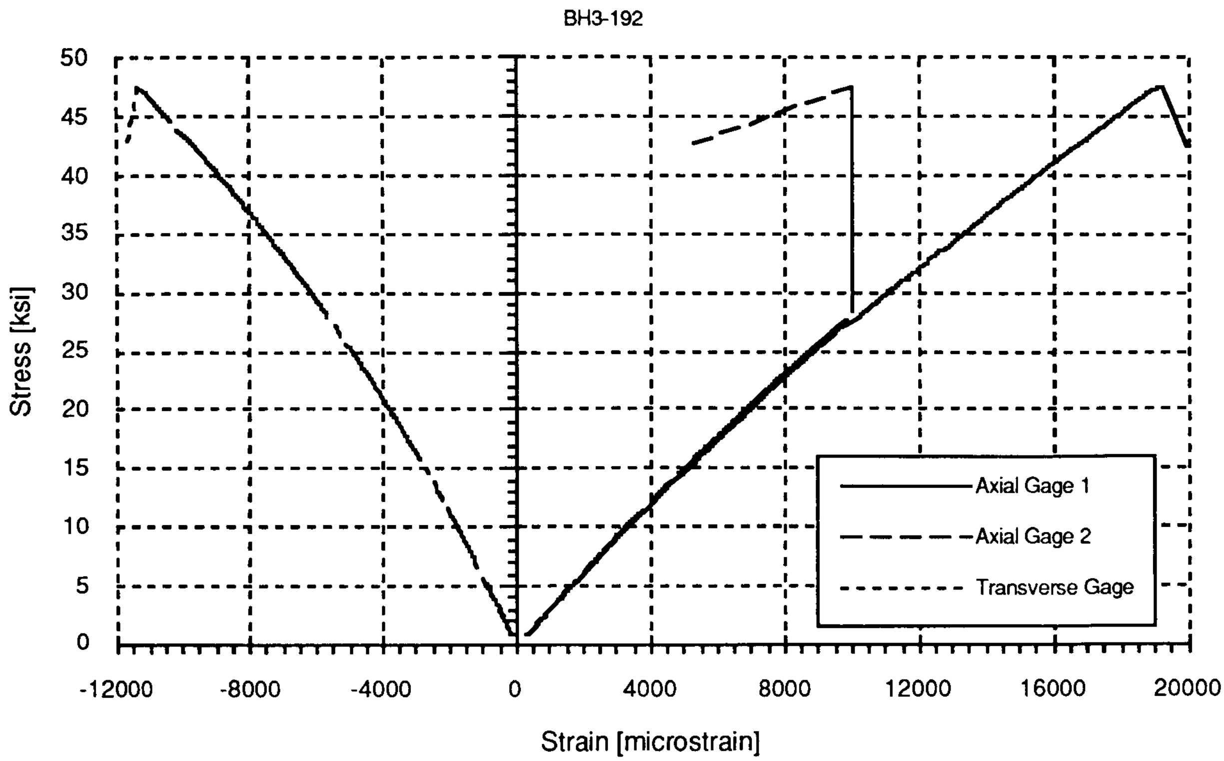

Figure B.15 Typical Transverse Compression Test Strain Data for Laminate L3.

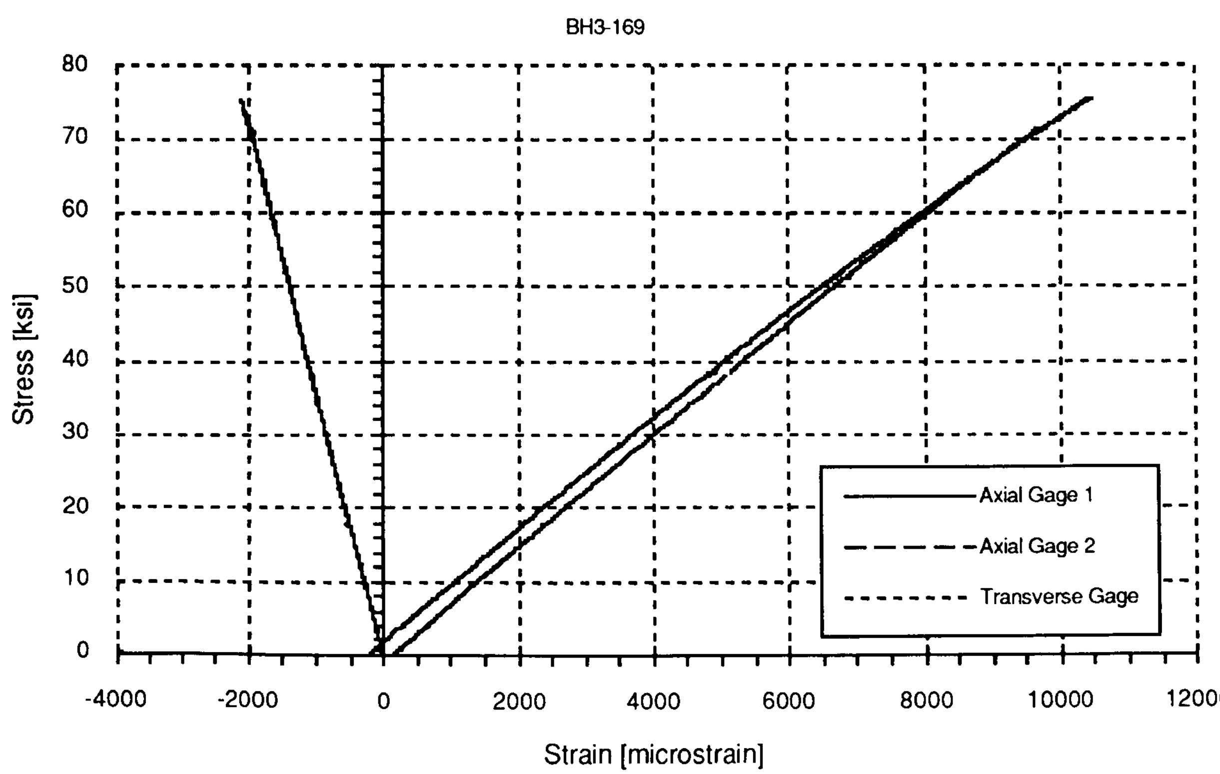

Figure B.16 Typical Transverse Compression Test Strain Data for Laminate L4.

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13. ABSTRACT (*Maximum 200 words*)

A comparison of the in-plane mechanical properties of unidirectional composite tape laminates and of 2-dimensional triaxially braided composite was conducted. The tape laminate layups were designed to match the percentage of axial fibers and the angle of the bias tows in the braided composite. The material system used for the laminates is AS4/3501-6 which was chosen as the closest available match to AS4/1895 used for the braids. This report documents the results of the testing of the laminates and compares these results with data previously obtained for the braided composite. The strength and stiffness properties measured here include tension, open-hole tension, filled-hole tension, compression and open-hole compression, all of these in both the longitudinal and transverse direction, in-plane shear and bearing.

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