Advanced General Aviation Transport Experiments

B – Basis Design Allowables for Epoxy – Based Prepreg

3M E-Glass Fabric
7781 / SP381

AGATE-WP3.3-033051-098

September 2001

J. Tomblin, J. McKenna, Y. Ng, K. S. Raju
National Institute for Aviation Research
Wichita State University
Wichita, KS 67260-0093

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Scope

The Advanced General Aviation Transport Experiments (AGATE) consortium is an industry-university-government partnership initiated by NASA to create the technological basis for revitalization of the United States general aviation industry.   It was founded in 1994 to develop affordable new technology as well as the industrial standards and certification methods for composite airframe, cockpit, flight systems and airspace infrastructure for Federal Aviation Regulations (FAR) Part 23 aircraft. The composite material properties contained within the document were generated under Work Package 3 : Integrated Design and Manufacturing Methods.

Although AGATE was focused towards the small general aviation aircraft (Part 23), the test methods and results contained in this document are consistent with MIL-HDBK-17-1E,2D,3E - Military Handbook for Polymer Matrix Composites. All material, specimens, fixtures and test results contained within this document were traceable and conformed by the Federal Aviation Administration (FAA) as part of the AGATE effort. It should be noted that before application of the basis values presented in this document to design, demonstration of the ability to consistently produce equivalent material properties as that evaluated during this program should be substantiated through an acceptable test program.

The test methods and results described in this document are intended to provide basic composite properties essential to most methods of analysis. These properties are considered to provide the initial base of the "building block" approach. Additional coupon level tests and subelement tests may be required to fully substantiate the full-scale design.

1.2 Symbols Used

ν_{12}^{tu}	major Poisson's ratio, tension
$\mu\varepsilon$	micro-strain
E^c	compressive modulus, laminate
E^t	tensile modulus, laminate
F_{12}^{su}	in – plane shear strength
F_{13}^{su}	apparent interlaminar shear strength
F^{cu}	compressive strength, laminate
F^{tu}	tensile strength, laminate
G_{12}^{s}	in – plane shear modulus

Superscripts

c	compression
cu	compression ultimate
s	shear
su	shear ultimate
t	tension
tu	tension ultimate

Subscripts

12	in – plane shear
13	interlaminar shear (apparent)

1.3 Acronyms and Definitions

A – Basis	95% lower confidence limit on the first population percentile
AGATE	Advanced General Aviation Transport Experiments
ASTM	American Society for Testing and Materials
B – Basis	95% lower confidence limit on the tenth population percentile
C. V.	coefficient of variation
CTD	cold temperature dry
CPT	cured ply thickness
DMA	dynamic mechanical analysis
dry	specimen tested with an "as fabricated" moisture content
ETD	elevated temperature dry
ETW	elevated temperature wet
FAR	Federal Aviation Regulations
FAW	fiber areal weight
Gl/Ep	Glass-Epoxy
NASA	National Aeronautics and Space Administration
RTD	room temperature dry
SACMA	Suppliers of Advanced Composite Materials Association
SRM	SACMA Recommended Method
T_g	glass transition temperature
t_{ply}	cured ply thickness
wet	specimen tested with an equilibrium moisture content per section 1.5.2

1.4 References

ASTM Standards

D3039-95	Tensile Properties of Polymer Matrix Composite Materials
D5379-93	Shear Properties of Composite Materials by the V-Notched Beam Method
D2344-89	Apparent Interlaminar Shear Strength of Parallel Fiber Composites by Short – Beam Method
D792-91	Density and Specific Gravity (Relative Density) of Plastics by Displacement
D2584-94	Ignition Loss of Cured Reinforced Plastics
D2734-94	Void Content of Reinforced Plastics
D695-91	Compressive Properties of Rigid Plastics

SACMA Standards

SRM 1-94	Compressive Properties of Oriented Fiber-Resin Composites
SRM 8-94	Short Beam Shear Strength of Oriented Fiber-Resin Composites
SRM 18-94	Glass Transition Temperature (T_g) Determination by DMA of Oriented Fiber-Resin Composites

Other Documents

FAA Document DOT/FAA/AR-00/47: Material Qualification and Equivalency for Polymer Matrix Composite Material Systems, J.S. Tomblin, Y.C. Ng and K.S. Raju, 2001.

MIL-HDBK-17 1E, 2D, 3E – Military Handbook for Polymer Matrix Composites

Cirrus Design Corporation: Material Properties Test Plan, February 1997.

1.5 Methodology

1.5.1 Test Matrix

Testing was performed according to the test methods delineated in the test matrix, with modifications as referenced in the AGATE report, *Material Qualification and Equivalency for Polymer Matrix Composite Material Systems*. The test matrix for properties included in this document is listed on the next page, with the following notation cited in each column:

x

where the first # represents the required number of prepreg batches, defined as: Prepreg containing 7781 E-Glass Fabric from one mill roll, impregnated with one batch of resin in one continuous manufacturing operation with traceability to all components. The second # represents the required number of replicates per prepreg batch. For example, "3 x 6" refers to three prepreg batches of material and six specimens per prepreg batch for a total requirement of 18 test specimens.

Table 1.5.1: Test Matrix and Standards Used

TEST	METHOD	NO. OF REPLICATES PER TEST CONDITION				
		CTD[1]	RTD[2]	ETW[3]	ETW[4]	ETD[5]
Laminate Tension Strength	ASTM D3039-95	1x3	5x8	5x8	3x4	3x4
Laminate Tension Modulus, Strength and Poisson's Ratio	ASTM D3039-95	1x3	5x3	5x3	3x2	3x2
Laminate Compression Strength	SACMA SRM 1-94	1x6	5x11	5x11	3x6	3x4
Laminate Compression Modulus	SACMA SRM 1-94	---	1x11	1x11	3x2	3x2
In-Plane Shear Strength	ASTM D5379-93	1x3	5x8	5x8	3x4	3x6
In-Plane Shear Modulus and Strength	ASTM D5379-93	1x3	5x3	5x3	3x2	3x2
Short Beam Shear	ASTM D2344-89	---	3x6	---	---	---
Fiber Volume	ASTM D2584-94	One sample per panel				
Resin Volume	ASTM D2584-94	One sample per panel				
Void Content	ASTM D2734-94	One sample per panel				
Cured Neat Resin Density	---	Supplied by manufacturer for material				
Glass Transition Temperature	SACMA SRM 18-94	1x5 dry, 1x5 wet				

Notes :

1   CTD: One prepreg lot of material tested (test temperature = -65 $\pm$ 5° F, moisture content = as fabricated, soak time at –65 was 3 min.)

2   RTD: Three prepreg lots of material tested (test temperature = 70 $\pm$ 10° F, moisture content = as fabricated)

3   ETW: Three prepreg lots of material tested (test temperature = 150 $\pm$ 5° F, moisture content = equilibrium per section 1.5.2, soak time at 150 was 60 sec.)

4   ETW: Three prepreg lots of material tested (test temperature = 180 $\pm$ 5° F, moisture content = as fabricated, soak time at 180 was 2-3 min.)

5   ETD: Three prepreg lots of material tested (test temperature = 150 $\pm$ 5° F, moisture content = as fabricated, soak time at 150 was 2-3 min.)

1.5.2 Environmental Conditioning

All 'wet' conditioned samples were exposed to elevated temperature and humidity conditions to establish moisture saturation of the material. Specimens were exposed to 85 ± 5 % relative humidity and 145 ± 5 °F until an equilibrium moisture weight gain of traveler, or witness coupons (1" x 1" x specimen thickness) was achieved. ASTM D5229 and SACMA SRM 11 were used as guidelines for environmental conditioning and moisture absorption.

Effective moisture equilibrium was achieved when the average moisture content of the traveler specimen changed by less than 0.05% for two consecutive readings within a span of 7 ± 0.5 days and was expressed by:

$$\frac{W_i - W_{i-1}}{W_b} \; < \; 0.0005$$

where W_i = weight at current time
W_{i-1} = weight at previous time
W_b = baseline weight prior to conditioning

It is common to see small fluctuations in an unfitted plot of the weight gain vs. time curve. There were no fluctuations that made significant errors in results or caused rejection in the moisture equilibrium criteria. Once the traveler coupons passed the criteria for two consecutive readings, the samples were removed from the environmental chamber and placed in a sealed bag with a moist paper or cotton towel for a maximum of 14 days until mechanical testing. Strain gauged specimens were removed from the controlled environment for a maximum of 2 hours for application of gages in ambient laboratory conditions.

1.5.3 Normalization Procedures

The normalization procedure attempts to reduce variability in fiber-dominated material properties by adjusting raw test values to a specified fiber volume content. Only the following properties were normalized:

- Laminate Tensile Strength and Modulus
- Laminate Compression Strength and Modulus

The normalization procedure was adopted from MIL-HDBK-17-1E, section 2.4.3.3. The procedure which was used to normalize the data is based on two primary assumptions:

- The relationship between fiber volume fraction and ultimate laminate strength is linear over the entire range of fiber/resin ratios. (It neglects the effects of resin starvation at high fiber contents.)

- Fiber volume is not commonly measured for each test sample, so this method accounts for the fiber volume variation between individual test specimens by utilizing a relationship between fiber volume fraction and laminate cured ply thickness. This relationship is virtually linear in the 0.45 to 0.65 fiber volume fraction range.

Additional information is detailed in FAA Document DOT/FAA/AR-00/47: Material Qualification and Equivalency for Polymer Matrix Composite Material Systems. For all normalized data contained in this document, the test values are normalized by cured ply thickness according to:

$$Normalized\ Value = Test\ Value \times \frac{CPT_{specimen}}{CPT_{normalizing}}$$

where:

$$CPT_{specimen} = \frac{Average\ Sample\ Thickness}{\#\ of\ plies}$$

1.5.4 Statistical Analysis

When compared to metallic materials, fiber reinforced composite materials exhibit a high degree of material property variability. This variability is due to many factors, including but not limited to: raw material and prepreg manufacture, material handling, part fabrication techniques, ply stacking sequence, environmental conditions, and testing techniques. This inherent variability drives up the cost of composite testing and tends to render smaller data sets than those produced for metallic materials. This necessitates the usage of statistical techniques for determining reasonable design allowables for composites.

The analyses and design allowable generation for both A and B basis values were performed using the procedure detailed in section 5.3 of FAA Document DOT/FAA/AR-00/47: Material Qualification and Equivalency for Polymer Matrix Composite Material Systems.

1.5.5 Material Performance Envelope and Interpolation

Using the B-basis numbers, a material performance envelope may be generated for the material system by plotting these values as a function of temperature. Figure 1.5.1 shows an example material performance envelope using B-basis values.
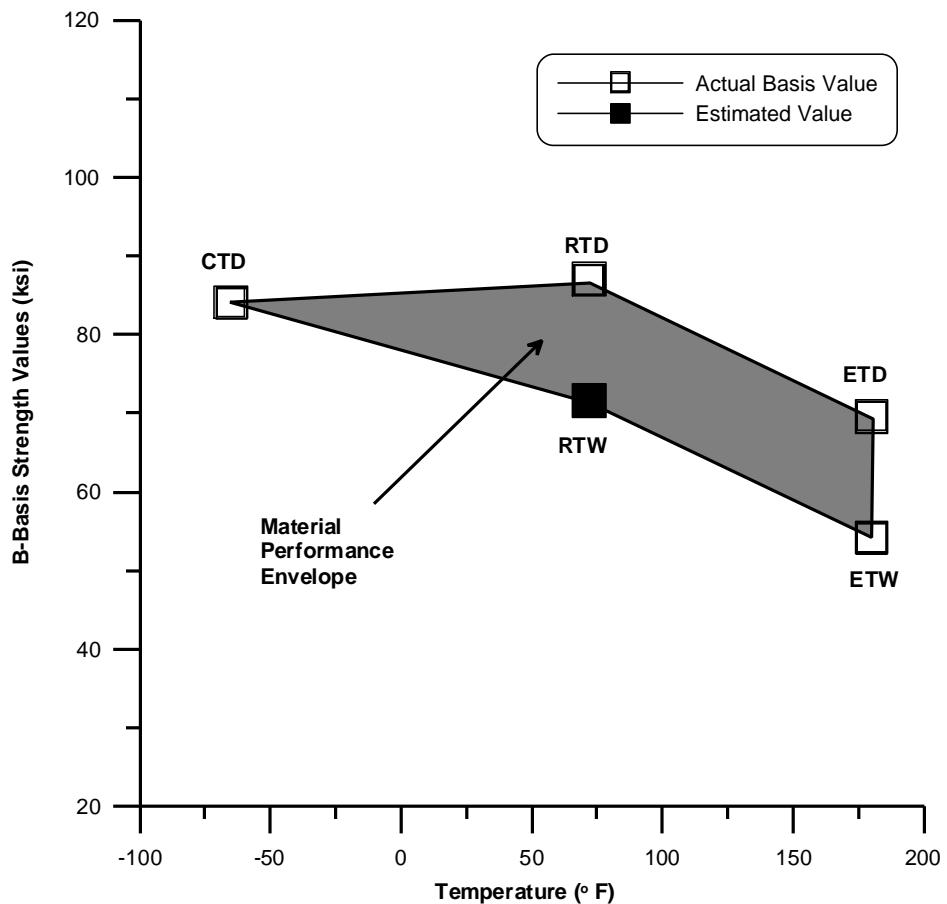
Figure 1.5.1 Material performance envelope.

Since each specific aircraft application of the qualified material may have different Material Operational Limits (MOL) than those tested in the material qualification (which is usually the upper limit), some applications may require a reduced MOL. In this case, simple linear interpolation may be used to obtain the corresponding basis values at the new application MOL.

This interpolation may be accomplished using the following simple relationships assuming $T_{RTD} < T_{MOL} < T_{ETD}$:

For the corresponding MOL "dry" basis value, the "interpolated" basis value using the qualification data is

$$B_{MOL} = B_{RTD} - \frac{(B_{RTD} - B_{ETD})(T_{RTD} - T_{MOL})}{(T_{RTD} - T_{ETD})}$$

where B_{MOL} = new application basis value interpolated to T_{MOL}
B_{RTD} = basis RTD strength value
B_{ETD} = basis ETD strength value
T_{RTD} = RTD test temperature
T_{ETD} = ETD test temperature
T_{MOL} = new application MOL temperature

For the corresponding MOL "wet" basis value, an estimated Room Temperature Wet (RTW) value must be calculated. This may be accomplished by the simple relation

$$B_{RTW} = B_{RTD} - (B_{ETD} - B_{ETW})$$

The "interpolated" wet basis value using the qualification data may then be obtained by

$$B_{MOL} = B_{RTW} - \frac{(B_{RTW} - B_{ETW})(T_{RTW} - T_{MOL})}{(T_{RTW} - T_{ETW})}$$

where: B_{MOL} = new application basis value interpolated to T_{MOL}
B_{RTW} = estimated basis RTW strength value
B_{ETW} = basis ETW strength value
T_{RTW} = RTW (i.e., RTD) test temperature
T_{ETW} = ETW test temperature
T_{MOL} = new application MOL temperature

These equations may also be used for interpolated mean strengths as well as A-basis values with the appropriate substitutions. It should be noted that because unforeseen material property drop-offs with respect to temperature and environment can occur, *extrapolation* to a higher MOL should not be attempted without additional testing and verification. In addition, the interpolation equations shown above are practical for materials obeying *typical* mechanical behavior. In most cases, some minimal amount of testing may also be required to verify the interpolated values.

1.5.5.1 Interpolation Example

This section provides an example of linear interpolations to a specific application environment less than the tested upper material limit used in qualification. Assuming a specific application environment of 150° F, Figure 1.5.2 depicts the linear interpolation of the B-basis design allowable to this environment. Using the above equations along with the nominal testing temperatures (see Table 1.5.1), the interpolated basis values at 150° F become

$$ETD \quad : \quad B_{MOL} = \ 75.106 \ \text{ksi}$$

$$ETW \quad : \quad B_{MOL} = \ 59.746 \ \text{ksi}$$
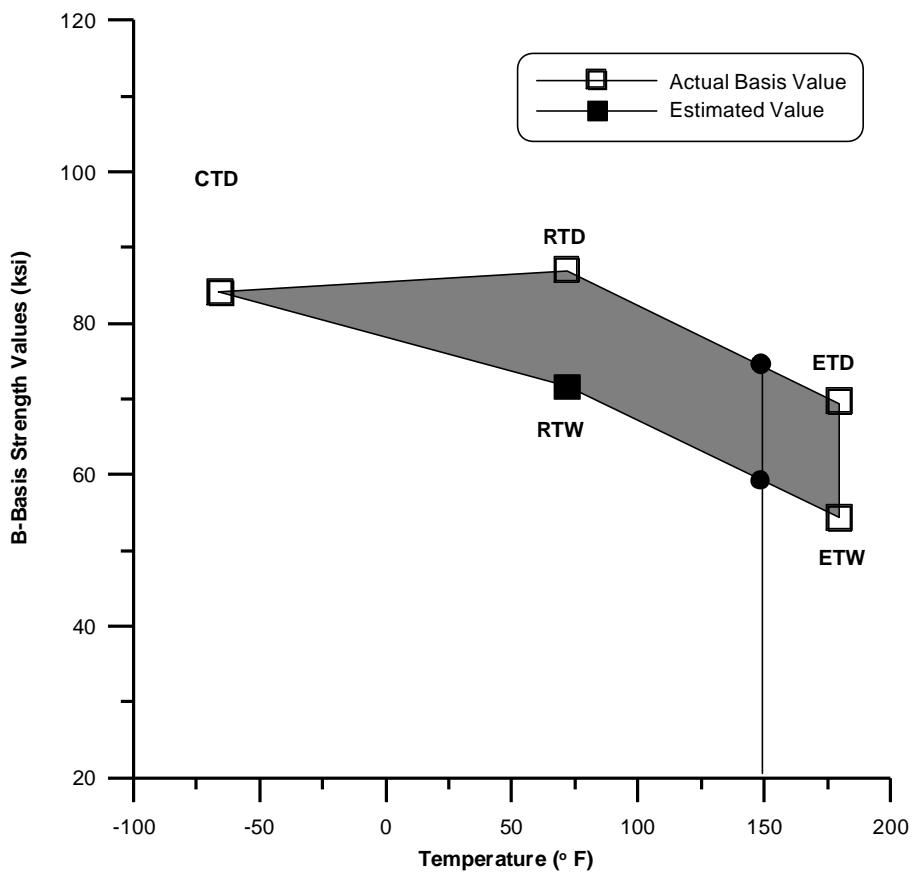
Figure 1.5.2   Example of 150° F interpolation for B-basis values.

2.0 3M 7781 E-GLASS / SP381 PREPREG PROPERTIES

2.1 Prepreg Documentation by Prepreg Lot

Batch ID - AGATE	1	2	3	4	5	6	7	8
Prepreg Documentation	**Prepreg Manufacturer & Product ID: 3M 7781 / SP381** **Material Identification (weave, form, class, etc.): SP 381 OST 7781 300FAW 38RC** **Impregnation Method: hot melt**							
Prepreg Batch or Lot #	106A2	126A	7001A7	7002A7	7006A7	7007G7	7009J7	7008H7
Date of Manufacture	10/30/96	12/16/96	1/29/97	1/30/97	4/30/97	7/18/97	9/16/97	8/7/97
Expiration Date	10/30/97	12/16/97	1/29/98	1/30/98	4/30/98	7/18/98	9/16/98	8/7/98
Resin Content [%]	38	38.7	37.6	38	36.7	39	39.3	39.3
Reinforcement Areal Weight [gsm] & Test Method	290	290.9	293.4	291.6	295	296	297.2	296.5
	Cirrus spec GEK0101 method 4.4.3							
Resin Flow [%] & Test Conditions	23.1	N/A	15	17	22	26	24.5	26.5
	Cirrus spec GEK0101 method 4.4.2							
Gel Time [min] & Test Conditions	8.7	8.6	8.3	8.3	7.9	7.0	7.1	6.9
	Cirrus spec GEK0101 method 4.4.1							
Volatile Content	N/A							

Reinforcement Documentation	**Fiber/Fabric Manufacturer & Product ID:**
	 7781 E-glass BGF 8HS
	  Finish/Sizing Type and %: 497A ; 0.08 –021%
	  Nominal tow or yarn count/inch: Warp 58, Fill 55							

Fabric Batch or Lot #	00848441/00010	00852428/00010	00855468/00010	00855469//00020	00857163/00010	00861790/542566 542577	00861790/00010	00862554/552770 552756
Date of Manufacture	9/24/96	12/2/96	1/21/97	1/20/97	2/17/97	4/21/97	4/21/97	5/5/97
Average Fiber Density & Test Method	Typical value = 2.60 (specific gravity) N/A by lot							
Matrix Documentation	**Resin Manufacturer & Product ID: PM61216**							
Matrix Batch or Lot #	19K6P	210M6R	97212A	97211A	7216D7	7217E7	7219J7	7218G7
Date of Manufacture	10/96	12/96	1/97	1/97	4/97	5/97	9/97	7/97
Average Neat Resin Density by Lot & Test Method	Typical value = 1.215 g/cc (ASTM D792) N/A by lot							

17

2.2 Process Specification

This specification does not address issues relating to safety, quality control, bagging material selection, bagging procedure, tool preparation, or equipment selection. Although these may affect overall part quality, it is the responsibility of the end user to develop procedures related to these issues in a manner that produces parts with high quality and consistency.

The following oven cure procedures are excerpts from Cirrus Design Corporation GEP0001 Rev. C specification, *Manufacture of Glass-Fiber Prepreg Assemblies, 260°F Cure*. All test specimens were cured per this specification by Cirrus Design Corporation. However, the effects of the upper and lower limits of vacuum, temperature, cure time, heat-up rate and hold temperature on the mechanical and thermal properties have not been investigated.

Prior to Cure

- Unitape orientation angle shall be within ±3° of the specified orientation.
- Before placing a bagged assembly in the oven, apply at least 22" Hg vacuum and check for bag leaks. Bag leaks greater than 3.0" Hg during 5 minutes shall be corrected.
- Debulk shall be performed every ten layers, or more frequently if required.

Oven Cure Procedure

- The maximum air temperature of the oven prior to loading is 160°F. Connect the calibrated thermocouples to the parts, allowing at least one thermocouple per part. The temperature of the part must be 150°F or less before removing from the oven
- Cure all prepreg parts according to the following cure cycle chart.
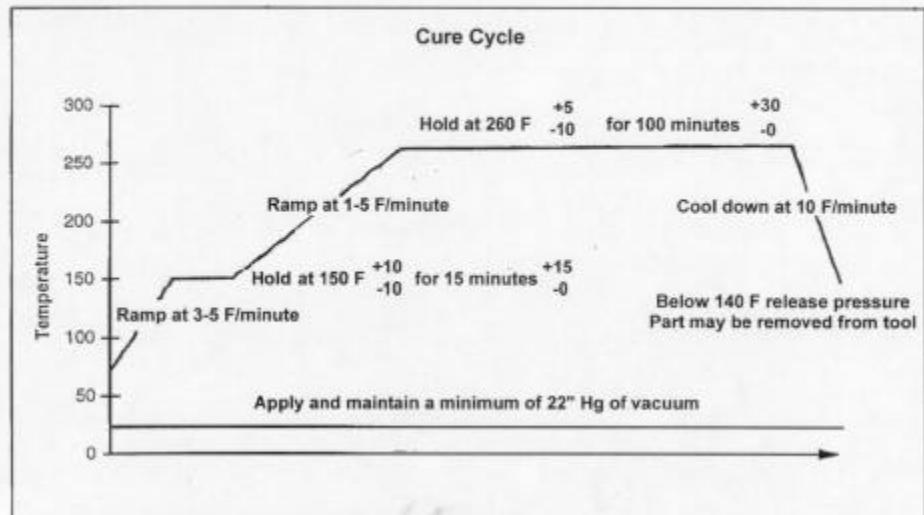
Figure 2.1: Sample prepreg cure cycle for SP381 / 7781 E-glass. Figure courtesy of Cirrus Design Corporation.

3.0 3M 7781 E-GLASS / SP381 LAMINATE PROPERTIES

Note: The mechanical properties included in this document do not represent true lamina (ply) properties due to the fabric orientation of the samples tested. Therefore, the term laminate is used throughout the document for clarity.

3.1 Test Results

3.1.1 Summary

MATERIAL:	SP381/7781 E-Glass Cloth			Date of fiber manufacture: 9/96 - 5/97	SP381/7781
FIBER:	BGF 7781	RESIN:	3M SP381	Date of resin manufacture: 10/96 - 7/97	
PREPEG:	3M SP381/7781 E-glass Cloth; 497A finish, 0.08 - 0.21% sizing			Date of prepeg manufacture: 10/96 - 8/97	Summary
T_g(dry): 293.2°F	T_g (wet): 243.0°F	T_g METHOD:	DMA(SRM 18-94)	Date of composite manufacture:2/97-1/98	
				Date of testing: 4/97-9/98	
PROCESSING:	vacuum bag cure (22+ in Hg) 250-265 °F for 100-130 min.			Date of analysis: 5/98-9/98	

LAMINATE MECHANICAL PROPERTY SUMMARY
Data Reported as: Measured
(Normalized by CPT = 0.0099 in.)

	CTD (-65°F)		RTD			ETD (180° F)		ETW (150° F)			ETW (180° F)	
	B-Basis	Mean	A-Basis	B-Basis	Mean	B-Basis	Mean	A-Basis	B-Basis	Mean	B-Basis	Mean
F^{tu} (ksi)	57.89 (58.01)	64.30 (64.84)	52.09 (52.06)	55.46 (55.65)	60.15 (60.64)	50.48 (50.24)	55.22 (55.24)	42.88 (42.65)	45.66 (45.60)	49.50 (49.66)	41.35 (40.95)	45.22 (45.02)
E^{t} (Msi)	---	3.52 (3.59)	---	---	3.58 (3.61)	---	3.29 (3.30)	---	---	3.29 (3.31)	---	3.27 (3.29)
n_{12}^{tu}	---	0.167	---	---	0.148	---	0.109	---	---	0.118	---	0.105
F^{cu} (ksi)	82.71 (80.68)	93.26 (91.58)	63.66 (63.43)	68.43 (68.48)	75.07 (75.50)	56.65 (57.25)	62.75 (63.77)	48.18 (48.00)	51.80 (51.82)	56.83 (57.14)	43.79 (44.76)	48.29 (49.30)
E^{c} (Msi)	---	---	---	---	3.54 (3.66)	---	3.62 (3.64)	---	---	3.45 (3.54)	---	3.54 (3.54)
F_{12}^{su} (ksi)	20.51	22.87	16.35	17.45	19.00	13.87	15.22	12.29	13.11	14.26	11.01	12.02
G_{12}^{s} (Msi)	---	0.67	---	---	0.59	---	0.51	---	---	0.45	---	0.47
F_{13}^{su**} (ksi)	---	---	7.24	7.71	8.36	---	---	---	---	---	---	---

**Apparent interlaminar shear strength

23

3.1.2 Individual Test Summaries

3.1.2.1 Tension, Laminate

		Tension, Laminate Gl/Ep 3M SP381/7781 E-glass cloth $[(0_f/90_f)_2/0_f/90_f/0_f/(90_f/0_f)_2]$

Material: 3M SP381/7781 E-glass cloth

Resin content:	33 - 37 wt.%	**Comp. density:**	0.06 - 0.07 g/cc
Fiber volume:	44 - 48 %	**Void content:**	0.5 - 2.3 %
Ply thickness:	0.0094 - 0.0104 in.		
Ply range:	11 ply		
Test method:	D3039-95	**Modulus calculation:**	linear fit from 1000 - 3000 $\mu\varepsilon$
Normalized by:	0.0099 in. ply thickness		

		CTD		RTD		ETD		ETW		ETW			
Test Temperature [°F]		-65		75		180		150		180			
Moisture Conditioning		dry		dry		dry		equilibrium		equilibrium			
Equilibrium at T, RH		as fabricated		as fabricated		as fabricated		145 F, 85 %		145 F, 85 %			
Source code		LAUXXXXB		LAUXXXXA		LAUXXXXG		LAUXXXXC		LAUXXXXF			
		Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured
F^{tu} (ksi)	**Mean**	64.84	64.30	60.64	60.15	55.24	55.22	49.66	49.50	45.02	45.22		
	Minimum	60.97	62.19	53.80	53.78	48.44	48.32	41.44	41.06	41.60	41.70		
	Maximum	69.19	67.98	67.79	66.12	58.50	58.61	57.22	55.70	47.41	50.00		
	C.V.(%)	4.09	3.18	5.33	5.13	5.37	5.58	5.79	5.09	4.38	5.00		
	B-value	58.01	57.89	55.65	55.46	50.24	50.48	45.60	45.66	40.95	41.35		
	A-value	54.29	54.39	52.06	52.09	47.02	47.44	42.65	42.88	38.33	38.85		
	No. Specimens	6		55		18		60		18			
	No. Prepreg Lots	1		5		3		5		3			
E^t (Msi)	**Mean**	3.59	3.52	3.61	3.58	3.30	3.29	3.31	3.29	3.29	3.27		
	Minimum	3.56	3.49	3.51	3.40	3.03	3.00	3.21	3.17	3.25	3.22		
	Maximum	3.64	3.56	3.90	3.77	3.37	3.38	3.40	3.42	3.34	3.30		
	C.V.(%)	1.14	0.96	2.63	3.22	4.00	4.41	1.44	2.34	0.99	0.78		
	No. Specimens	3		15		6		17		6			
	No. Prepreg Lots	1		5		3		5		3			
n_{12}^t	**Mean**		0.167		0.148		0.109		0.118		0.105		
	No. Specimens	3		15		6		11		6			
	No. Prepreg Lots	1		5		3		4		3			

25

3.1.2.2 Compression, Laminate

		Compression, Laminate GI/Ep
Material:	3M SP381/7781 E-glass cloth	3M SP381/7781 E-glass cloth

Material: 3M SP381/7781 E-glass cloth

Resin content:	35 - 37 wt.%	**Comp. density:**	0.06 - 0.07 g/cc
Fiber volume:	44 - 46 %	**Void content:**	0.5 - 1.5 %
Ply thickness:	0.0089 - 0.0106 in.		
Ply range:	12-13 ply		

Compression, Laminate GI/Ep 3M SP381/7781 E-glass cloth $[(0_f/90_f)_3/0_f/(90_f/0_f)_3]$

Test method:	SRM 1-94, D695-91 (mod)	**Modulus calculation:**	linear fit from 1000 - 3000 $\mu\varepsilon$

Normalized by: 0.0099 in. ply thickness

		CTD		RTD		ETD		ETW		ETW			
Test Temperature [°F]		-65		75		180		150		180			
Moisture Conditioning		dry		dry		dry		equilibrium		equilibrium			
Equilibrium at T, RH		as fabricated		as fabricated		as fabricated		145 F, 85 %		145 F, 85 %			
Source code		LAKXXXXB		LAKXXXXA		LAKXXXXG		LAKXXXXC		LAKXXXXF			
		Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured
	Mean	91.58	93.26	75.50	75.07	63.77	62.75	57.14	56.83	49.30	48.29		
	Minimum	86.92	86.38	65.28	64.88	56.98	55.19	46.80	49.40	45.41	44.76		
	Maximum	97.68	100.77	82.56	82.48	70.63	70.44	64.81	65.55	55.18	53.94		
	C.V.(%)	3.77	5.79	5.01	5.02	5.77	6.48	7.65	6.79	5.06	4.50		
F^{cu}	**B-value**	80.68	82.71	68.48	68.43	57.25	56.65	51.82	51.80	44.47	43.79		
(ksi)	**A-value**	74.74	76.96	63.43	63.66	53.06	52.73	48.00	48.18	41.21	40.75		
	No. Specimens	6		55		18		54		28			
	No. Prepreg Lots	1		5		3		5		3			
	Mean			3.66	3.54	3.64	3.62	3.54	3.45	3.54	3.54		
	Minimum			3.61	3.44	3.54	3.51	3.44	3.27	3.47	3.43		
	Maximum			3.71	3.71	3.91	3.96	3.60	3.65	3.63	3.79		
E^c	**C.V.(%)**			0.99	2.17	3.73	4.68	1.28	2.80	1.77	3.70		
(Msi)	**No. Specimens**			11		6		11		6			
	No. Prepreg Lots			1		3		1		3			

26

3.1.2.3 Shear, 12 axis

Material:	3M SP381/7781 E-glass cloth				**Shear, 12-axis** **Gl/Ep** **3M SP381/7781 E-glass cloth** $[(0_f/90_f)_3/0_f/90_f/0_f/(90_f/0_f)_3]$	
Resin content:	34 - 38 wt.%	**Comp. density:**	0.06 - 0.07 g/cc			
Fiber volume:	43 - 47 %	**Void content:**	0.7 - 2.2 %			
Ply thickness:	0.0091 - 0.0104 in.					
Ply range:	15-16 ply					
Test method:	D5379-93	**Modulus calculation:**	linear fit from 1000 - 6000 $\mu\varepsilon$			
Normalized by:	N/A					

		CTD		RTD		ETD		ETW		ETW			
Test Temperature [°F]		-65		75		180		150		180			
Moisture Conditioning		dry		dry		dry		equilibrium		equilibrium			
Equilibrium at T, RH		as fabricated		as fabricated		as fabricated		145 F, 85 %		145 F, 85 %			
Source code		LANXXXXB		LANXXXXA		LANXXXXG		LANXXXXC		LANXXXXF			
		Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured
	Mean		22.87		18.97		15.22		14.26		12.02		
	Minimum		21.73		17.11		13.91		12.61		10.83		
	Maximum		23.80		21.21		16.72		15.79		13.39		
	C.V.(%)		3.80		4.93		6.10		4.53		6.68		
F_{12}^{su}	**B-value**		20.51		17.45		13.87		13.11		11.01		
(ksi)	**A-value**		19.23		16.35		13.01		12.29		10.32		
	No. Specimens		6		55		18		55		29		
	No. Prepreg Lots		1		5		3		5		3		
	Mean		0.67		0.59		0.51		0.45		0.47		
	Minimum		0.61		0.45		0.48		0.36		0.39		
	Maximum		0.74		0.69		0.56		0.54		0.51		
G_{12}^{s}	**C.V.(%)**		10.02		10.73		5.37		13.23		8.90		
(Msi)	**No. Specimens**		3		15		6		15		6		
	No. Prepreg Lots		1		5		3		5		3		

27

3.1.2.4 Shear, 13 axis

		Shear, 13-axis Gl/Ep 3M SP381/7781 E-glass cloth $[(0_f/90_f)_3/(0_f)_2/(90_f/0_f)_3]$		
Material:	3M SP381/7781 E-glass cloth			
Resin content: 23 - 34 wt.%		**Comp. density:** 0.07 - 0.08 g/cc		
Fiber volume: 47 - 63 %		**Void content:** 0.0 - 1.7 %		
Ply thickness: 0.0088 - 0.0098 in.				
Ply range: 14 ply				
Test method: D2344-89		**Modulus calculation:** N/A		
Normalized by: N/A				

		RTD												
Test Temperature [°F]			75											
Moisture Conditioning			dry											
Equilibrium at T, RH			as fabricated											
Source code			LAQXXXXA											
	Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured
Mean				8.36										
Minimum				7.69										
Maximum				8.98										
C.V.(%)				4.24										
F_{13}^{su} (ksi) **B-value**				7.71										
A-value				7.24										
No. Specimens				25										
No. Prepreg Lots				3										

NOTES: These values represent the apparent interlaminar shear properties and are to be used for quality control purposes only. Do not use these values for interlaminar shear strength design values.

28

3.1.3 Individual Test Charts

3.1.3.1 Tension, Laminate

Laminate Tension -- Normalized Strength
SP381/ 7781 E-Glass Cloth
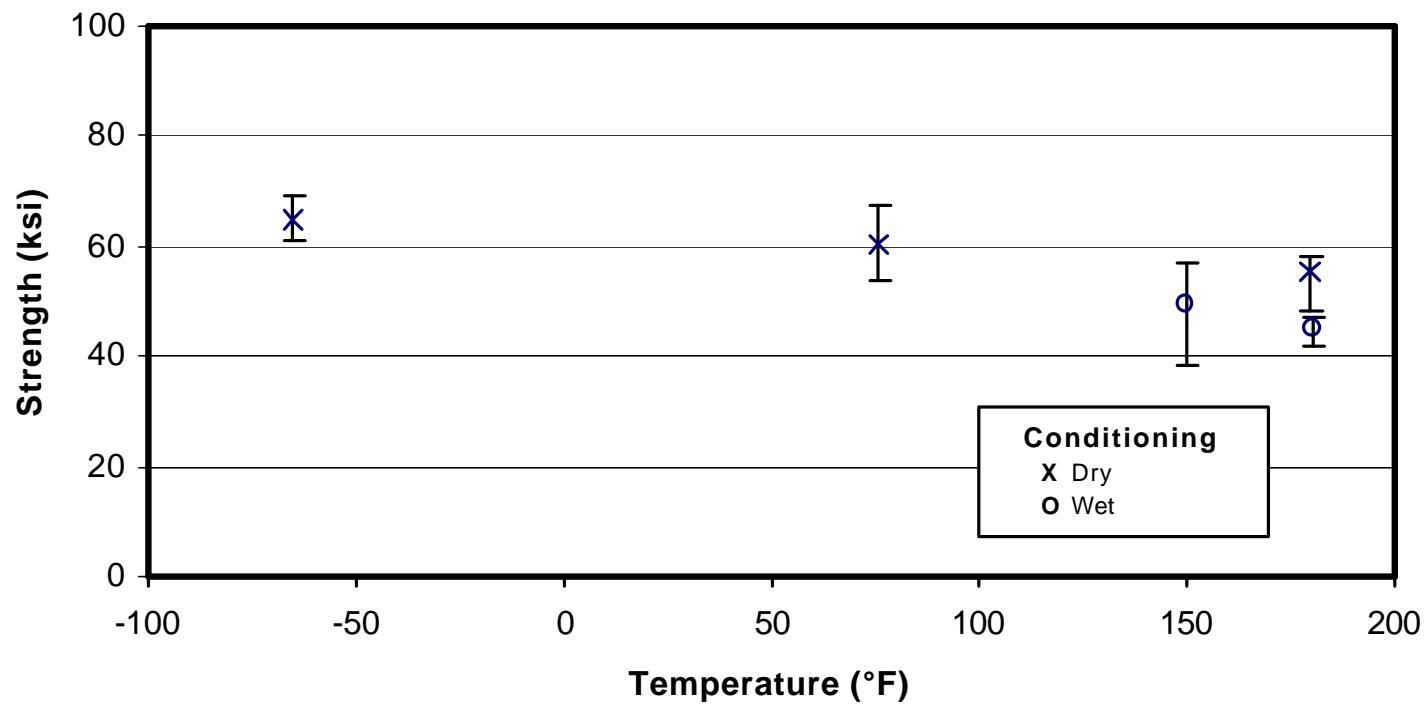
NOTE: The symbols represent the 'pooled' average of all tests, and the bars represent the upper and lower limit of the data.

3.1.3.2 Compression, Laminate
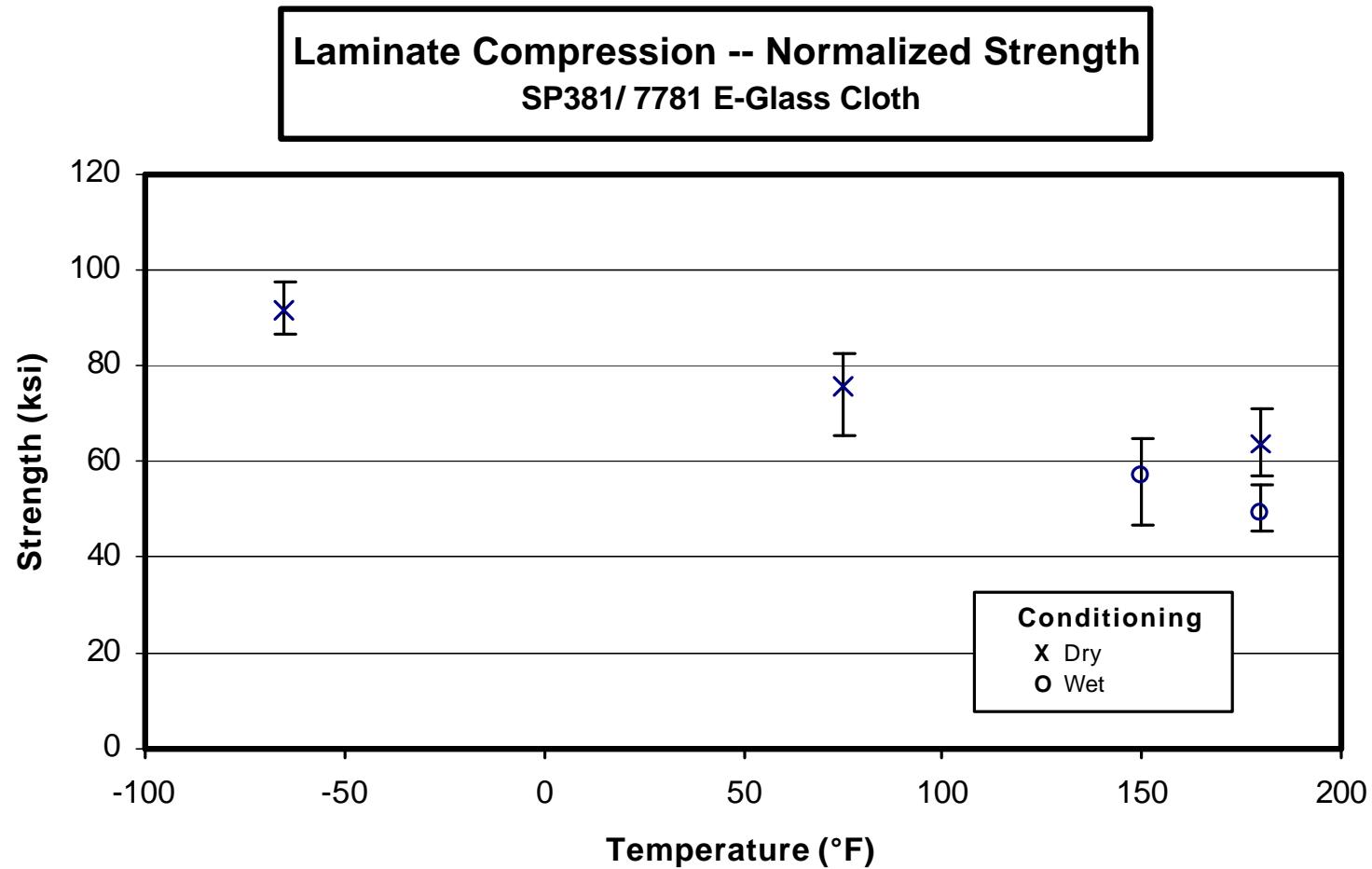
Laminate Compression -- Normalized Strength
SP381/ 7781 E-Glass Cloth

NOTE: The symbols represent the 'pooled' average of all tests, and the bars represent the upper and lower limit of the data.

3.1.3.3 Shear, 12 axis
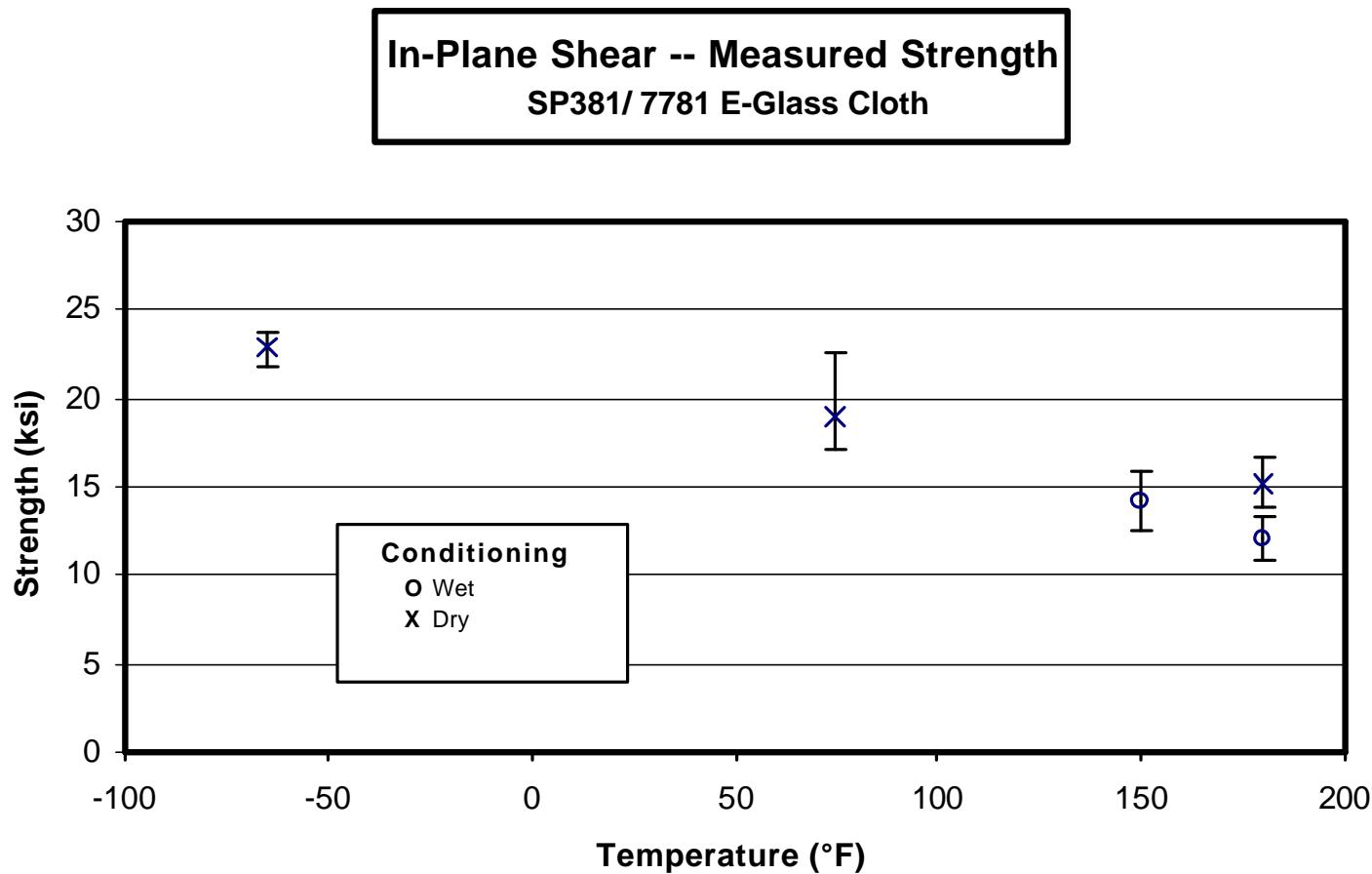
In-Plane Shear -- Measured Strength
SP381/ 7781 E-Glass Cloth

NOTE: The symbols represent the 'pooled' average of all tests, and the bars represent the upper and lower limit of the data.

3.1.3.4 Shear, 13 axis
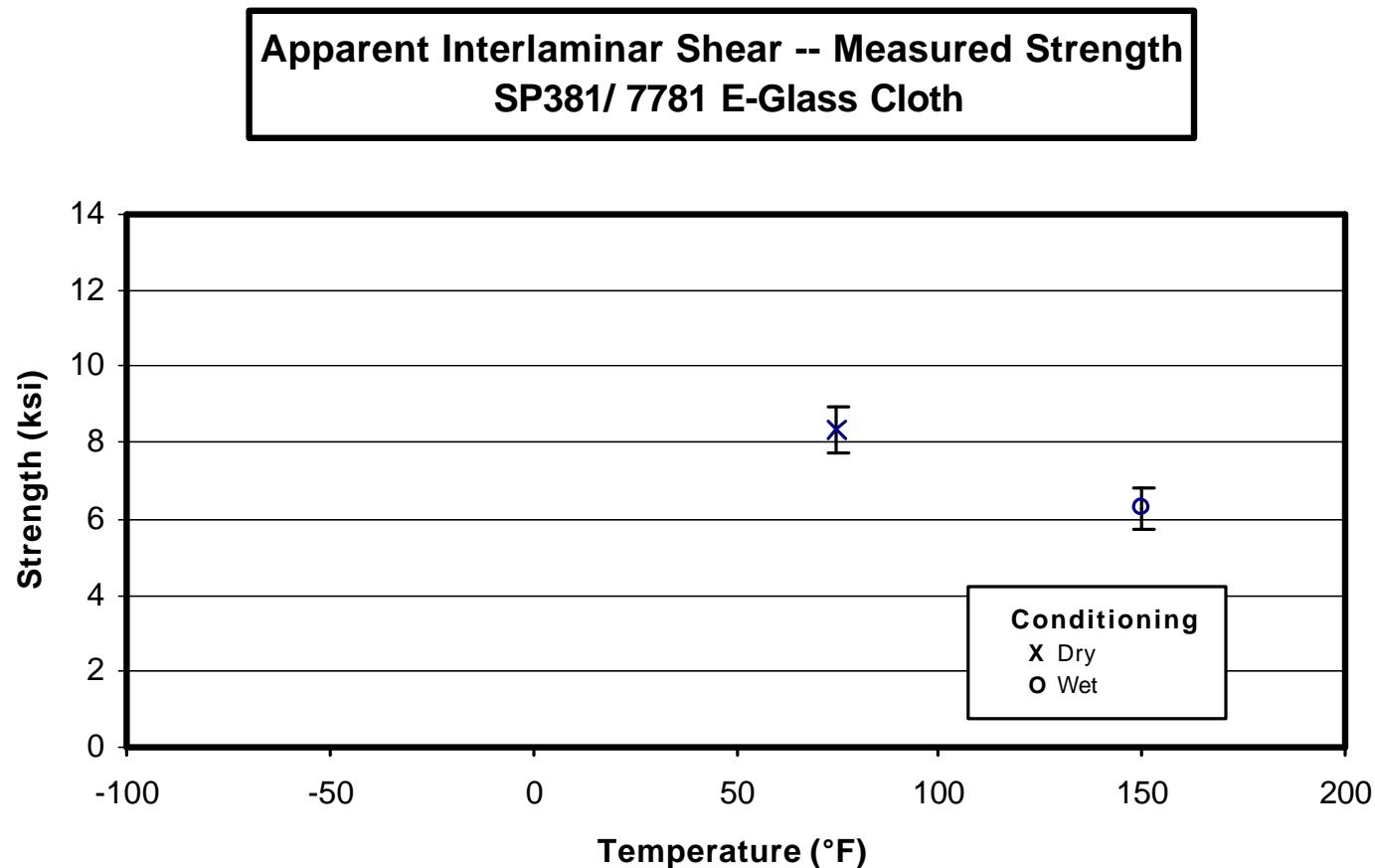
**Apparent Interlaminar Shear -- Measured Strength
SP381/ 7781 E-Glass Cloth**



NOTE: The symbols represent the 'pooled' average of all tests, and the bars represent the upper and lower limit of the data.

3.2 Raw Data

Specimen Naming Convention

Test coupons were identified using an eight-digit specimen code, with the significance of each digit delineated below. A representative sample ID is shown for reference purposes.

$$\text{L A J 2 \quad 1 2 5 F}$$

1st Character: Fabricator
   'L' designates Cirrus

2nd Character: Material System
   'A' designates 7781 E-glass / SP381

3rd Character: Test Type
   'J' designates 0° Tension
   Strength and Modulus, other
   test types will be clearly labeled
   at the top of each sheet

4th Character: Prepreg Batch ID
   See Table 2.1 for Cirrus Batch ID /
   Sample Batch ID correlation.

5th Character: Panel Number
   The panel(s) fabricated for a specific test method.

6th Character: Subpanel Number
   The sub-panel(s) cut from each panel, with subpanel
   numbers labeled increasing from reference edge.

7th Character: Sample Number
   The sample(s) cut from each subpanel, with sample
   numbers labeled increasing from reference edge.

8th Character: Test Condition
   'A' --- RTD
   'B' --- CTD
   'C' --- ETW, 150°F
   'F' --- ETW, 180°F
   'G' --- ETD, 180°F
   See Table 1.5.1 for condition parameters.

34

3.2.1 Raw Data Spreadsheets and Scatter Charts

Laminate Tension -- (RTD)
Strength & Modulus
**SP381/ 7781 E-Glass Cloth**

normalizing t_{ply} [in]
0.0099

Specimen Number	Batch Number	Strength [ksi]	Modulus [Msi]	Poisson's Ratio	Avg. Specimen Thickn. [in]	# Plies in Laminate	Avg. t_{ply} [in]	Strength$_{norm}$ [ksi]	Modulus$_{norm}$ [Msi]
LAU2111A	2	54.617	3.542	0.148	0.108	11	0.00981	54.115	3.509
LAU2112A	2	56.329	3.573	0.143	0.109	11	0.00989	56.252	3.568
LAU2113A	2	58.887	3.626	0.147	0.108	11	0.00984	58.535	3.604
LAU2714A	2	57.684			0.110	11	0.00999	58.205	
LAU2715A	2	60.934			0.104	11	0.00947	58.285	
LAU2121A	2	56.000			0.109	11	0.00991	56.077	
LAU2122A	2	53.781			0.109	11	0.00990	53.798	
LAU2123A	2	57.777			0.108	11	0.00984	57.449	
LAU2124A	2	55.781			0.109	11	0.00992	55.866	
LAU2125A	2	55.864			0.107	11	0.00973	54.898	
LAU2126A	2	55.899			0.109	11	0.00988	55.780	
LAU3311A	3	56.674	3.438	0.144	0.113	11	0.01028	58.834	3.569
LAU3312A	3	57.434	3.432	0.144	0.113	11	0.01030	59.763	3.571
LAU3313A	3	58.364	3.395	0.146	0.114	11	0.01032	60.856	3.540
LAU3314A	3	59.796			0.114	11	0.01035	62.514	
LAU3315A	3	60.626			0.114	11	0.01033	63.251	
LAU3316A	3	59.118			0.110	11	0.01002	59.815	
LAU3321A	3	55.466			0.113	11	0.01030	57.724	
LAU3322A	3	58.289			0.112	11	0.01021	60.109	
LAU3323A	3	57.622			0.114	11	0.01036	60.285	
LAU3324A	3	57.828			0.111	11	0.01008	58.881	
LAU3326A	3	59.525			0.113	11	0.01031	61.985	
LAU4221A	4	61.515	3.504	0.150	0.112	11	0.01017	63.220	3.601
LAU4222A	4	61.561	3.505	0.151	0.112	11	0.01022	63.577	3.619
LAU4223A	4	63.329	3.766	0.157	0.113	11	0.01025	65.597	3.901
LAU4224A	4	63.964			0.112	11	0.01017	65.726	
LAU4311A	4	59.084			0.113	11	0.01031	61.534	
LAU4312A	4	63.979			0.113	11	0.01027	66.358	
LAU4321A	4	65.364			0.113	11	0.01027	67.785	
LAU4322A	4	63.397			0.114	11	0.01033	66.172	
LAU4323A	4	63.061			0.114	11	0.01032	65.744	
LAU4324A	4	59.984			0.113	11	0.01032	62.499	
LAU4325A	4	64.006			0.113	11	0.01027	66.426	
LAU5311A	5	66.124	3.730	0.143	0.104	11	0.00949	63.412	3.577
LAU5321A	5	62.760	3.621	0.166	0.106	11	0.00963	61.060	3.523
LAU5322A	5	63.513	3.767	0.148	0.107	11	0.00977	62.648	3.715
LAU5323A	5	65.510			0.105	11	0.00953	63.034	
LAU5324A	5	63.820			0.107	11	0.00970	62.560	
LAU5325A	5	61.363			0.107	11	0.00972	60.274	
LAU5411A	5	61.117			0.105	11	0.00958	59.115	
LAU5412A	5	65.493			0.105	11	0.00952	63.007	
LAU5413A	5	63.338			0.106	11	0.00967	61.884	
LAU5414A	5	63.768			0.107	11	0.00968	62.372	
LAU5415A	5	62.820			0.105	11	0.00955	60.580	
LAU6111A	6	61.193	3.576	0.147	0.110	11	0.01003	62.008	3.624
LAU6112A	6	58.860	3.582	0.141	0.109	11	0.00990	58.869	3.582
LAU6113A	6	57.724	3.615	0.149	0.109	11	0.00986	57.512	3.602
LAU6114A	6	59.064			0.110	11	0.01000	59.651	
LAU6115A	6	59.430			0.110	11	0.00998	59.893	
LAU6121A	6	60.798			0.108	11	0.00986	60.537	
LAU6122A	6	59.588			0.110	11	0.01000	60.199	
LAU6123A	6	58.522			0.109	11	0.00992	58.621	
LAU6124A	6	59.788			0.110	11	0.01000	60.401	
LAU6125A	6	61.463			0.107	11	0.00976	60.569	
LAU6211A	6	58.603			0.110	11	0.01002	59.294	

|	Strength	Modulus	Poisson				Avg. t_{ply} norm	Strength norm	Modulus norm
Average	60.149	3.578	0.148			Average$_{norm}$	0.00998	60.644	3.607
Standard Dev.	3.088	0.115	0.006			Standard Dev.$_{norm}$		3.232	0.095
Coeff. of Var. [%]	5.133	3.224	4.181			Coeff. of Var. [%]$_{norm}$		5.330	2.626
Min. Value	53.781	3.395	0.141			Min. Value$_{norm}$	0.0095	53.798	3.509
Max. Value	66.124	3.767	0.166			Max. Value$_{norm}$	0.0104	67.785	3.901
Number of Spec.	55	15	15			Number of Spec.$_{norm}$		55	15

36

**Laminate Tension -- (RTD)
Normalized Strength**
SP381/ 7781 E-Glass Cloth

Pooled Average = 60.644 [ksi]
Pooled Standard Deviation = 3.232 [ksi]
Pooled Coeff. of Variation = 5.330 [%]

**Laminate Tension -- (RTD)
Normalized Modulus**
SP381/ 7781 E-Glass Cloth

Pooled Average = 3.607 [Msi]
Pooled Standard Deviation = 0.095 [Msi]
Pooled Coeff. of Variation = 2.626 [%]

37
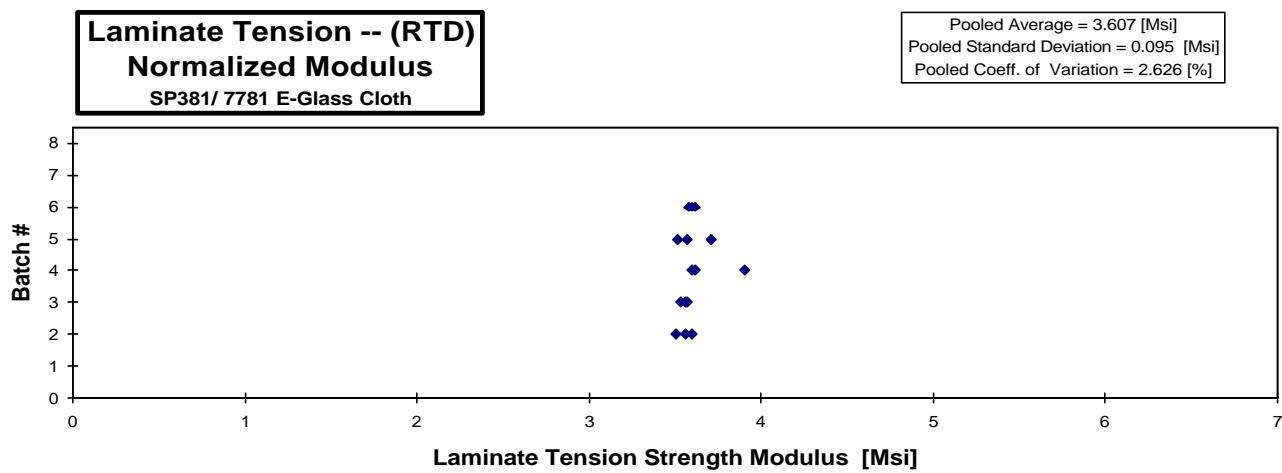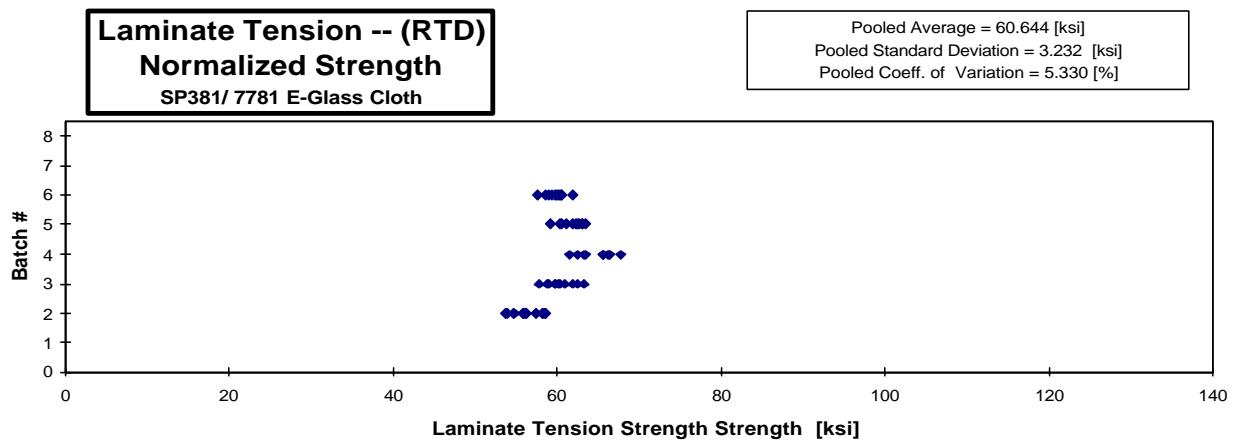
Laminate Tension -- (CTD)
Strength & Modulus
SP381/ 7781 E-Glass Cloth

normalizing t_{plv}
[in]
0.0099

Specimen Number	Batch Number	Strength [ksi]	Modulus [Msi]	Poisson's Ratio	Avg. Specimen Thickn. [in]	# Plies in Laminate	Avg. t_{ply} [in]	Strength$_{norm}$ [ksi]	Modulus$_{norm}$ [Msi]
LAU2721B	2	63.560	3.558	0.163	0.111	11	0.01012	64.951	3.636
LAU2722B	2	62.959	3.493	0.168	0.111	11	0.01009	64.163	3.560
LAU2723B	2	67.985	3.511	0.170	0.111	11	0.01008	69.192	3.573
LAU2724B	2	64.140			0.111	11	0.01011	65.485	
LAU2715B	2	64.963			0.108	11	0.00980	64.287	
LAU2716B	2	62.189			0.107	11	0.00971	60.970	

	Strength	Modulus	Poisson's				t_{ply}	Strength$_{norm}$	Modulus$_{norm}$
Average	64.299	3.521	0.167		Average$_{norm}$	0.00998		64.842	3.590
Standard Dev.	2.042	0.034	0.004		Standard Dev.$_{norm}$			2.650	0.041
Coeff. of Var. [%]	3.176	0.959	2.320		Coeff. of Var. [%]$_{norm}$			4.086	1.136
Min. Value	62.189	3.493	0.163		Min. Value$_{norm}$	0.0097		60.970	3.560
Max.Value	67.985	3.558	0.170		Max. Value$_{norm}$	0.0101		69.192	3.636
Number of Spec.	6	3	3		Number of Spec.$_{norm}$			6	3

38

Laminate Tension -- (CTD)
Normalized Strength
SP381/ 7781 E-Glass Cloth

Pooled Average = 64.842 [ksi]
Pooled Standard Deviation = 2.650 [ksi]
Pooled Coeff. of Variation = 4.086 [%]
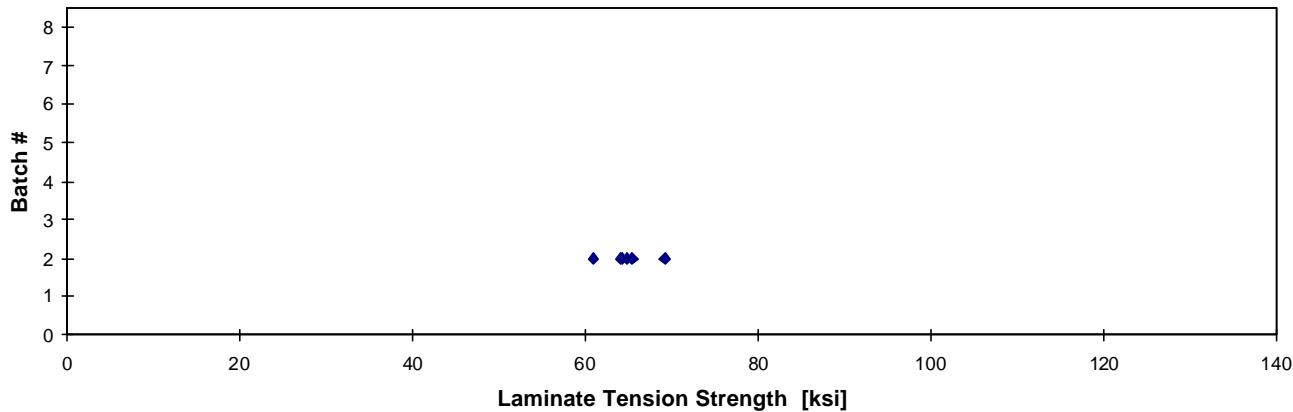
Laminate Tension -- (CTD)
**Normalized Modulus**
SP381/ 7781 E-Glass Cloth

Pooled Average = 3.590 [Msi]
Pooled Standard Deviation = 0.041 [Msi]
Pooled Coeff. of Variation = 1.136 [%]
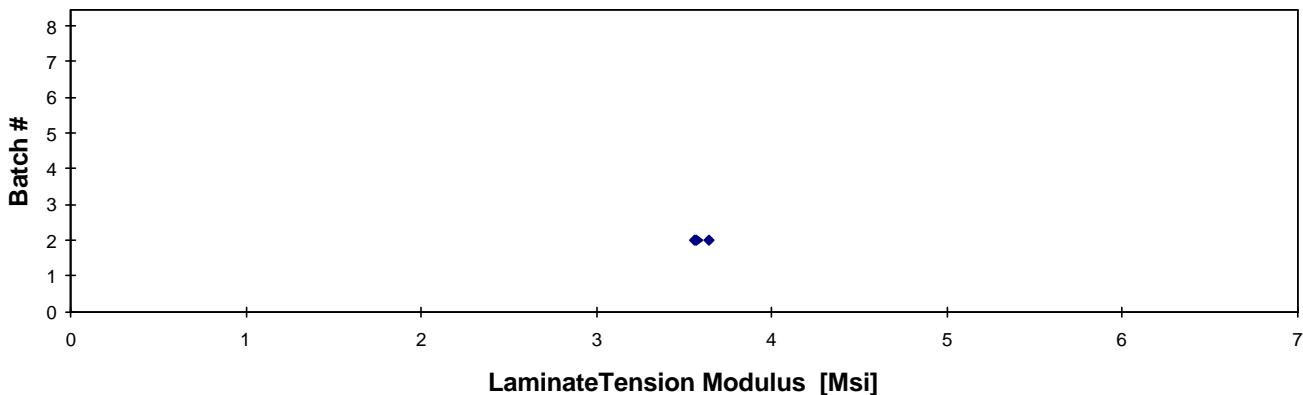
39

Laminate Tension -- (ETW - 150°)
**Strength & Modulus**
SP381/ 7781 E-Glass Cloth

normalizing t_{ply} [in]

0.0099

Specimen Number	Batch Number	Strength [ksi]	Modulus [Msi]	Poisson's Ratio	Avg. Specimen Thickn. [in]	# Plies in Laminate	Avg. t_{ply} [in]	Strength$_{norm}$ [ksi]	Modulus$_{norm}$ [Msi]
LAU2811C	2	50.701			0.108	11	0.00983	50.344	
LAU2812C	2	53.146			0.106	11	0.00966	51.878	
LAU2821C	2	51.258			0.112	11	0.01022	52.898	
LAU2822C	2	48.072			0.113	11	0.01025	49.764	
LAU2823C	2	50.751	3.290		0.113	11	0.01023	52.429	3.399
LAU2824C	2	50.749	3.312		0.111	11	0.01010	51.758	3.378
LAU2825C	2	51.284	3.169		0.113	11	0.01025	53.112	3.282
LAU2911C	2	51.776			0.110	11	0.00997	52.149	
LAU2912C	2	51.491			0.104	11	0.00950	49.395	
LAU2913C	2	53.130			0.107	11	0.00973	52.211	
LAU2914C	2	51.075			0.111	11	0.01006	51.888	
LAU2915C	2	51.359	3.356		0.109	11	0.00989	51.288	3.351
LAU2921C	2	49.696	3.279		0.111	11	0.01006	50.502	3.333
LAU2922C	2	50.999	3.245		0.110	11	0.01003	51.678	3.289
LAU2923C	2	49.796			0.110	11	0.00997	50.162	
LAU2924C	2	49.540			0.107	11	0.00972	48.645	
LAU2925C	2	51.073			0.109	11	0.00993	51.237	
LAU3111C	3	46.081	3.223	0.123	0.110	11	0.01002	46.631	3.262
LAU311XC	3	46.950	3.301	0.121	0.108	11	0.00984	46.662	3.281
LAU3113C	3	46.685	3.235	0.124	0.111	11	0.01010	47.643	3.301
LAU3114C	3	47.112			0.110	11	0.00996	47.379	
LAU3115C	3	47.786			0.108	11	0.00978	47.223	
LAU3116C	3	48.048			0.112	11	0.01015	49.261	
LAU3411C	3	44.929			0.109	11	0.00993	45.059	
LAU3412C	3	50.152			0.108	11	0.00983	49.784	
LAU3413C	3	50.877			0.110	11	0.01000	51.399	
LAU3414C	3	51.194			0.109	11	0.00991	51.226	
LAU3415C	3	49.541			0.108	11	0.00982	49.162	
LAU4111C	4	50.367	3.249	0.113	0.112	11	0.01022	52.009	3.355
LAU4112C	4	48.978	3.220	0.118	0.112	11	0.01022	50.575	3.325
LAU4113C	4	54.107	3.250	0.123	0.113	11	0.01024	55.970	3.361
LAU4114C	4	51.052			0.112	11	0.01014	52.302	
LAU4115C	4	55.704			0.112	11	0.01017	57.222	
LAU4121C	4	51.713			0.113	11	0.01023	53.430	
LAU4122C	4	47.440			0.112	11	0.01020	48.870	
LAU4123C	4	50.780			0.112	11	0.01019	52.272	
LAU4124C	4	49.245			0.112	11	0.01018	50.624	
LAU4125C	4	48.051			0.112	11	0.01020	49.493	
LAU4212C	4	54.712			0.113	11	0.01026	56.705	
LAU5111C	5	48.747	3.404	0.108	0.106	11	0.00966	47.568	3.322
LAU5112C	5	51.019	3.418	0.115	0.105	11	0.00953	49.121	3.291
LAU5113C	5	51.060	3.395	0.126	0.105	11	0.00954	49.216	3.272
LAU5114C	5	48.634			0.106	11	0.00968	47.547	
LAU5115C	5	51.130			0.107	11	0.00968	50.019	
LAU5121C	5	51.361			0.105	11	0.00959	49.749	
LAU5122C	5	46.587			0.106	11	0.00965	45.404	
LAU5123C	5	47.918			0.106	11	0.00965	46.708	
LAU5124C	5	47.842			0.107	11	0.00970	46.861	
LAU5125C	5	49.381			0.107	11	0.00969	48.353	
LAU5221C	5	49.718			0.107	11	0.00970	48.698	
LAU7114C	7	41.059	3.179	0.099	0.110	11	0.00999	41.442	3.209
LAU7122C	7	48.330			0.109	11	0.00990	48.315	
LAU7123C	7	46.121			0.108	11	0.00985	45.902	
LAU7124C	7	45.054			0.110	11	0.00996	45.309	
LAU7125C	7	49.403			0.109	11	0.00986	49.221	
LAU7215C	7	48.159			0.109	11	0.00988	48.063	
LAU7221C	7	47.403			0.108	11	0.00984	47.127	
LAU7222C	7	49.535			0.109	11	0.00989	49.466	
LAU7223C	7	46.359			0.109	11	0.00987	46.232	
LAU7224C	7	47.711	3.354	0.124	0.108	11	0.00978	47.142	3.314

|	Strength [ksi]	Modulus [Msi]	Poisson's Ratio		Avg. t_{ply} [in]	Strength$_{norm}$ [ksi]	Modulus$_{norm}$ [Msi]
Average	49.499	3.287	0.118	Average$_{norm}$	0.00993	49.662	3.313
Standard Dev.	2.520	0.077	0.008	Standard Dev.$_{norm}$		2.877	0.048
Coeff. of Var. [%]	5.090	2.335	6.965	Coeff. of Var. [%]$_{norm}$		5.793	1.435
Min. Value	41.059	3.169	0.099	Min. Value$_{norm}$	0.0095	41.442	3.209
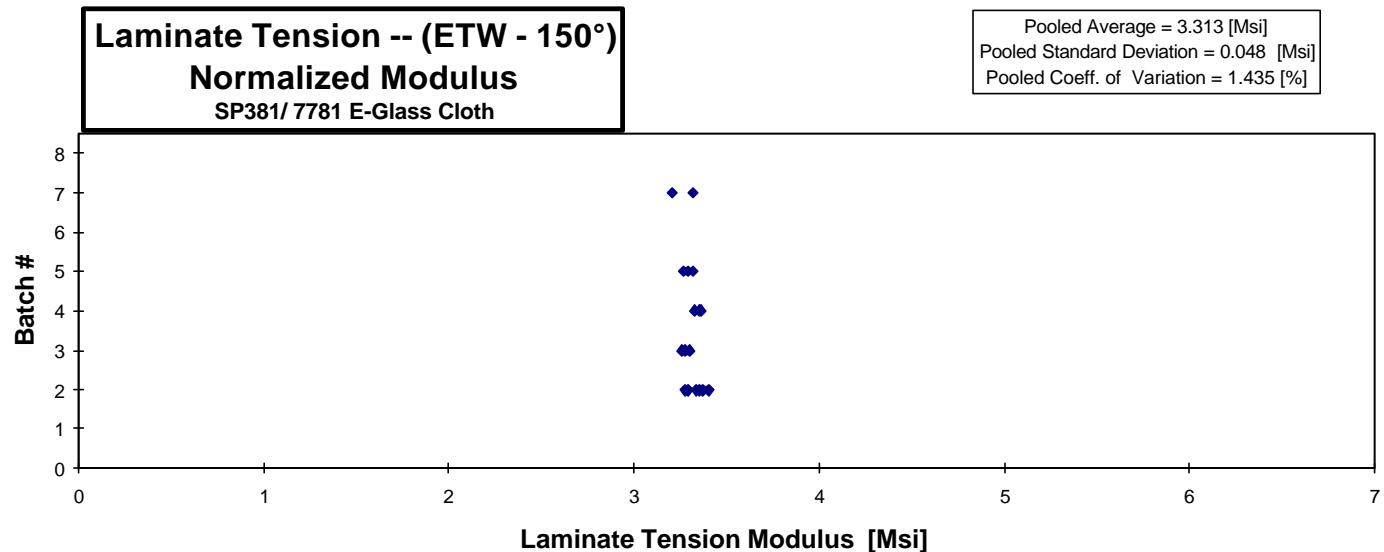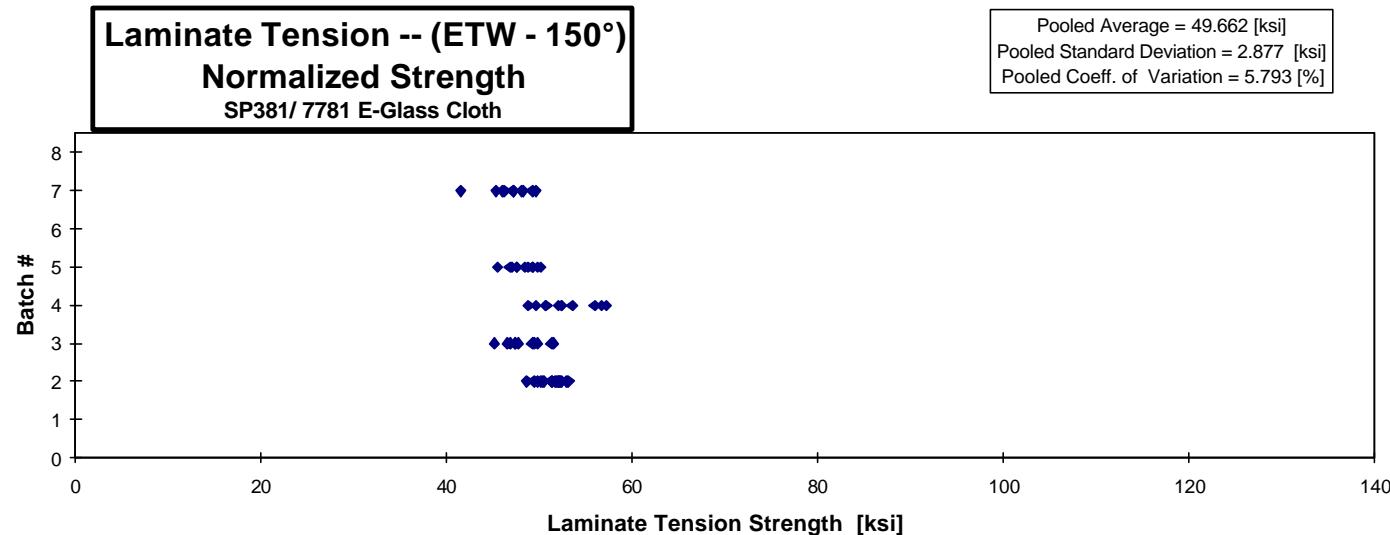
40

Laminate Tension -- (ETW - 150°)
Normalized Strength
SP381/ 7781 E-Glass Cloth

Pooled Average = 49.662 [ksi]
Pooled Standard Deviation = 2.877 [ksi]
Pooled Coeff. of Variation = 5.793 [%]

Batch #

Laminate Tension Strength [ksi]

Laminate Tension -- (ETW - 150°)
Normalized Modulus
SP381/ 7781 E-Glass Cloth

Pooled Average = 3.313 [Msi]
Pooled Standard Deviation = 0.048 [Msi]
Pooled Coeff. of Variation = 1.435 [%]

Batch #

Laminate Tension Modulus [Msi]

41

Laminate Tension -- (ETW - 180°)
**Strength & Modulus**
SP381/ 7781 E-Glass Cloth

normalizing t_{blv}
[in]
0.0099

Specimen Number	Batch Number	Strength [ksi]	Modulus [Msi]	Poisson's Ratio	Avg. Specimen Thickn. [in]	# Plies in Laminate	Avg. t_{plv} [in]	Strength$_{norm}$ [ksi]	Modulus$_{norm}$ [Msi]
LAU6212F	6	46.856	3.272	0.101	0.109	11	0.00993	47.021	3.283
LAU6213F	6	47.311	3.284	0.111	0.109	11	0.00992	47.405	3.290
LAU6221F	6	50.001			0.103	11	0.00936	47.277	
LAU6222F	6	45.700			0.105	11	0.00958	44.203	
LAU6223F	6	47.768			0.106	11	0.00959	46.291	
LAU6224F	6	43.305			0.107	11	0.00973	42.569	
LAU7111F	7	45.935	3.299	0.101	0.110	11	0.01004	46.567	3.344
LAU7113F	7	46.397	3.224	0.098	0.110	11	0.01000	46.859	3.256
LAU7115F	7	41.806			0.111	11	0.01012	42.714	
LAU7211F	7	41.704			0.109	11	0.00988	41.602	
LAU7212F	7	42.562			0.109	11	0.00988	42.497	
LAU7213F	7	43.646			0.108	11	0.00984	43.399	
LAU8111F	8	44.908	3.269	0.108	0.110	11	0.00996	45.162	3.287
LAU8112F	8	44.628	3.259	0.113	0.109	11	0.00988	44.560	3.254
LAU8113F	8	42.656			0.110	11	0.00996	42.930	
LAU8114F	8	45.839			0.109	11	0.00995	46.085	
LAU8115F	8	46.010			0.110	11	0.00997	46.334	
LAU8221F	8	46.961			0.109	11	0.00990	46.947	

	Strength [ksi]	Modulus [Msi]	Poisson's Ratio			t_{plv} [in]	Strength$_{norm}$	Modulus$_{norm}$
Average	45.222	3.268	0.105	Average$_{norm}$	0.00986	45.023	3.286
Standard Dev.	2.260	0.025	0.006	Standard Dev.$_{norm}$		1.971	0.033
Coeff. of Var. [%]	4.997	0.778	5.664	Coeff. of Var. [%]$_{norm}$		4.377	0.995
Min. Value	41.704	3.224	0.098	Min. Value$_{norm}$	0.0094	41.602	3.254
Max. Value	50.001	3.299	0.113	Max. Value$_{norm}$	0.0101	47.405	3.344
Number of Spec.	18	6	6	Number of Spec.$_{norm}$		18	6
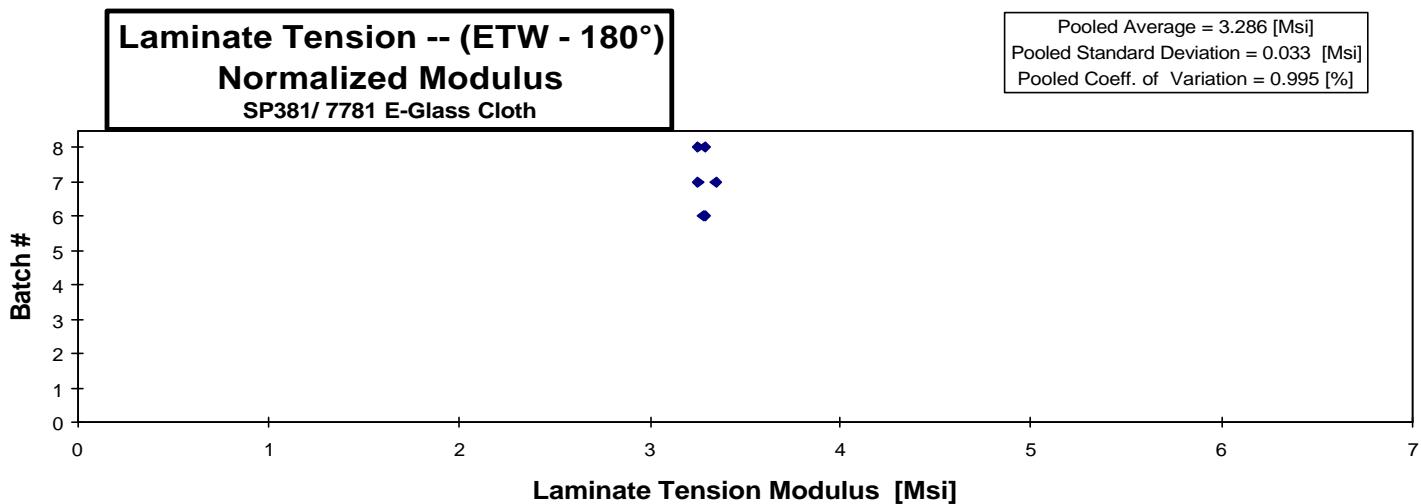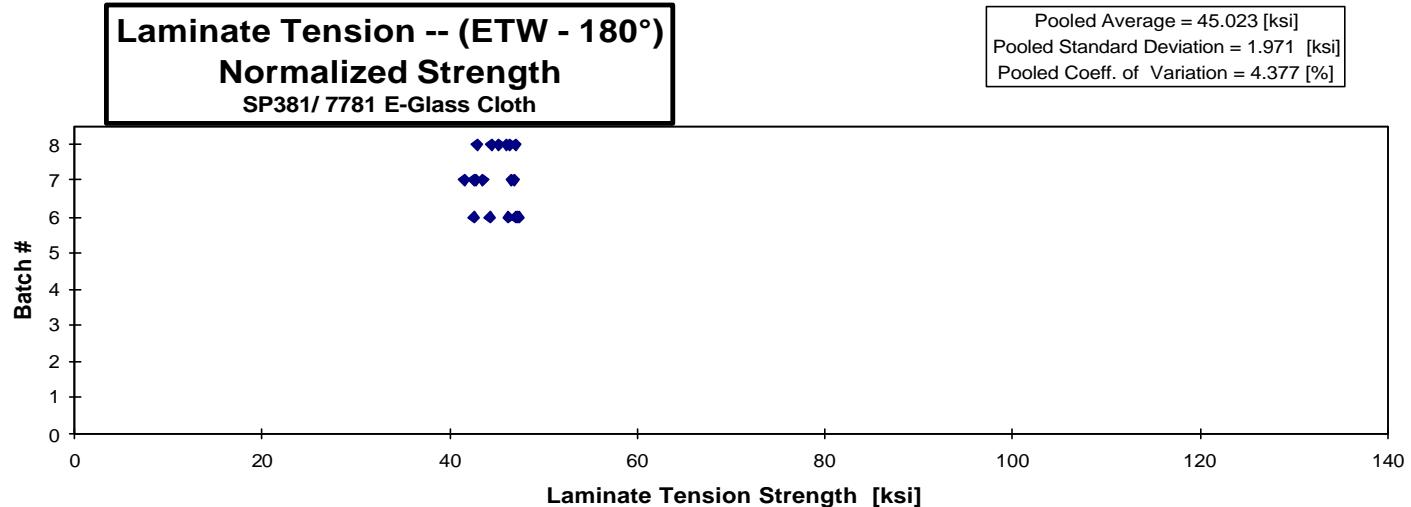
**Laminate Tension -- (ETW - 180°)
Normalized Strength**
SP381/ 7781 E-Glass Cloth

Pooled Average = 45.023 [ksi]
Pooled Standard Deviation = 1.971 [ksi]
Pooled Coeff. of Variation = 4.377 [%]

**Laminate Tension -- (ETW - 180°)
Normalized Modulus**
SP381/ 7781 E-Glass Cloth

Pooled Average = 3.286 [Msi]
Pooled Standard Deviation = 0.033 [Msi]
Pooled Coeff. of Variation = 0.995 [%]

43

Laminate Tension -- (ETD - 180°)
Strength & Modulus
SP381/ 7781 E-Glass Cloth

normalizing t_{ply}
[in]

| 0.0099 |

Specimen Number	Batch Number	Strength [ksi]	Modulus [Msi]	Poisson's Ratio	Avg. Specimen Thickn. [in]	# Plies in Laminate	Avg. t_{ply} [in]	Strength$_{norm}$ [ksi]	Modulus$_{norm}$ [Msi]
LAU6411G	6	55.650	3.365	0.114	0.109	11	0.00992	55.744	3.371
LAU6412G	6	53.113	3.368	0.116	0.109	11	0.00990	53.121	3.368
LAU6413G	6	58.226			0.109	11	0.00992	58.342	
LAU6421G	6	58.320			0.107	11	0.00975	57.427	
LAU6422G	6	58.610			0.106	11	0.00965	57.103	
LAU6423G	6	56.428			0.110	11	0.01002	57.093	
LAU7111G	7	57.316	3.000	0.118	0.110	11	0.01001	57.965	3.034
LAU7112G	7	57.912	3.308	0.111	0.110	11	0.01000	58.497	3.341
LAU7113G	7	57.570			0.110	11	0.01001	58.187	
LAU7114G	7	51.568			0.111	11	0.01011	52.649	
LAU7115G	7	55.190			0.110	11	0.01002	55.883	
LAU7221G	7	57.011			0.107	11	0.00971	55.938	
LAU8121G	8	54.607			0.108	11	0.00981	54.089	
LAU8122G	8	53.228			0.108	11	0.00986	53.017	
LAU8123G	8	55.577			0.109	11	0.00990	55.552	
LAU8124G	8	56.235	3.379	0.095	0.108	11	0.00985	55.977	3.364
LAU8211G	8	49.016			0.109	11	0.00994	49.226	
LAU8212G	8	48.318	3.328	0.103	0.109	11	0.00992	48.437	3.336

	Strength	Modulus	Poisson's				Avg. t_{ply}	Strength$_{norm}$	Modulus$_{norm}$
Average	55.216	3.291	0.109	Average$_{norm}$			0.00991	55.236	3.302
Standard Dev.	3.083	0.145	0.009	Standard Dev.$_{norm}$				2.968	0.132
Coeff. of Var. [%]	5.583	4.412	8.026	Coeff. of Var. [%]$_{norm}$				5.373	4.004
Min. Value	48.318	3.000	0.095	Min. Value $_{norm}$			0.0096	48.437	3.034
Max. Value	58.610	3.379	0.118	Max. Value $_{norm}$			0.0101	58.497	3.371
Number of Spec.	18	6	6	Number of Spec. $_{norm}$				18	6

44

Laminate Tension -- (ETD - 180°)
Normalized Strength
SP381/ 7781 E-Glass Cloth

Pooled Average = 55.236 [ksi]
Pooled Standard Deviation = 2.968 [ksi]
Pooled Coeff. of Variation = 5.373 [%]

Batch #

Laminate Tension Strength [ksi]

Laminate Tension -- (ETD - 180°)
Normalized Modulus
SP381/ 7781 E-Glass Cloth

Pooled Average = 3.302 [Msi]
Pooled Standard Deviation = 0.132 [Msi]
Pooled Coeff. of Variation = 4.004 [%]

Batch #

Laminate Tension Modulus [Msi]

45

Laminate Compression -- (RTD)
Strength & Modulus
SP381/ 7781 E-Glass Cloth

normalizing t_{ply} [in]

0.0099

Specimen Number	Batch Number	Strength [ksi]	Modulus [Msi]	Avg. Specimen Thickn. [in]	# Plies in Laminate	Avg. t_{ply} [in]	Strength$_{norm}$ [ksi]	Modulus$_{norm}$ [Msi]
LAK1142A	1	71.627		0.133	13	0.01019	73.742	
LAK1143A	1	77.220		0.133	13	0.01021	79.650	
LAK1151A	1	68.845		0.128	13	0.00987	68.605	
LAK1152A	1	71.696		0.128	13	0.00985	71.306	
LAK1153A	1	71.088		0.129	13	0.00988	70.978	
LAK1154A	1	64.875		0.130	13	0.00996	65.278	
LAK1155A	1	81.184		0.128	13	0.00985	80.743	
LAK1111A	1	73.142		0.132	13	0.01012	74.734	
LAK1112A	1	79.977		0.131	13	0.01004	81.096	
LAK1113A	1	70.452		0.132	13	0.01012	71.985	
LAK1114A	1	76.874		0.133	13	0.01021	79.293	
LAK2111A	2	76.212		0.131	13	0.01006	77.426	
LAK2112A	2	78.834		0.132	13	0.01013	80.703	
LAK2113A	2	80.188		0.133	13	0.01019	82.555	
LAK2114A	2	78.925		0.131	13	0.01010	80.488	
LAK2115A	2	76.696		0.133	13	0.01019	78.960	
LAK2116A	2	70.813		0.132	13	0.01017	72.766	
LAK2117A	2	71.262		0.133	13	0.01025	73.782	
LAK2118A	2	77.494		0.133	13	0.01021	79.933	
LAK2119A	2	69.152		0.133	13	0.01019	71.194	
LAK2131A	2	72.337		0.134	13	0.01027	75.035	
LAK2132A	2	71.499		0.133	13	0.01025	74.027	
LAL2131A	2		3.505	0.134	13	0.01031		3.651
LAL2132A	2		3.708	0.125	13	0.00964		3.610
LAL2133A	2		3.523	0.135	13	0.01036		3.688
LAL2134A	2		3.480	0.135	13	0.01037		3.644
LAL2135A	2		3.438	0.135	13	0.01039		3.609
LAL2136A	2		3.616	0.130	13	0.01001		3.655
LAL2137A	2		3.487	0.135	13	0.01037		3.652
LAL2138A	2		3.486	0.135	13	0.01039		3.658
LAL2139A	2		3.597	0.133	13	0.01022		3.714
LAL213AA	2		3.535	0.135	13	0.01039		3.711
LAL213BA	2		3.518	0.135	13	0.01040		3.696
LAK3141A	3	76.218		0.132	13	0.01006	72.338	
LAK3142A	3	75.973		0.133	13	0.00994	71.568	
LAK3143A	3	75.635		0.133	13	0.01002	79.632	
LAK3144A	3	73.390		0.133	13	0.01008	78.323	
LAK3145A	3	76.955		0.133	13	0.01006	73.543	
LAK3146A	3	72.567		0.130	13	0.01006	74.597	
LAK3147A	3	76.354		0.132	13	0.01004	71.943	
LAK3148A	3	77.100		0.133	13	0.01006	77.157	
LAK3149A	3	78.682		0.133	13	0.01000	72.931	
LAK3113A	3	77.757		0.131	13	0.01006	77.664	
LAK3114A	3	74.321		0.130	13	0.01000	75.673	
LAK4121A	4	71.204		0.131	13	0.01006	72.338	
LAK4122A	4	71.264		0.129	13	0.00994	71.568	
LAK4123A	4	78.684		0.130	13	0.01002	79.632	
LAK4124A	4	76.947		0.131	13	0.01008	78.323	
LAK4125A	4	72.390		0.131	13	0.01006	73.543	
LAK4126A	4	73.427		0.131	13	0.01006	74.597	
LAK4127A	4	70.951		0.131	13	0.01004	71.943	
LAK4128A	4	75.947		0.131	13	0.01006	77.157	
LAK4141A	4	72.202		0.130	13	0.01000	72.931	
LAK4142A	4	76.447		0.131	13	0.01006	77.664	
LAK4143A	4	74.916		0.130	13	0.01000	75.673	
LAK5211A	5	71.984		0.128	13	0.00982	71.383	
LAK5212A	5	77.645		0.124	13	0.00953	74.749	
LAK5213A	5	72.031		0.131	13	0.01009	73.402	
LAK5214A	5	76.866		0.127	13	0.00975	75.701	
LAK5215A	5	82.481		0.128	13	0.00981	81.712	
LAK5221A	5	77.840		0.128	13	0.00983	77.326	
LAK5222A	5	81.871		0.128	13	0.00982	81.219	
LAK5231A	5	76.049		0.126	13	0.00972	74.631	
LAK5232A	5	78.788		0.127	13	0.00980	77.962	
LAK5233A	5	71.576		0.126	13	0.00973	70.310	
LAK5234A	5	82.022		0.124	13	0.00955	79.122	

|	Strength	Modulus				$_{norm}$	Strength	Modulus
Average	75.071	3.536			Average$_{norm}$	0.01005	75.501	3.663
Standard Dev.	3.770	0.077			Standard Dev.$_{norm}$		3.781	0.036
Coeff. of Var. [%]	5.021	2.172			Coeff. of Var. [%]$_{norm}$		5.008	0.985
Min. Value	64.875	3.438			Min. Value$_{norm}$	0.0095	65.278	3.609
Max. Value	82.481	3.708			Max. Value$_{norm}$	0.0104	82.555	3.714
Number of Spec.	55	11			Number of Spec. $_{norm}$		55	11

46

Laminate Compression -- (RTD)
Normalized Strength
SP381/ 7781 E-Glass Cloth

Pooled Average = 75.501 [ksi]
Pooled Standard Deviation = 3.781 [ksi]
Pooled Coeff. of Variation = 5.008 [%]

Laminate Compression -- (RTD)
Normalized Modulus
SP381/ 7781 E-Glass Cloth

Pooled Average = 3.663 [Msi]
Pooled Standard Deviation = 0.036 [Msi]
Pooled Coeff. of Variation = 0.985 [%]

47
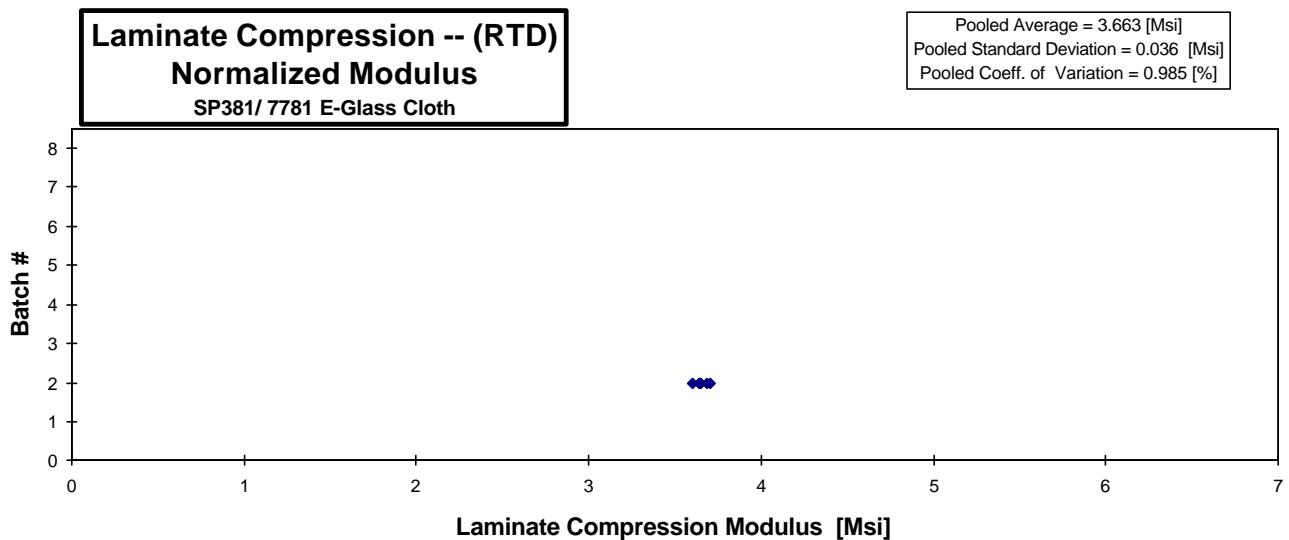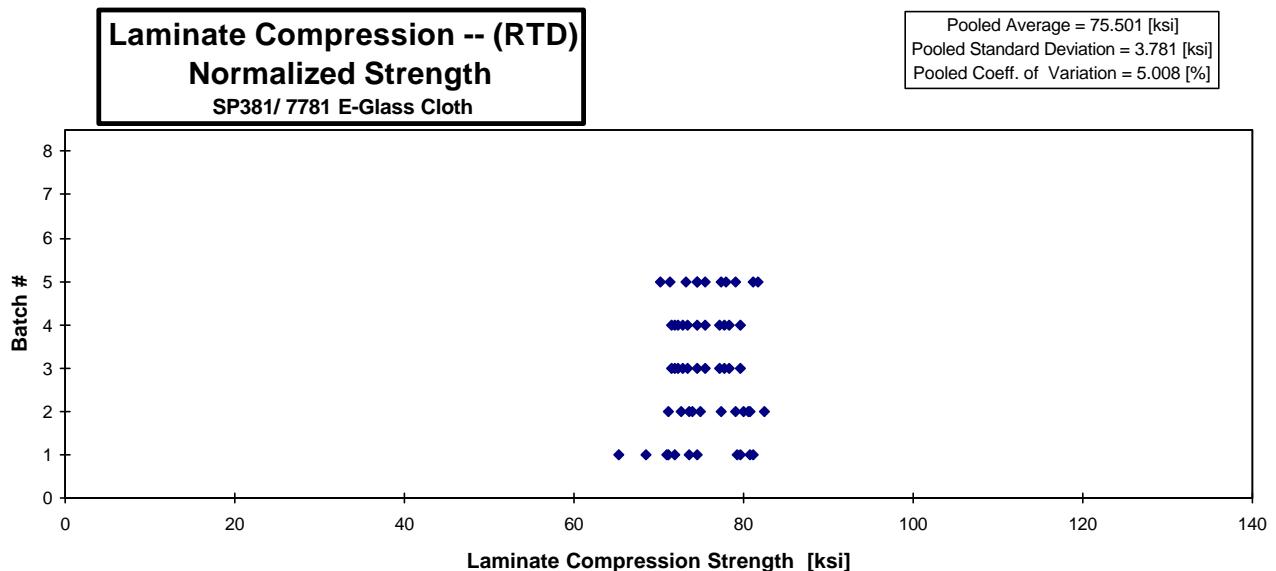
| Laminate Compression -- (CTD) Strength SP381/ 7781 E-Glass Cloth					normalizing t_{ply} [in] 0.0099	

Specimen Number	Batch Number	Strength [ksi]	Avg. Specimen Thickn. [in]	# Plies in Laminate	Avg. t_{ply} [in]	Strength$_{norm}$ [ksi]
LAK2144B	2	91.442	0.129	13	0.00988	91.300
LAK2145B	2	100.771	0.125	13	0.00960	97.678
LAK2146B	2	86.381	0.130	13	0.00996	86.918
LAK2147B	2	98.699	0.119	13	0.00913	91.068
LAK2148B	2	91.031	0.129	13	0.00988	90.889
LAK2149B	2	91.225	0.129	13	0.00994	91.615

Average	93.258	Average$_{norm}$	0.00973		91.578
Standard Dev.	5.399	Standard Dev.$_{norm}$			3.456
Coeff. of Var. [%]	5.789	Coeff. of Var. [%]$_{norm}$			3.774
Min. Value	86.381	Min. Value $_{norm}$	0.0091		86.918
Max. Value	100.771	Max. Value $_{norm}$	0.0100		97.678
Number of Spec.	6	Number of Spec. $_{norm}$			6

Laminate Compression -- (CTD)
Normalized Strength
SP381/ 7781 E-Glass Cloth

Pooled Average = 91.578 [ksi]
Pooled Standard Deviation = 3.456 [ksi]
Pooled Coeff. of Variation = 3.774 [%]

Laminate Compression -- (ETW - 150°) Strength & Modulus SP381/ 7781 E-Glass Cloth						normalizing t_{ply} [in] 0.0099		

Specimen Number	Batch Number	Strength [ksi]	Modulus [Msi]	Avg. Specimen Thickn. [in]	# Plies in Laminate	Avg. t_{ply} [in]	Strength$_{norm}$ [ksi]	Modulus$_{norm}$ [Msi]
LAK1112C	1	60.640		0.130	13	0.01000	61.252	
LAK1113C	1	60.739		0.130	13	0.00998	61.234	
LAK1114C	1	60.875		0.129	13	0.00992	61.017	
LAK1115C	1	58.964		0.129	13	0.00992	59.102	
LAK1121C	1	55.512		0.128	13	0.00983	55.103	
LAK1122C	1	65.547		0.127	13	0.00979	64.808	
LAK1141C	1	56.029		0.132	13	0.01012	57.248	
LAK1142C	1	61.250		0.129	13	0.00990	61.274	
LAK1143C	1	58.591		0.133	13	0.01025	60.662	
LAK1144C	1	63.285		0.132	13	0.01012	64.662	
LAK1145C	1	63.202		0.131	13	0.01008	64.331	
LAK2121C	2	51.896		0.133	13	0.01019	53.428	
LAK2122C	2	49.774		0.133	13	0.01019	51.244	
LAK2123C	2	55.340		0.133	13	0.01019	56.974	
LAK2124C	2	49.719		0.133	13	0.01019	51.187	
LAK2125C	2	53.066		0.133	13	0.01019	54.633	
LAK2126C	2	54.172		0.130	13	0.01002	54.825	
LAK2127C	2	58.513		0.132	13	0.01017	60.127	
LAK2128C	2	53.342		0.132	13	0.01017	54.813	
LAK2129C	2	53.101		0.133	13	0.01019	54.669	
LAK212AC	2	49.400		0.133	13	0.01019	50.859	
LAK2131C	2	55.745		0.133	13	0.01019	57.391	
LAL2111C	2		3.479	0.133	13	0.01025		3.601
LAL2112C	2		3.424	0.133	13	0.01022		3.534
LAL2113C	2		3.407	0.133	13	0.01025		3.528
LAL2114C	2		3.410	0.133	13	0.01024		3.528
LAL2115C	2		3.445	0.133	13	0.01025		3.567
LAL2116C	2		3.516	0.130	13	0.01000		3.550
LAL2117C	2		3.649	0.125	13	0.00963		3.549
LAL2118C	2		3.472	0.133	13	0.01023		3.588
LAL2119C	2		3.498	0.132	13	0.01016		3.590
LAL2121C	2		3.266	0.136	13	0.01043		3.440
LAL2122C	2		3.362	0.134	13	0.01034		3.511
LAK3121C	3	56.151		0.133	13	0.01019	57.809	
LAK3122C	3	58.462		0.132	13	0.01017	60.074	
LAK3123C	3	56.768		0.129	13	0.00994	57.010	
LAK3124C	3	61.225		0.132	13	0.01015	62.795	
LAK3125C	3	59.573		0.132	13	0.01013	60.985	
LAK3126C	3	58.498		0.133	13	0.01019	60.225	
LAK3127C	3	58.636		0.133	13	0.01019	60.367	
LAK3132C	3	59.758		0.129	13	0.00990	59.781	
LAK3133C	3	58.236		0.131	13	0.01010	59.390	
LAK3134C	3	61.095		0.131	13	0.01008	62.186	
LAK4132C	4	60.995		0.129	13	0.00988	60.900	
LAK4133C	4	61.322		0.130	13	0.01002	62.061	
LAK4134C	4	55.160		0.130	13	0.01000	55.717	
LAK4135C	4	57.783		0.129	13	0.00994	58.030	
LAK4137C	4	55.117		0.129	13	0.00992	55.246	
LAK4138C	4	57.293		0.129	13	0.00994	57.538	
LAK4139C	4	53.374		0.130	13	0.01000	53.913	
LAK4141C	4	58.512		0.128	13	0.00983	58.080	
LAK4142C	4	61.749		0.130	13	0.01000	62.372	
LAK4143C	4	59.874		0.130	13	0.00998	60.363	
LAK4144C	4	59.532		0.131	13	0.01010	60.712	
LAK5212C	5	55.979		0.127	13	0.00975	55.120	
LAK5213C	5	53.023		0.127	13	0.00973	52.137	
LAK5214C	5	55.862		0.116	13	0.00892	50.317	
LAK5221C	5	55.819		0.126	13	0.00968	54.550	
LAK5222C	5	51.311		0.117	13	0.00903	46.796	
LAK5223C	5	54.111		0.126	13	0.00973	53.175	
LAK5224C	5	52.721		0.124	13	0.00952	50.694	
LAK5231C	5	51.337		0.127	13	0.00974	50.509	
LAK5232C	5	55.740		0.122	13	0.00935	52.622	
LAK5233C	5	55.029		0.127	13	0.00976	54.227	
LAK5234C	5	49.815		0.127	13	0.00976	49.090	

|	Strength [ksi]	Modulus [Msi]		Avg. t_{ply} [in]	Strength$_{norm}$ [ksi]	Modulus$_{norm}$ [Msi]
Average	56.825	3.448	Average$_{norm}$	0.00999	57.141	3.544
Standard Dev.	3.855	0.097	Standard Dev.$_{norm}$		4.372	0.045
Coeff. of Var. [%]	6.785	2.799	Coeff. of Var. [%]$_{norm}$		7.652	1.276
Min. Value	49.400	3.266	Min. Value $_{norm}$	0.0089	46.796	3.440
Max. Value	65.547	3.649	Max. Value $_{norm}$	0.0104	64.808	3.601
Number of Spec.	54	11	Number of Spec. $_{norm}$		54	11
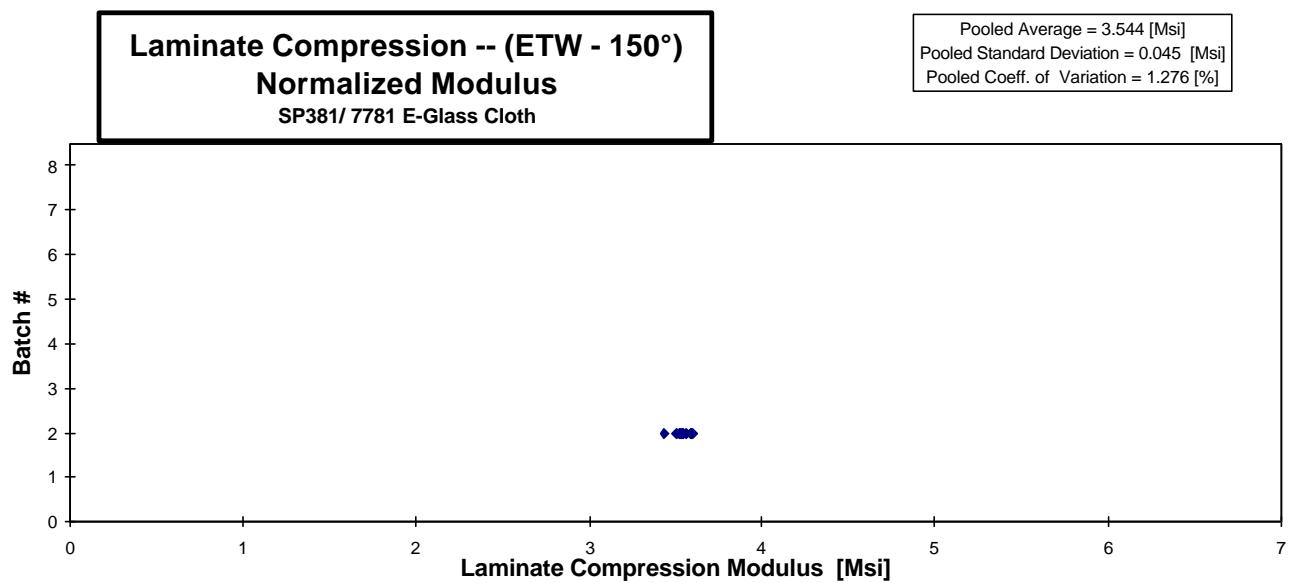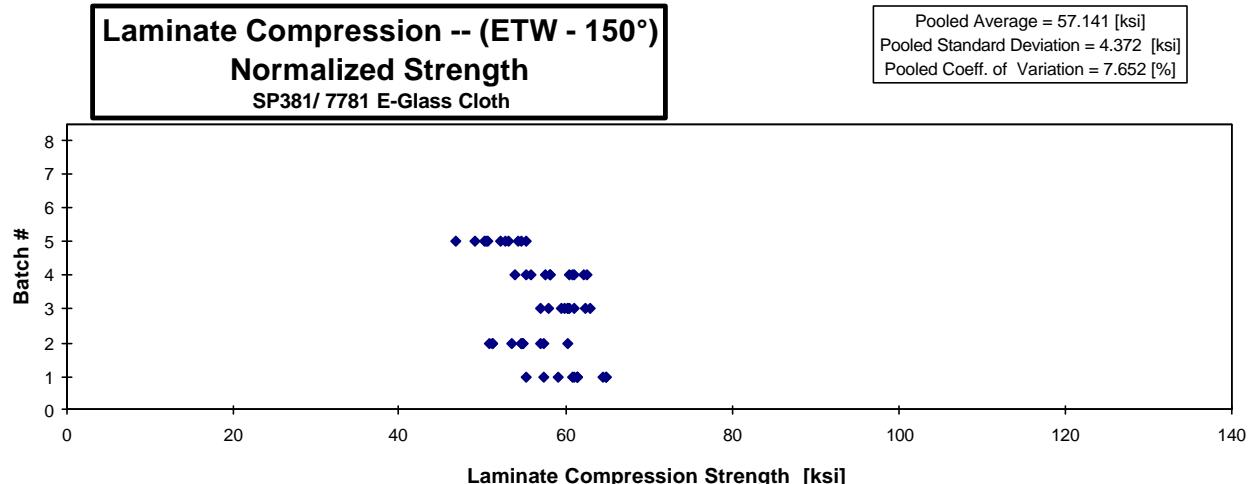
Laminate Compression -- (ETW - 150°)
Normalized Strength
SP381/ 7781 E-Glass Cloth

Pooled Average = 57.141 [ksi]
Pooled Standard Deviation = 4.372 [ksi]
Pooled Coeff. of Variation = 7.652 [%]

Laminate Compression -- (ETW - 150°)
Normalized Modulus
SP381/ 7781 E-Glass Cloth

Pooled Average = 3.544 [Msi]
Pooled Standard Deviation = 0.045 [Msi]
Pooled Coeff. of Variation = 1.276 [%]

Laminate Compression -- (ETW - 180°)
Strength & Modulus
SP381/ 7781 E-Glass Cloth

normalizing t_{ply} [in]

0.0099

Specimen Number	Batch Number	Strength [ksi]	Modulus [Msi]	Avg. Specimen Thickn. [in]	# Plies in Laminate	Avg. t_{ply} [in]	Strength$_{norm}$ [ksi]	Modulus$_{norm}$ [Msi]
LAK6121F	6	47.333		0.120	12	0.01001	47.861	
LAK6122F	6	49.097		0.121	12	0.01009	50.058	
LAK6123F	6	48.289		0.120	12	0.00997	48.614	
LAK6124F	6	46.995		0.121	12	0.01011	48.003	
LAK6125F	6	44.955		0.120	12	0.01000	45.409	
LAK6126F	6	45.220		0.120	12	0.01002	45.781	
LAK6127F	6	47.634		0.115	12	0.00960	46.191	
LAK6128F	6	46.438		0.119	12	0.00993	46.594	
LAK6129F	6	49.370		0.121	12	0.01004	50.086	
LAK6139F	6	49.790		0.122	12	0.01017	51.131	
LAL6111F	6		3.583	0.117	12	0.00974		3.527
LAL6112F	6		3.788	0.114	12	0.00948		3.626
LAK7121F	7	49.342		0.131	13	0.01008	50.243	
LAK7122F	7	46.054		0.131	13	0.01005	46.752	
LAK7123F	7	47.895		0.130	13	0.01003	48.546	
LAK7124F	7	51.089		0.130	13	0.01003	51.764	
LAK7125F	7	48.038		0.130	13	0.01000	48.533	
LAK7131F	7	50.582		0.131	13	0.01004	51.289	
LAK7132F	7	49.679		0.131	13	0.01011	50.731	
LAK7133F	7	49.698		0.132	13	0.01012	50.818	
LAK7134F	7	45.731		0.131	13	0.01006	46.486	
LAK7135F	7	46.983		0.130	13	0.01000	47.448	
LAL712AF	7		3.524	0.132	13	0.01013		3.606
LAL7123F	7		3.426	0.132	13	0.01017		3.519
LAK8115F	8	53.944		0.132	13	0.01013	55.181	
LAK8116F	8	49.930		0.138	13	0.01060	53.450	
LAK8117F	8	48.833		0.135	13	0.01037	51.167	
LAK8118F	8	45.460		0.134	13	0.01032	47.377	
LAK8119F	8	44.758		0.135	13	0.01038	46.923	
LAK8136F	8	51.026		0.133	13	0.01022	52.662	
LAK8137F	8	49.646		0.133	13	0.01023	51.324	
LAK8138F	8	48.196		0.134	13	0.01028	50.021	
LAL8112F	8		3.488	0.129	13	0.00991		3.492
LAL8113F	8		3.457	0.129	13	0.00994		3.470

|	Strength	Modulus		t_{ply}	Strength	Modulus
Average	48.286	3.544	Average$_{norm}$	0.01007	49.302	3.540
Standard Dev.	2.172	0.131	Standard Dev.$_{norm}$		2.495	0.063
Coeff. of Var. [%]	4.499	3.697	Coeff. of Var. [%]$_{norm}$		5.061	1.769
Min. Value	44.758	3.426	Min. Value$_{norm}$	0.0095	45.409	3.470
Max. Value	53.944	3.788	Max. Value$_{norm}$	0.0106	55.181	3.626
Number of Spec.	28	6	Number of Spec.$_{norm}$		28	6
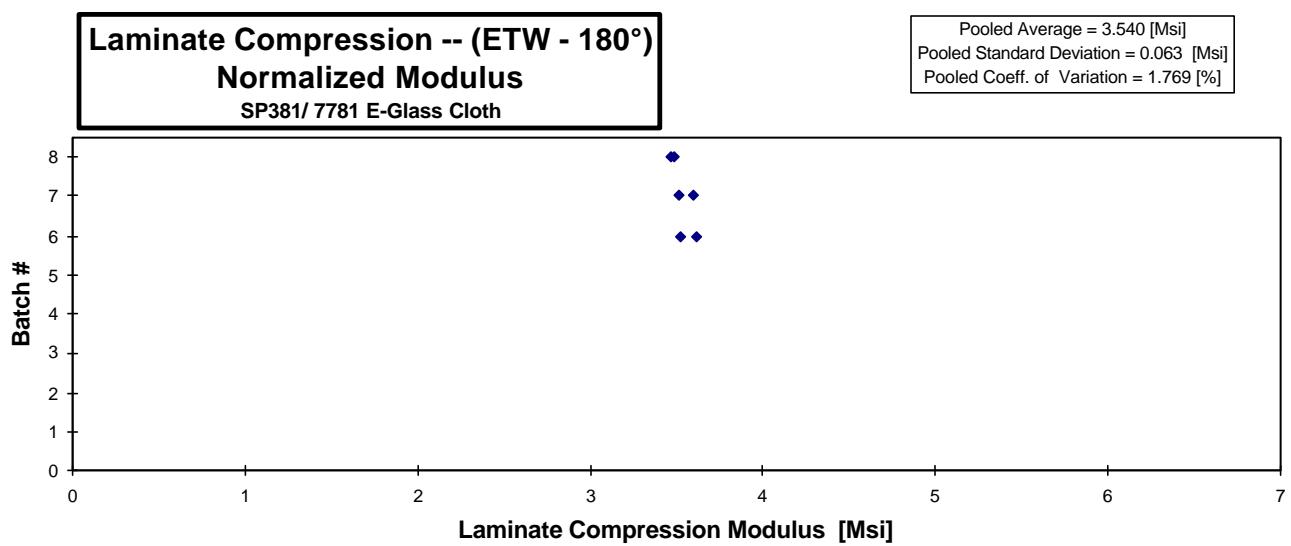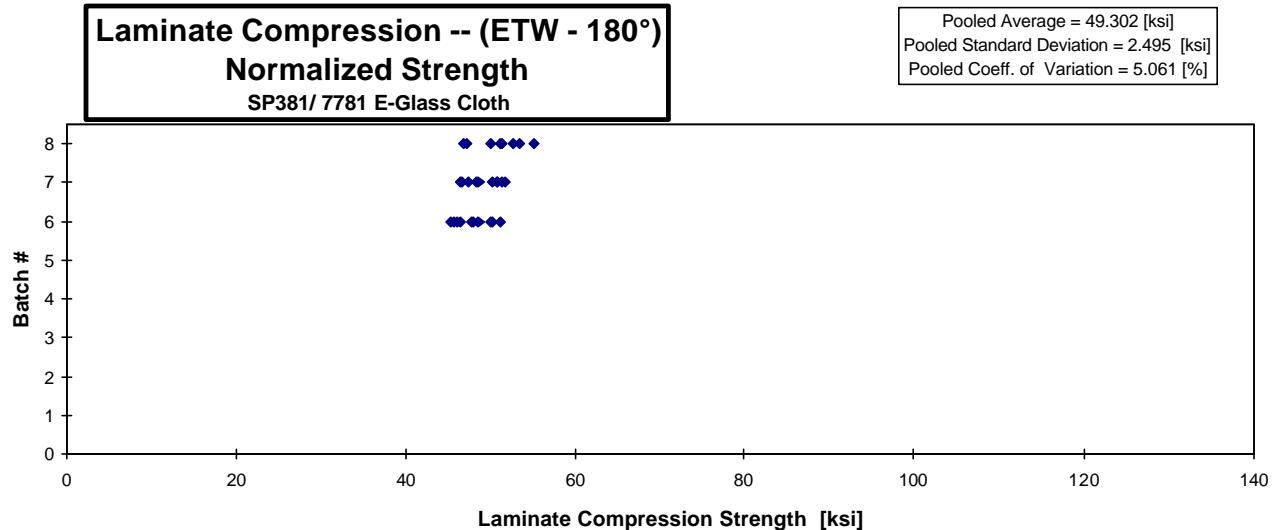
52

**Laminate Compression -- (ETW - 180°)
Normalized Strength**
SP381/ 7781 E-Glass Cloth

Pooled Average = 49.302 [ksi]
Pooled Standard Deviation = 2.495 [ksi]
Pooled Coeff. of Variation = 5.061 [%]

Batch #

Laminate Compression Strength [ksi]

**Laminate Compression -- (ETW - 180°)
Normalized Modulus**
SP381/ 7781 E-Glass Cloth

Pooled Average = 3.540 [Msi]
Pooled Standard Deviation = 0.063 [Msi]
Pooled Coeff. of Variation = 1.769 [%]

Batch #

Laminate Compression Modulus [Msi]

53

Laminate Compression -- (ETD - 180°) Strength & Modulus
SP381/ 7781 E-Glass Cloth

normalizing t_{ply} [in]

0.0099

Specimen Number	Batch Number	Strength [ksi]	Modulus [Msi]	Avg. Specimen Thickn. [in]	# Plies in Laminate	Avg. t_{ply} [in]	Strength$_{norm}$ [ksi]	Modulus$_{norm}$ [Msi]
LAK6131G	6	62.967		0.120	12	0.01002	63.749	
LAK6132G	6	63.205		0.122	12	0.01014	64.734	
LAK6133G	6	60.249		0.121	12	0.01006	61.251	
LAK6134G	6	55.190		0.124	12	0.01029	57.385	
LAK6135G	6	55.517		0.122	12	0.01016	56.978	
LAK6136G	6	59.538		0.123	12	0.01021	61.392	
LAL6116G	6		3.614	0.117	12	0.00972		3.547
LAL611AG	6		3.961	0.117	12	0.00976		3.907
LAK7126G	7	67.212		0.130	13	0.01003	68.126	
LAK7127G	7	65.016		0.130	13	0.01003	65.850	
LAK7128G	7	67.894		0.130	13	0.01000	68.567	
LAK7129G	7	64.857		0.128	13	0.00984	64.454	
LAK7136G	7	65.056		0.130	13	0.00998	65.561	
LAK7137G	7	61.249		0.131	13	0.01008	62.379	
LAL7121G	7		3.544	0.132	13	0.01016		3.637
LAL7122G	7		3.537	0.131	13	0.01007		3.599
LAK8111G	8	60.681		0.131	13	0.01005	61.600	
LAK8112G	8	58.038		0.132	13	0.01018	59.661	
LAK8113G	8	64.093		0.132	13	0.01018	65.935	
LAK8114G	8	64.123		0.133	13	0.01019	66.016	
LAK8131G	8	64.183		0.128	13	0.00982	63.647	
LAK8132G	8	70.439		0.129	13	0.00993	70.631	
LAL8118G	8		3.513	0.130	13	0.00997		3.538
LAL811AG	8		3.562	0.131	13	0.01006		3.620

	Strength	Modulus				Avg. t_{ply}	Strength$_{norm}$	Modulus$_{norm}$
Average	62.750	3.622			Average$_{norm}$	0.01004	63.773	3.641
Standard Dev.	4.067	0.169			Standard Dev.$_{norm}$		3.680	0.136
Coeff. of Var. [%]	6.481	4.679			Coeff. of Var. [%]$_{norm}$		5.770	3.733
Min. Value	55.190	3.513			Min. Value $_{norm}$	0.0097	56.978	3.538
Max. Value	70.439	3.961			Max. Value $_{norm}$	0.0103	70.631	3.907
Number of Spec.	18	6			Number of Spec. $_{norm}$		18	6

54

Laminate Compression -- (ETD - 180°)
Normalized Strength
SP381/ 7781 E-Glass Cloth

Pooled Average = 63.773 [ksi]
Pooled Standard Deviation = 3.680 [ksi]
Pooled Coeff. of Variation = 5.770 [%]

Laminate Compression -- (ETD - 180°)
Normalized Modulus
SP381/ 7781 E-Glass Cloth

Pooled Average = 3.641 [Msi]
Pooled Standard Deviation = 0.136 [Msi]
Pooled Coeff. of Variation = 3.733 [%]

55
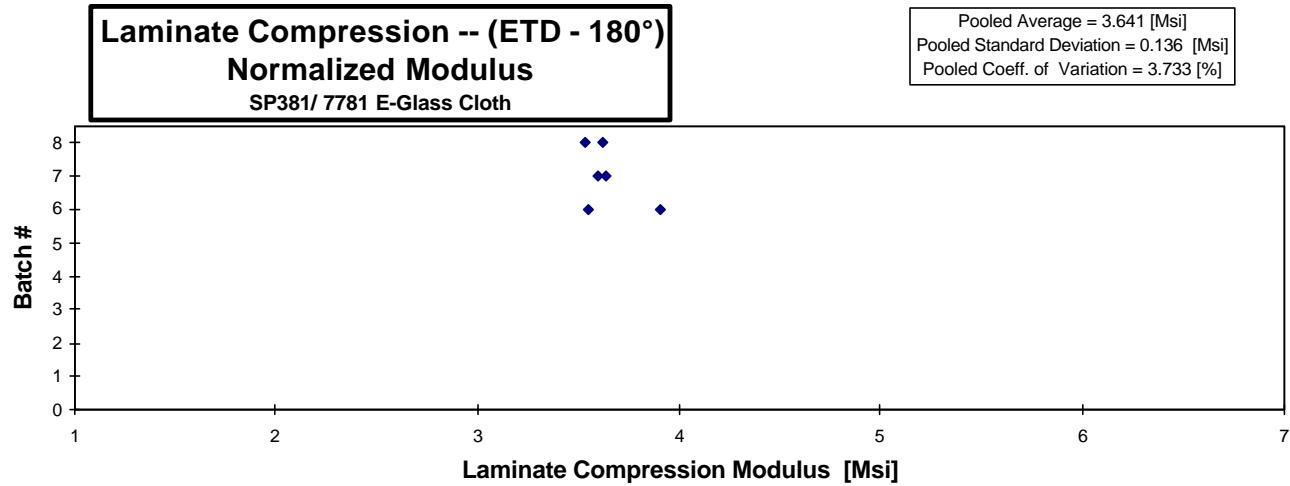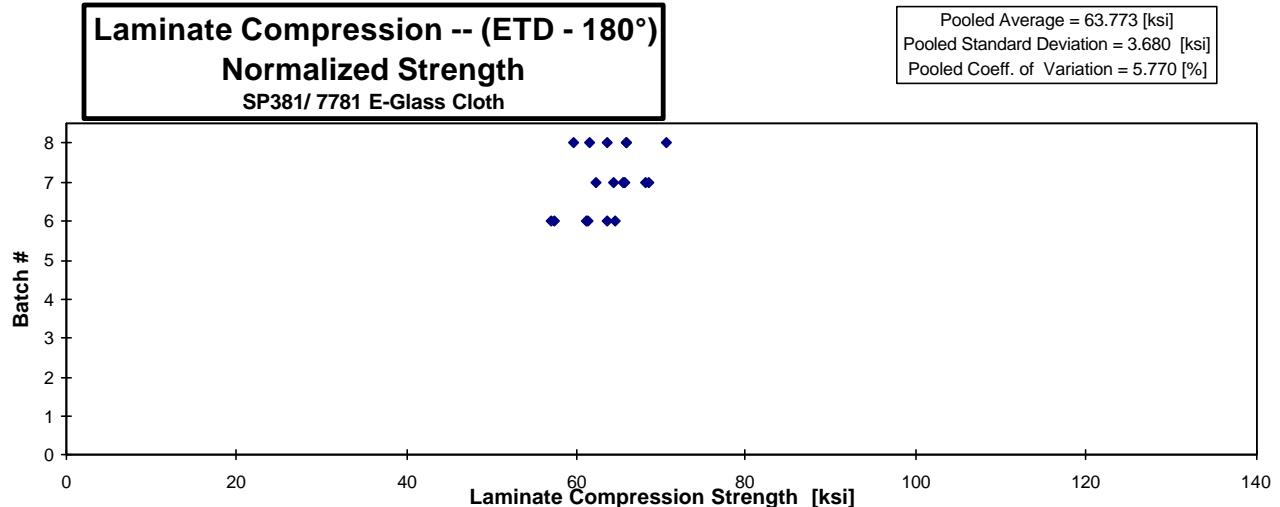
In-Plane Shear -- (RTD)
Strength & Modulus
SP381/ 7781 E-Glass Cloth

Specimen Number	Batch Number	Strength [ksi]	Modulus [Msi]	Avg. Specimen Thickn. [in]	# Plies in Laminate	Avg. t_{ply} [in]
LAN1131A	1	19.393		0.149	15	0.00993
LAN1132A	1	19.773	0.586	0.148	15	0.00989
LAN1133A	1	19.799	0.667	0.149	15	0.00994
LAN1134A	1	20.081		0.149	15	0.00994
LAN1135A	1	19.791		0.147	15	0.00981
LAN1137A	1	19.504		0.148	15	0.00988
LAN1138A	1	19.695		0.146	15	0.00974
LAN1139A	1	19.243		0.141	15	0.00943
LAN113AA	1	18.621		0.149	15	0.00992
LAN1121A	1	20.307		0.146	15	0.00974
LAN1118A	1	18.824	0.667	0.141	15	0.00937
LAN2121A	2	17.567	0.524	0.154	15	0.01026
LAN2122A	2	17.111	0.572	0.151	15	0.01004
LAN2123A	2	18.116		0.153	15	0.01022
LAN2124A	2	17.746		0.152	15	0.01015
LAN2125A	2	18.160		0.154	15	0.01027
LAN2126A	2	17.212		0.153	15	0.01019
LAN2141A	2	18.346		0.156	15	0.01037
LAN2142A	2	18.204		0.156	15	0.01038
LAN2143A	2	18.380		0.155	15	0.01030
LAN2144A	2	18.524	0.604	0.155	15	0.01032
LAN2145A	2	17.876		0.154	15	0.01025
LAN3111A	3	18.119	0.626	0.153	15	0.01018
LAN3112A	3	17.943	0.623	0.149	15	0.00991
LAN3113A	3	19.652	0.536	0.152	15	0.01016
LAN3114A	3	18.846		0.153	15	0.01018
LAN3115A	3	18.030		0.153	15	0.01020
LAN3116A	3	19.313		0.153	15	0.01020
LAN3117A	3	17.857		0.153	15	0.01019
LAN3118A	3	18.165		0.153	15	0.01017
LAN3119A	3	17.796		0.153	15	0.01017
LAN3121A	3	18.469		0.152	15	0.01014
LAN3122A	3	18.436		0.153	15	0.01017
LAN4141A	4	18.720	0.452	0.151	15	0.01009
LAN4142A	4	18.941	0.688	0.150	15	0.00998
LAN4143A	4	18.772		0.152	15	0.01015
LAN4144A	4	18.390		0.152	15	0.01014
LAN4145A	4	19.307		0.146	15	0.00977
LAN4146A	4	18.133		0.152	15	0.01014
LAN4211A	4	18.828		0.162	16	0.01012
LAN4212A	4	19.382		0.162	16	0.01011
LAN4213A	4	19.430		0.162	16	0.01011
LAN4214A	4	19.451	0.635	0.162	16	0.01015
LAN4215A	4	18.773		0.161	16	0.01008
LAN5111A	5	18.544	0.550	0.144	15	0.00960
LAN5112A	5	19.882	0.577	0.144	15	0.00960
LAN5113A	5	21.210	0.551	0.136	15	0.00905
LAN5114A	5	19.684		0.144	15	0.00963
LAN5115A	5	21.083		0.144	15	0.00958
LAN5116A	5	19.781		0.144	15	0.00963
LAN5117A	5	20.232		0.142	15	0.00947
LAN5131A	5	20.398		0.145	15	0.00966
LAN5132A	5	19.783		0.146	15	0.00971
LAN5133A	5	20.118		0.144	15	0.00957
LAN5134A	5	19.775		0.147	15	0.00982

|						
Average		18.973	0.591		Average	0.0100
Standard Dev.		0.935	0.063			
Coeff. of Var. [%]		4.931	10.727			
Min. Value		17.111	0.452		Min. Value	0.0091
Max. Value		21.210	0.688		Max. Value	0.0104
Number of Spec.		55	15			

**In-Plane Shear -- (RTD)
Measured Strength**
SP381/ 7781 E-Glass Cloth

Pooled Average = 18.973 [ksi]
Pooled Standard Deviation = 0.935 [ksi]
Pooled Coeff. of Variation = 4.931 [%]

**In-Plane Shear -- (RTD)
Measured Modulus**
SP381/ 7781 E-Glass Cloth

Pooled Average = 0.591 [Msi]
Pooled Standard Deviation = 0.063 [Msi]
Pooled Coeff. of Variation = 10.727 [%]
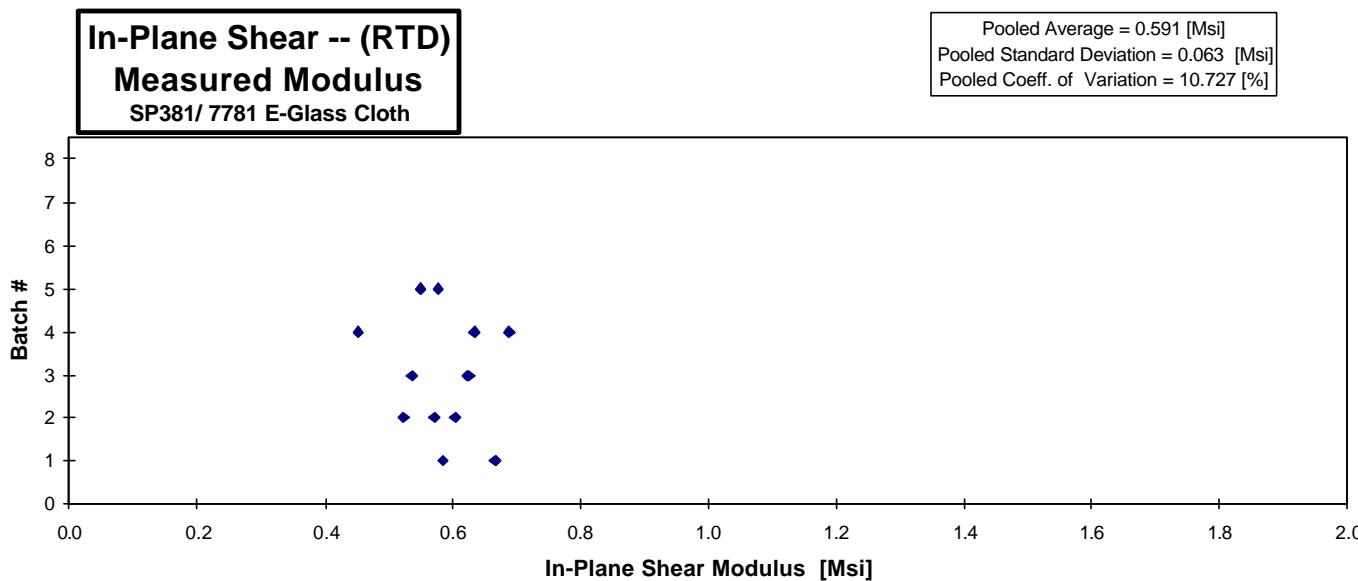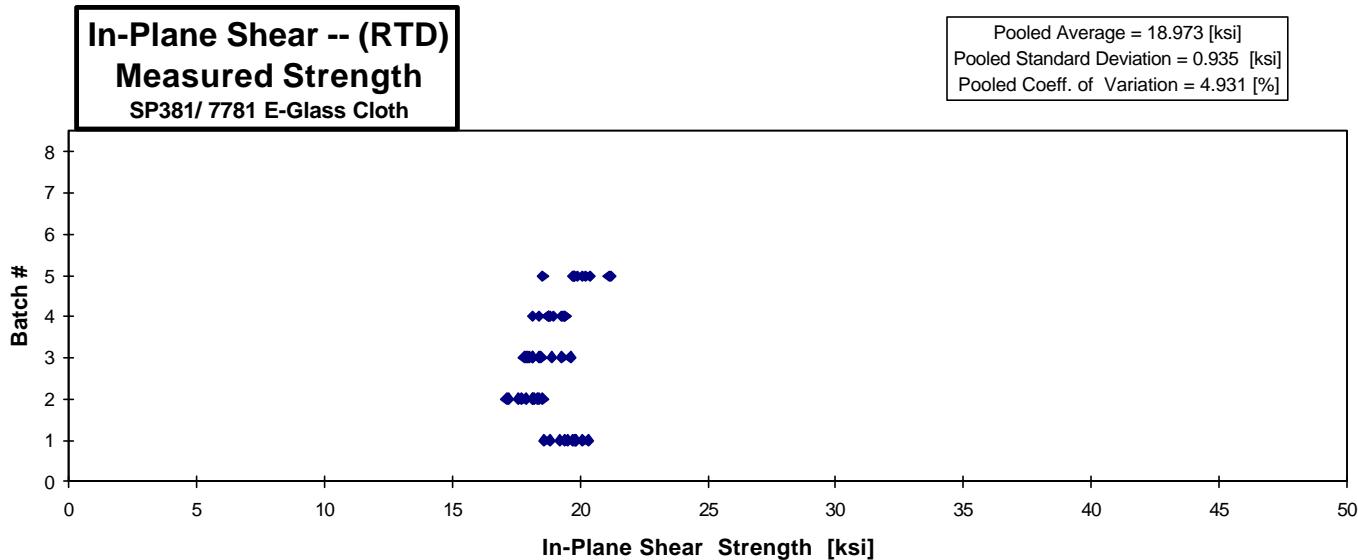
In-Plane Shear -- (CTD)
Strength & Modulus
SP381/ 7781 E-Glass Cloth

Specimen Number	Batch Number	Strength [ksi]	Modulus [Msi]	Avg. Specimen Thickn. [in]	# Plies in Laminate	Avg. t_{ply} [in]
LAN2221B	2	23.204		0.153	15	0.01019
LAN2222B	2	21.881	0.607	0.151	15	0.01006
LAN2223B	2	21.728	0.741	0.153	15	0.01023
LAN2224B	2	23.009	0.665	0.144	15	0.00961
LAN2225B	2	23.801		0.154	15	0.01029
LAN2226B	2	23.566		0.154	15	0.01029

|						
Average		22.865	0.671	Average	0.0101	
Standard Dev.		0.868	0.067			
Coeff. of Var. [%]		3.796	10.017			
Min. Value		21.728	0.607	Min. Value	0.0096	
Max. Value		23.801	0.741	Max. Value	0.0103	
Number of Spec.		6	3			

58

**In-Plane Shear -- (CTD)
Measured Strength**
SP381/ 7781 E-Glass Cloth

Pooled Average = 22.865 [ksi]
Pooled Standard Deviation = 0.868 [ksi]
Pooled Coeff. of Variation = 3.796 [%]

In-Plane Shear Strength [ksi]

**In-Plane Shear -- (CTD)
Measured Modulus**
SP381/ 7781 E-Glass Cloth

Pooled Average = 0.671 [Msi]
Pooled Standard Deviation = 0.067 [Msi]
Pooled Coeff. of Variation = 10.017 [%]

In-Plane Shear Modulus [Msi]
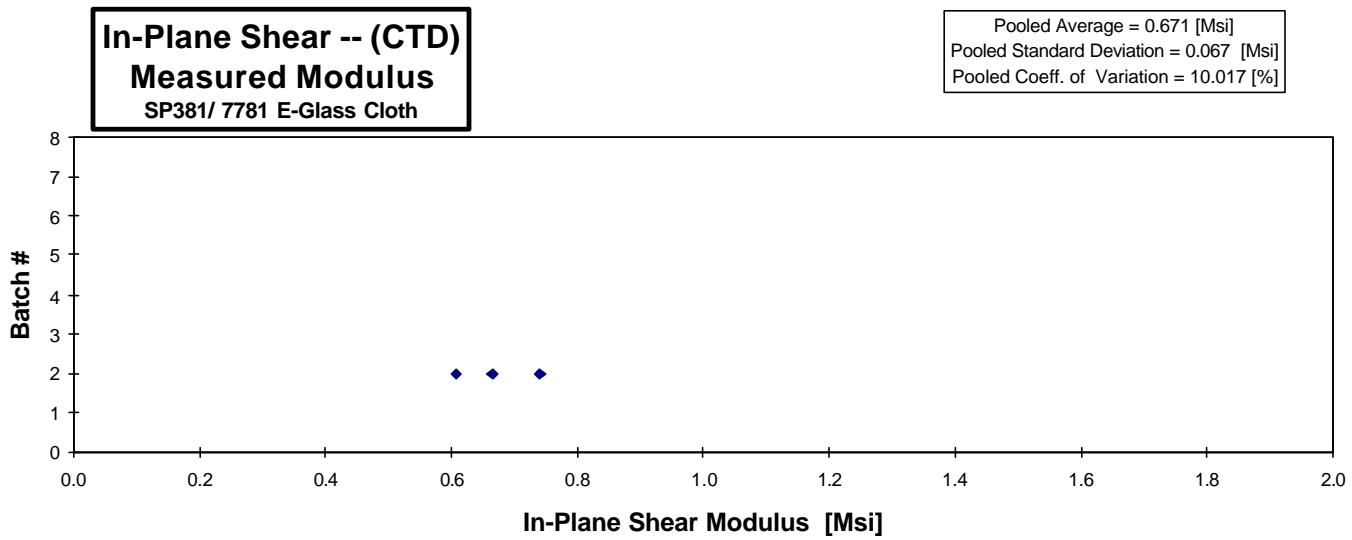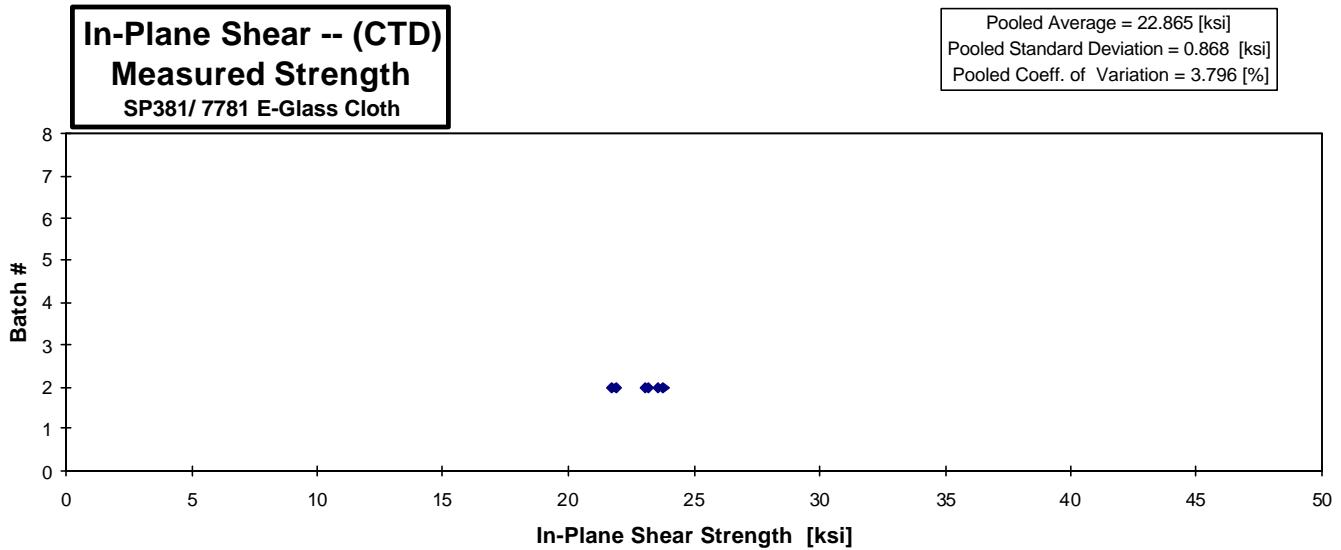
In-Plane Shear -- (ETW - 150°)
Strength & Modulus
SP381/ 7781 E-Glass Cloth

Specimen Number	Batch Number	Strength [ksi]	Modulus [Msi]	Avg. Specimen Thickn. [in]	# Plies in Laminate	Avg. t_{plv} [in]
LAN1111C	1	14.714	0.445	0.140	15	0.00935
LAN1112C	1	15.378	0.449	0.141	15	0.00937
LAN1113C	1	14.773	0.457	0.140	15	0.00933
LAN1114C	1	14.855		0.141	15	0.00943
LAN1115C	1	14.964		0.139	15	0.00926
LAN1116C	1	14.880		0.139	15	0.00925
LAN1117C	1	14.533		0.141	15	0.00939
LAN1118C	1	13.933		0.137	15	0.00910
LAN1121C	1	14.401		0.140	15	0.00931
LAN1141C	1	14.780		0.149	15	0.00995
LAN1142C	1	14.509		0.149	15	0.00992
LAN2111C	2	15.028		0.154	15	0.01026
LAN2112C	2	14.777		0.154	15	0.01026
LAN2113C	2	14.643		0.153	15	0.01021
LAN2114C	2	13.476		0.153	15	0.01020
LAN2115C	2	14.243		0.153	15	0.01021
LAN2116C	2	14.363		0.151	15	0.01004
LAN2117C	2	13.788		0.153	15	0.01022
LAN2131C	2	14.410	0.367	0.155	15	0.01033
LAN2132C	2	15.051	0.485	0.155	15	0.01035
LAN2133C	2	15.791	0.381	0.155	15	0.01036
LAN2134C	2	15.457		0.154	15	0.01028
LAN3121C	3	13.977	0.538	0.152	15	0.01014
LAN3122C	3	14.199	0.507	0.152	15	0.01017
LAN3123C	3	14.181	0.538	0.152	15	0.01012
LAN3124C	3	14.219		0.152	15	0.01015
LAN3126C	3	14.575		0.152	15	0.01015
LAN3127C	3	14.451		0.152	15	0.01014
LAN3131C	3	14.328		0.153	15	0.01020
LAN3132C	3	14.610		0.153	15	0.01017
LAN3133C	3	14.352		0.152	15	0.01015
LAN3134C	3	14.688		0.153	15	0.01019
LAN3135C	3	14.542		0.152	15	0.01016
LAN4111C	4	12.609		0.153	15	0.01018
LAN4113C	4	13.624	0.360	0.151	15	0.01007
LAN4114C	4	13.638	0.381	0.153	15	0.01018
LAN4115C	4	12.921	0.402	0.156	15	0.01039
LAN4116C	4	13.018		0.149	15	0.00990
LAN4121C	4	13.416		0.153	15	0.01023
LAN4122C	4	13.187		0.153	15	0.01020
LAN4123C	4	13.482		0.153	15	0.01020
LAN4131C	4	13.525		0.153	15	0.01021
LAN4132C	4	13.504		0.153	15	0.01020
LAN4133C	4	13.262		0.153	15	0.01019
LAN5141C	5	14.002		0.144	15	0.00957
LAN5142C	5	14.062		0.145	15	0.00968
LAN5143C	5	13.796		0.152	15	0.01015
LAN5211C	5	14.331		0.144	15	0.00962
LAN5212C	5	14.427		0.145	15	0.00966
LAN5213C	5	14.715		0.145	15	0.00968
LAN5214C	5	14.548		0.137	15	0.00914
LAN5215C	5	14.216		0.145	15	0.00964
LAN5216C	5	14.311	0.482	0.144	15	0.00957
LAN5221C	5	14.329	0.471	0.146	15	0.00972
LAN5222C	5	14.397	0.487	0.144	15	0.00959

	Strength	Modulus			
Average	14.258	0.450	Average	0.0099
Standard Dev.	0.645	0.060		
Coeff. of Var. [%]	4.526	13.232		
Min. Value	12.609	0.360	Min. Value	0.0091
Max. Value	15.791	0.538	Max. Value	0.0104
Number of Spec.	55	15		

60

In-Plane Shear -- (ETW - 150°)
Measured Strength
SP381/ 7781 E-Glass Cloth

Pooled Average = 14.258 [ksi]
Pooled Standard Deviation = 0.645 [ksi]
Pooled Coeff. of Variation = 4.526 [%]

In-Plane Shear Strength [ksi]

**In-Plane Shear -- (ETW - 150°)**
Measured Modulus
SP381/ 7781 E-Glass Cloth

Pooled Average = 0.450 [Msi]
Pooled Standard Deviation = 0.060 [Msi]
Pooled Coeff. of Variation = 13.232 [%]

In-Plane Shear Modulus [Msi]

61
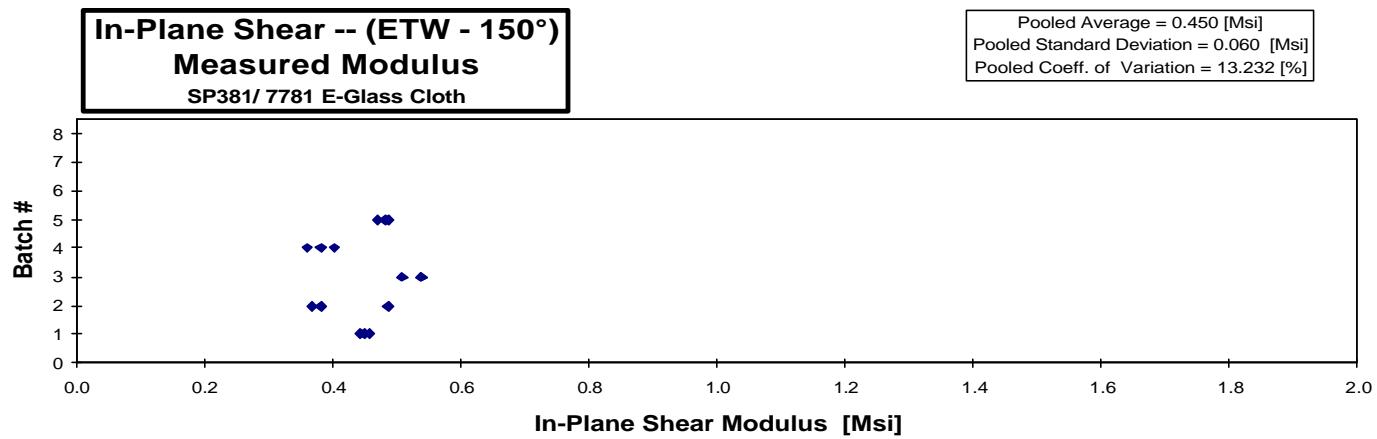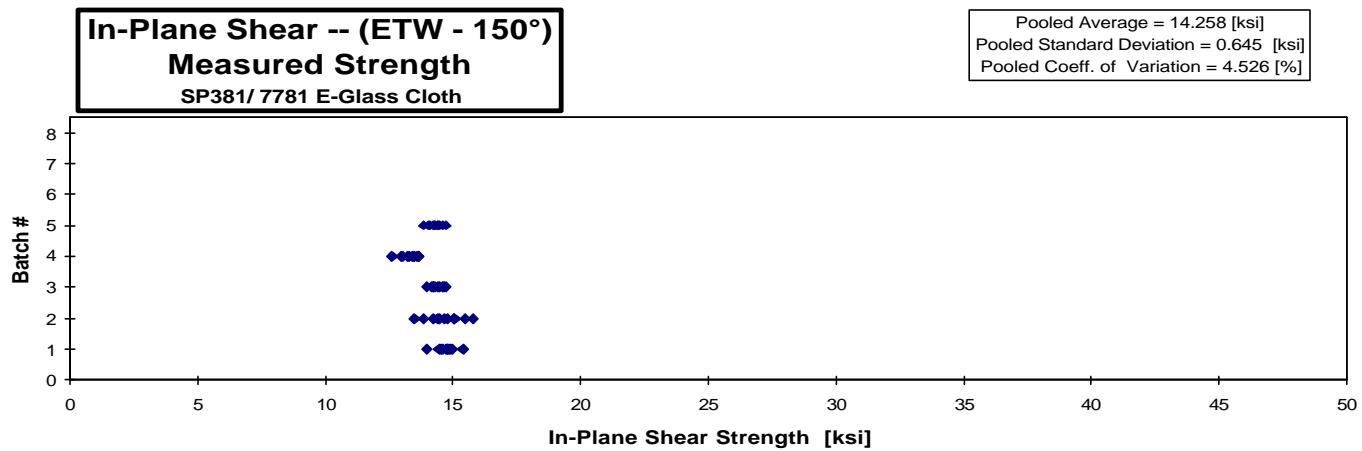
In-Plane Shear -- (ETW - 180°)
Strength & Modulus
SP381/ 7781 E-Glass Cloth

Specimen Number	Batch Number	Strength [ksi]	Modulus [Msi]	Avg. Specimen Thickn. [in]	# Plies in Laminate	Avg. t_{ply} [in]
LAN6111F	6	12.115		0.150	15	0.01001
LAN6112F	6	12.318		0.150	15	0.00998
LAN6114F	6	11.442		0.151	15	0.01006
LAN6115F	6	11.513		0.151	15	0.01008
LAN6116F	6	11.559		0.147	15	0.00977
LAN6117F	6	11.417		0.149	15	0.00996
LAN6121F	6	10.829	0.506	0.152	15	0.01013
LAN6122F	6	10.873	0.476	0.151	15	0.01008
LAN6123F	6	11.073		0.152	15	0.01012
LAN7111F	7	13.392	0.476	0.146	15	0.00971
LAN7112F	7	12.194	0.387	0.151	15	0.01006
LAN7113F	7	13.074		0.150	15	0.00997
LAN7131F	7	13.012		0.148	15	0.00986
LAN7132F	7	13.333		0.144	15	0.00958
LAN7133F	7	12.629		0.151	15	0.01006
LAN7134F	7	13.012		0.150	15	0.00998
LAN7135F	7	12.928		0.150	15	0.01002
LAN7136F	7	13.189		0.149	15	0.00991
LAN7137F	7	13.007		0.151	15	0.01008
LAN8111F	8	11.693	0.489	0.147	15	0.00979
LAN8112F	8	11.207	0.459	0.147	15	0.00978
LAN8113F	8	11.531		0.146	15	0.00975
LAN8114F	8	11.328		0.142	15	0.00948
LAN8115F	8	11.720		0.147	15	0.00983
LAN8116F	8	11.291		0.148	15	0.00986
LAN8117F	8	11.163		0.146	15	0.00976
LAN8131F	8	11.805		0.148	15	0.00989
LAN8132F	8	12.159		0.149	15	0.00992
LAN8133F	8	11.887		0.147	15	0.00977

Average		12.024	0.466			0.0099
Standard Dev.		0.803	0.041			
Coeff. of Var. [%]		6.682	8.896			
Min. Value		10.829	0.387	Min. Value		0.0095
Max. Value		13.392	0.506	Max. Value		0.0101
Number of Spec.		29	6			

62

In-Plane Shear -- (ETW - 180°)
Measured Strength
SP381/ 7781 E-Glass Cloth

Pooled Average = 12.024 [ksi]
Pooled Standard Deviation = 0.803 [ksi]
Pooled Coeff. of Variation = 6.682 [%]

In-Plane Shear Strength [ksi]

In-Plane Shear -- (ETW - 180°)
Measured Modulus
SP381/ 7781 E-Glass Cloth

Pooled Average = 0.466 [Msi]
Pooled Standard Deviation = 0.041 [Msi]
Pooled Coeff. of Variation = 8.896 [%]

In-Plane Shear Modulus [Msi]

63

In-Plane Shear -- (ETD - 180°)
Strength & Modulus
SP381/ 7781 E-Glass Cloth

Specimen Number	Batch Number	Strength [ksi]	Modulus [Msi]	Avg. Specimen Thickn. [in]	# Plies in Laminate	Avg. t_{ply} [in]
LAN6121G	6	13.970	0.494	0.150	15	0.01003
LAN6122G	6	16.031	0.555	0.152	15	0.01012
LAN6123G	6	13.912		0.145	15	0.00964
LAN6131G	6	14.743		0.150	15	0.01002
LAN6132G	6	15.272		0.150	15	0.01001
LAN6133G	6	15.226		0.149	15	0.00995
LAN7112G	7	15.725	0.482	0.150	15	0.01002
LAN7113G	7	16.409	0.491	0.150	15	0.01001
LAN7114G	7	16.317		0.149	15	0.00996
LAN7111G	7	16.649		0.149	15	0.00996
LAN7121G	7	15.632		0.150	15	0.01001
LAN7122G	7	16.721		0.151	15	0.01009
LAN8121G	8	14.091	0.493	0.151	15	0.01008
LAN8122G	8	14.355	0.517	0.150	15	0.01000
LAN8131G	8	14.921		0.148	15	0.00985
LAN8133G	8	14.626		0.140	15	0.00934
LAN8134G	8	14.893		0.148	15	0.00990
LAN8137G	8	14.459		0.149	15	0.00991

Average		15.219	0.505			0.0099
Standard Dev.		0.928	0.027			
Coeff. of Var. [%]		6.100	5.370			
Min. Value		13.912	0.482		Min. Value	0.0093
Max. Value		16.721	0.555		Max. Value	0.0101
Number of Spec.		18	6			

In-Plane Shear -- (ETD - 180°)
Measured Strength
SP381/ 7781 E-Glass Cloth

Pooled Average = 15.219 [ksi]
Pooled Standard Deviation = 0.928 [ksi]
Pooled Coeff. of Variation = 6.100 [%]

In-Plane Shear -- (ETD - 180°)
Measured Modulus
SP381/ 7781 E-Glass Cloth

Pooled Average = 0.505 [Msi]
Pooled Standard Deviation = 0.027 [Msi]
Pooled Coeff. of Variation = 5.370 [%]
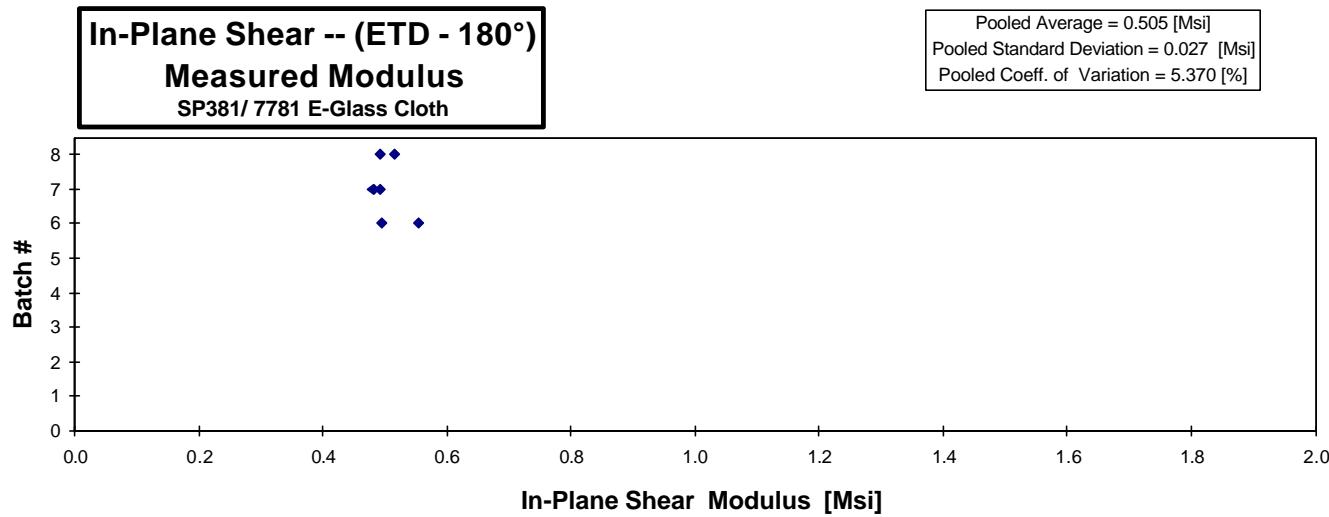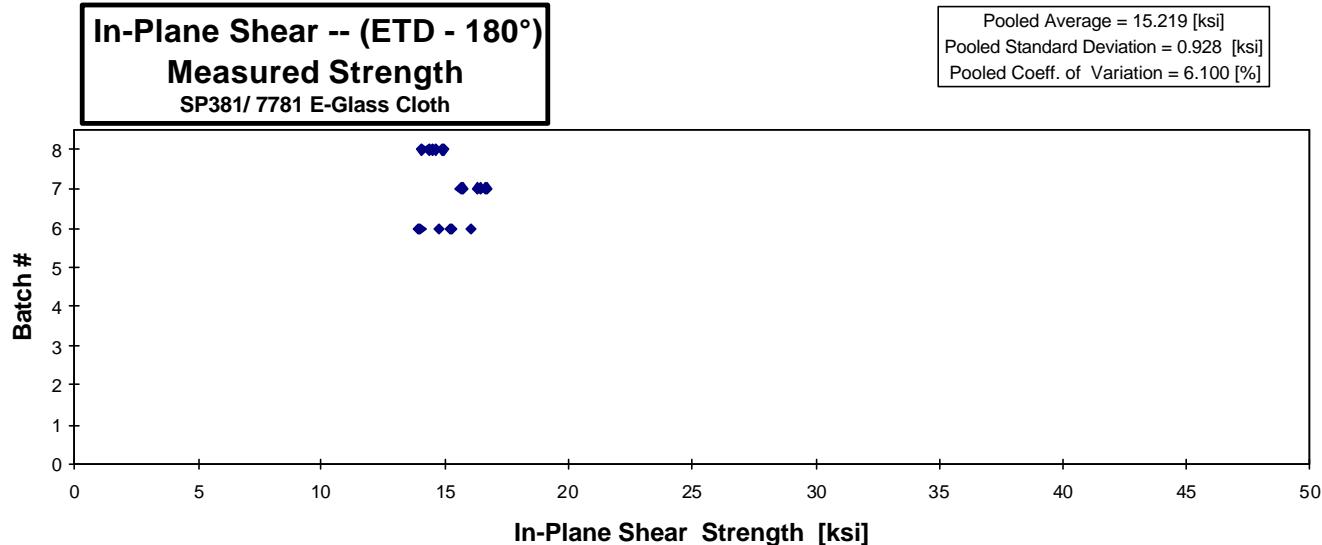
Apparent Interlaminar Shear -- (RTD)
Strength
SP381/ 7781 E-Glass Cloth

Specimen Number	Batch Number	Strength [ksi]	Avg. Specimen Thickn. [in]	# Plies in Laminate	Avg. t_{ply} [in]
LAQ1121A	1	8.319	0.125	14	0.00892
LAQ1122A	1	8.386	0.124	14	0.00884
LAQ1123A	1	8.456	0.125	14	0.00895
LAQ1124A	1	8.609	0.126	14	0.00901
LAQ1141A	1	8.254	0.128	14	0.00918
LAQ1142A	1	8.520	0.130	14	0.00929
LAQ1143A	1	8.637	0.130	14	0.00928
LAQ1144A	1	8.340	0.130	14	0.00927
LAQ1145A	1	8.504	0.130	14	0.00926
LAQ2121A	2	8.562	0.132	14	0.00945
LAQ2122A	2	8.576	0.133	14	0.00948
LAQ2123A	2	8.411	0.133	14	0.00950
LAQ2124A	2	8.486	0.131	14	0.00935
LAQ2125A	2	8.615	0.132	14	0.00943
LAQ2126A	2	8.566	0.132	14	0.00940
LAQ2127A	2	8.895	0.131	14	0.00933
LAQ2128A	2	8.808	0.131	14	0.00933
LAQ2129A	2	8.982	0.133	14	0.00950
LAQ3121A	3	7.982	0.136	14	0.00968
LAQ3123A	3	7.880	0.135	14	0.00967
LAQ3124A	3	7.691	0.136	14	0.00973
LAQ3125A	3	7.921	0.135	14	0.00964
LAQ3126A	3	7.835	0.136	14	0.00973
LAQ3127A	3	7.857	0.136	14	0.00970
LAQ3128A	3	7.945	0.136	14	0.00974

Average	8.361	Average	0.00939
Standard Dev.	0.354		
Coeff. of Var. [%]	4.235		
Min. Value	7.691	Min. Value	0.0088
Max. Value	8.982	Max. Value	0.0097
Number of Spec.	25		

66

Apparent Interlaminar Shear -- (RTD)
Measured Strength
SP381/ 7781 E-Glass Cloth

Pooled Average = 8.361 [ksi]
Pooled Standard Deviation = 0.354 [ksi]
Pooled Coeff. of Variation = 4.235 [%]
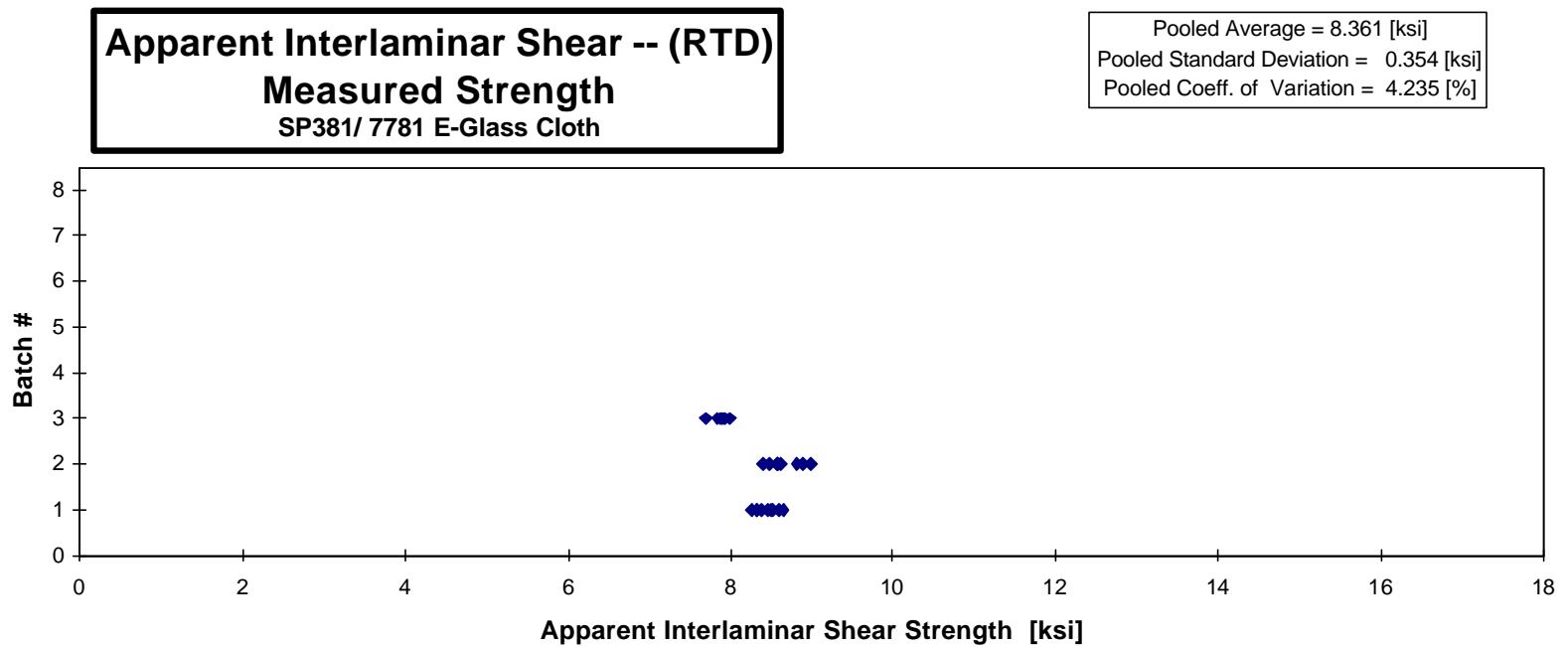
3.2.3 Representative Shear Stress-Strain Curve

The following stress-strain curve is representative of the 7781 E-glass / SP381 prepreg system. The tension and compression stress-strain curves are not presented in graphical form. If strain design allowables from these tests are required, simple one-dimensional linear stress-strain relationships may be used to obtain corresponding strain design values. This process should approximate tensile and compressive strain behavior relatively well but may produce extremely conservative strain values in shear due to the nonlinear behavior. A more realistic approach for shear strain design allowables is to use a maximum strain value of 5% (reference MIL-HDBK-17-1E, section 5.7.6). If a nonlinear analysis of the material's shear behavior is required, the curve-fit of the shear stress-strain curve may be used. The representative shear stress-strain curve was obtained by taking the average of all the sample shear curves and determining the best-fit line through the data. The actual data points also presented on the chart to demonstrate material variability.

Shear Stress vs. Shear Strain, RTD

$$y^{-1} = a + b/x$$
$$r^2 = 0.99971065$$
$$a = 6.5311365e\text{-}05$$
$$b = 1.1842552e\text{-}06$$
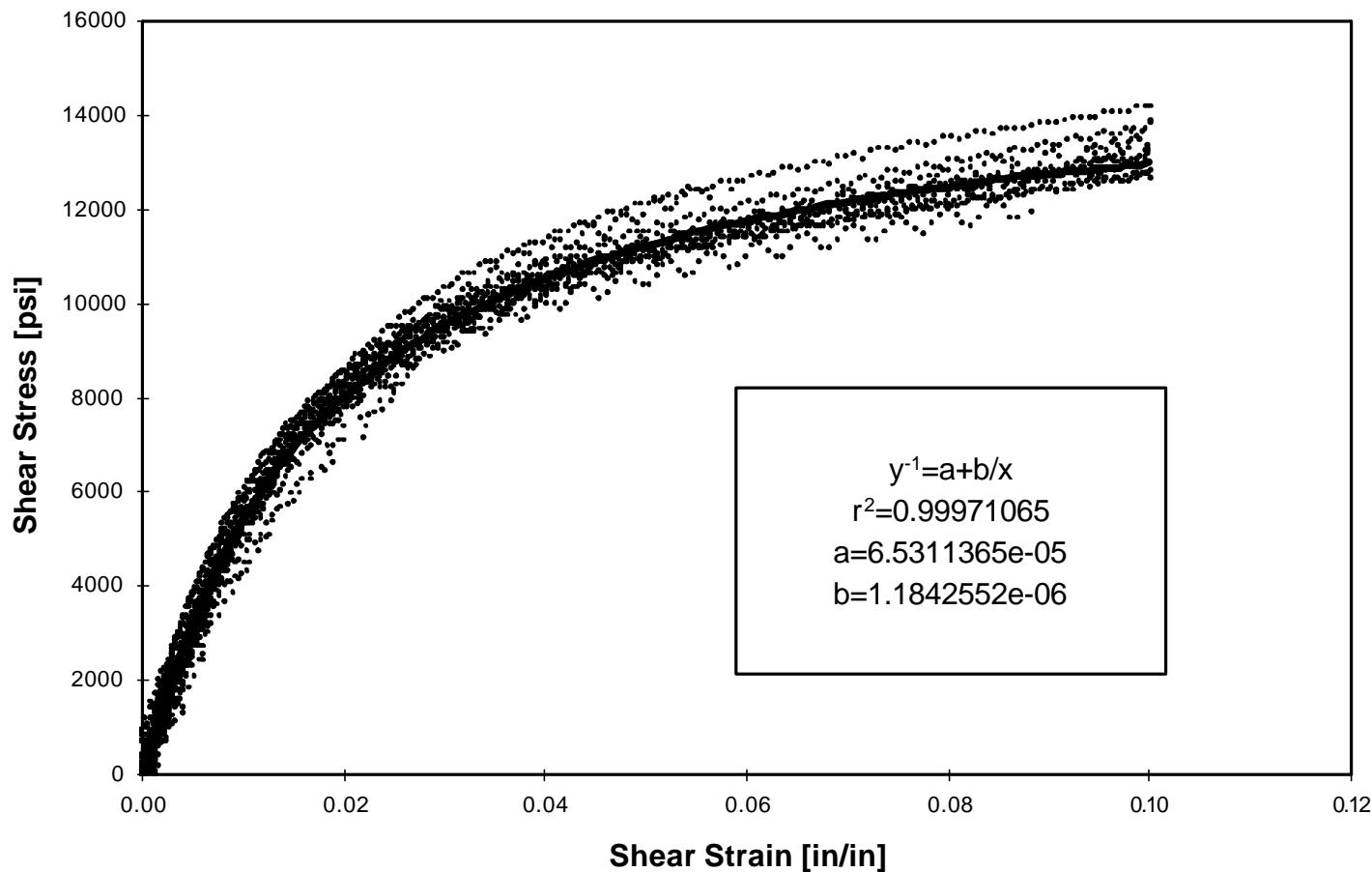
Representative shear stress-strain curve for 7781 / SP381, tested at room temperature ambient condition.

3.3 Statistical Results

3.3.1 Plot by Condition

DISTRIBUTION OF GROUPED DATA FOR DIFFERENT TEST CONDITIONS

SP381/ 7781 E-Glass Cloth
Cirrus

DISTRIBUTION OF GROUPED DATA FOR DIFFERENT TEST CONDITIONS

SP381/ 7781 E-Glass Cloth
Cirrus
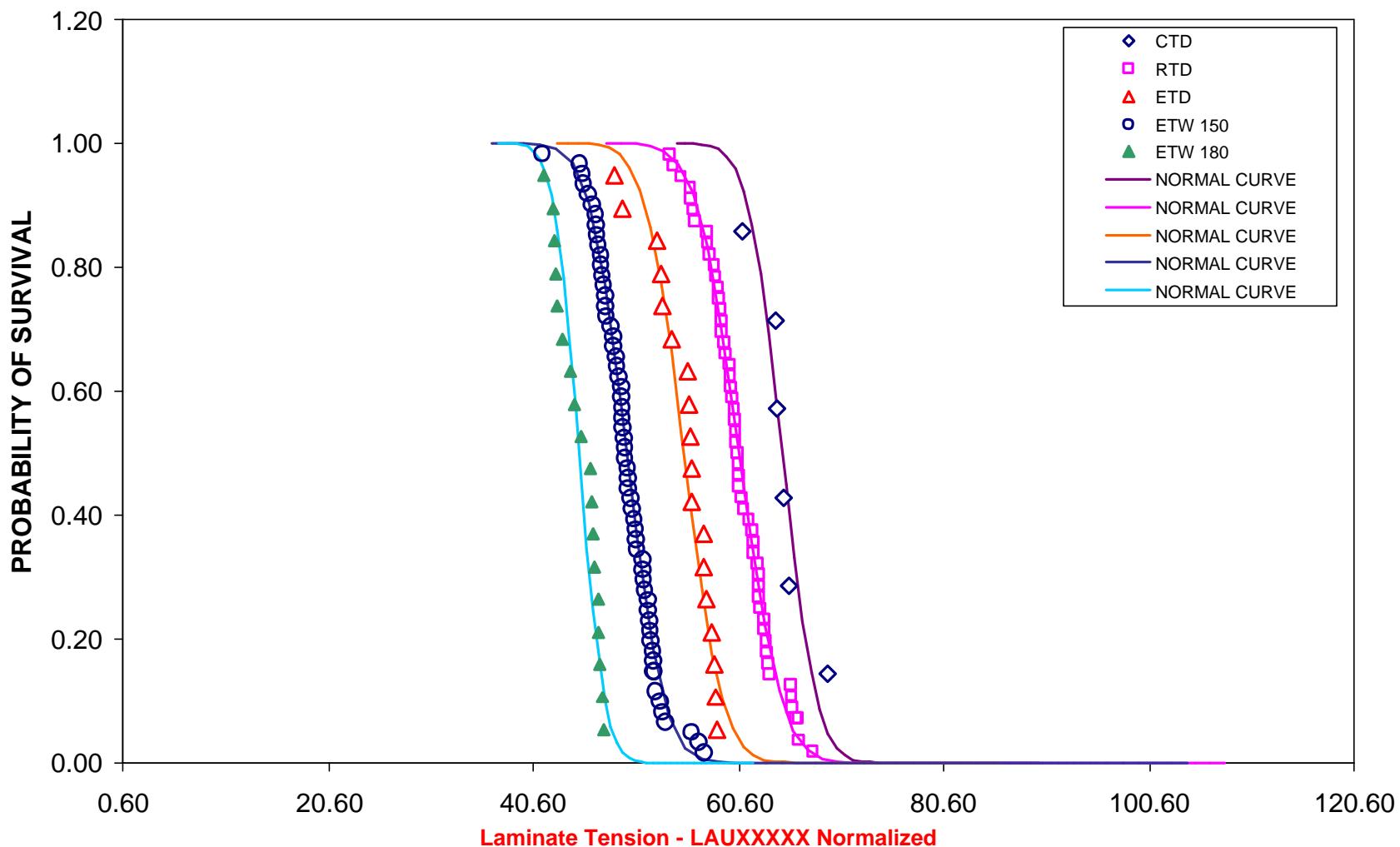
DISTRIBUTION OF GROUPED DATA FOR DIFFERENT TEST CONDITIONS

SP381/ 7781 E-Glass Cloth
Cirrus
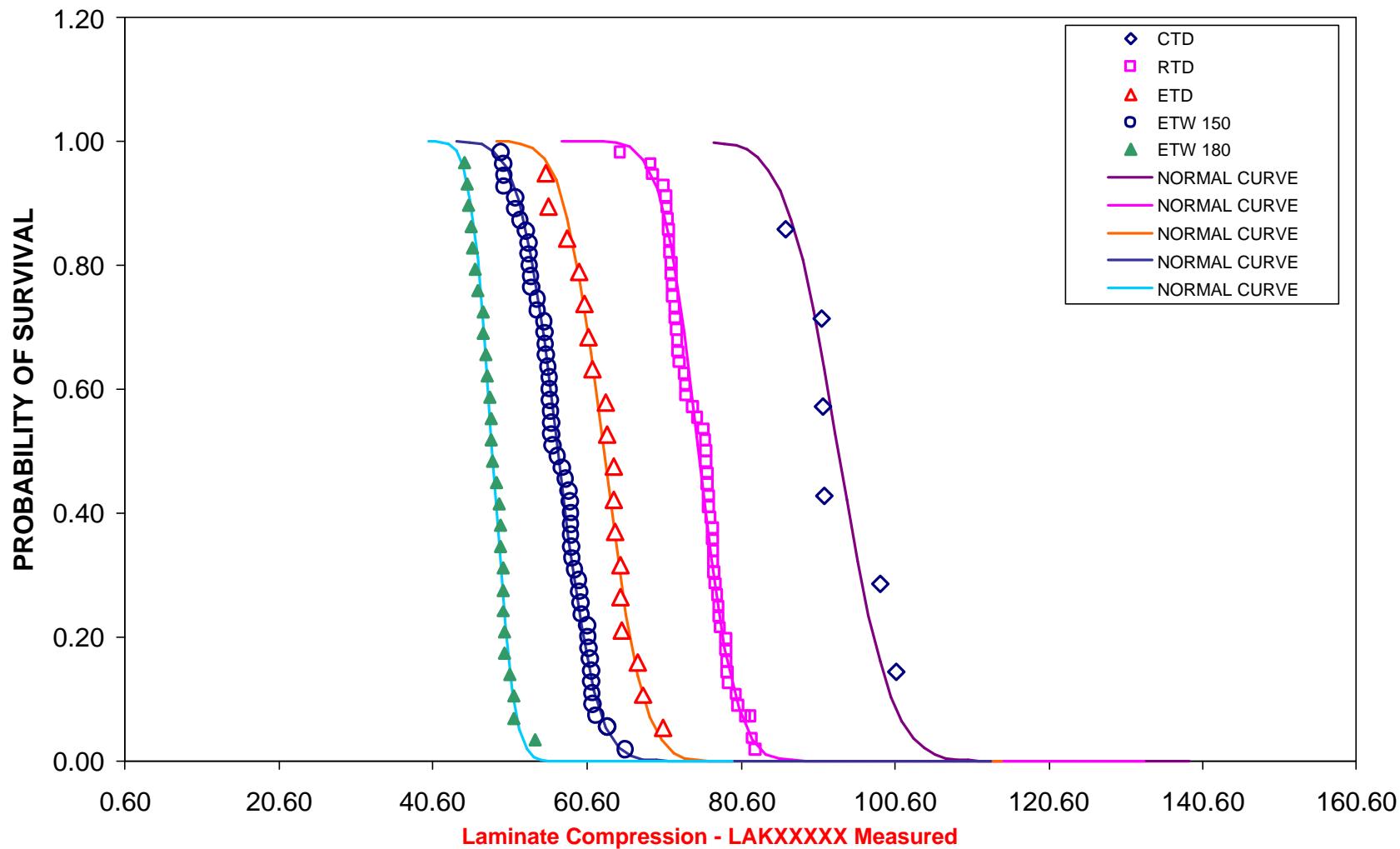
DISTRIBUTION OF GROUPED DATA FOR DIFFERENT TEST CONDITIONS

SP381/ 7781 E-Glass Cloth
Cirrus
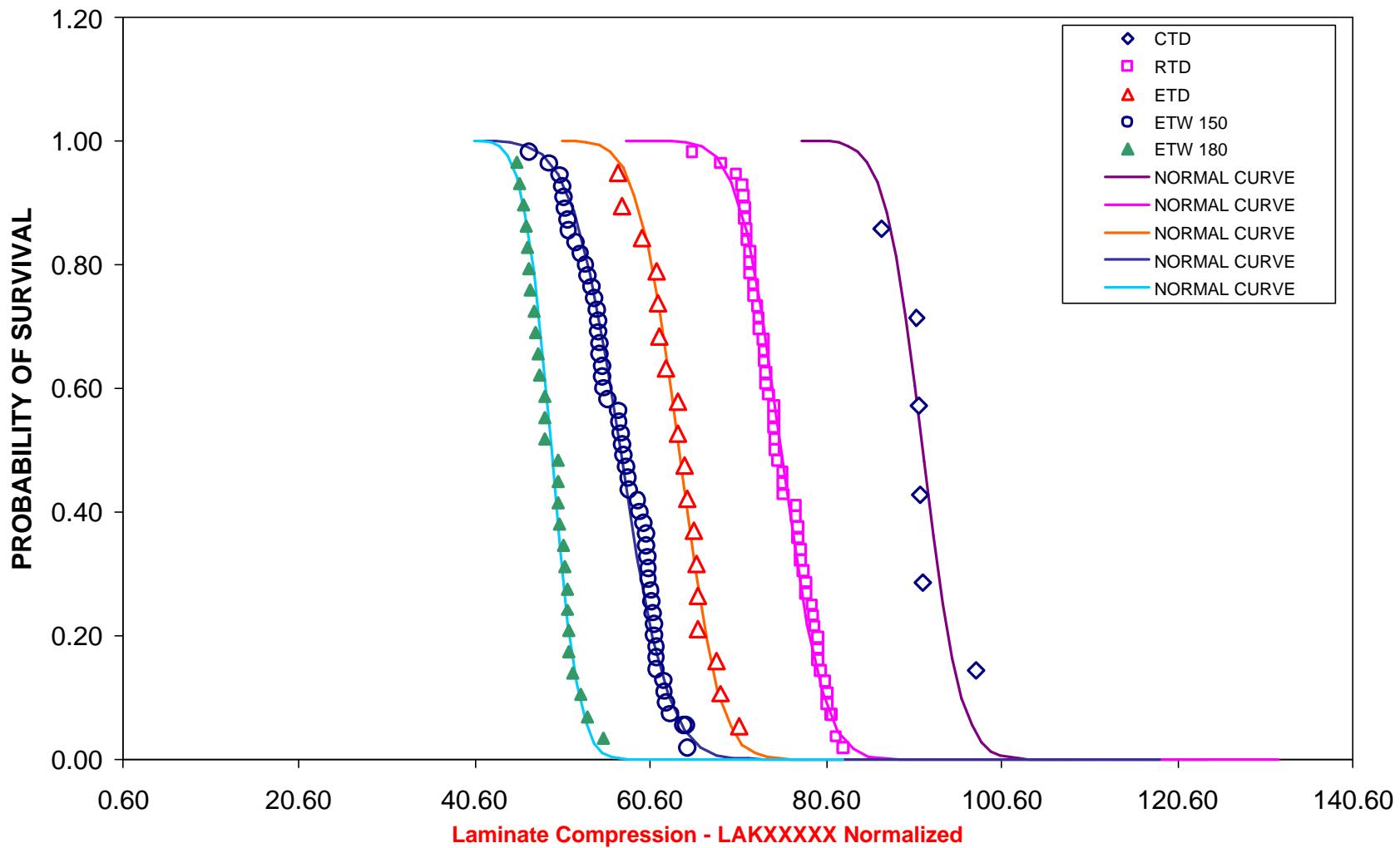
DISTRIBUTION OF GROUPED DATA FOR DIFFERENT TEST CONDITIONS

SP381/ 7781 E-Glass Cloth
Cirrus

DISTRIBUTION OF GROUPED DATA FOR DIFFERENT TEST CONDITIONS

SP381/ 7781 E-Glass Cloth
Cirrus
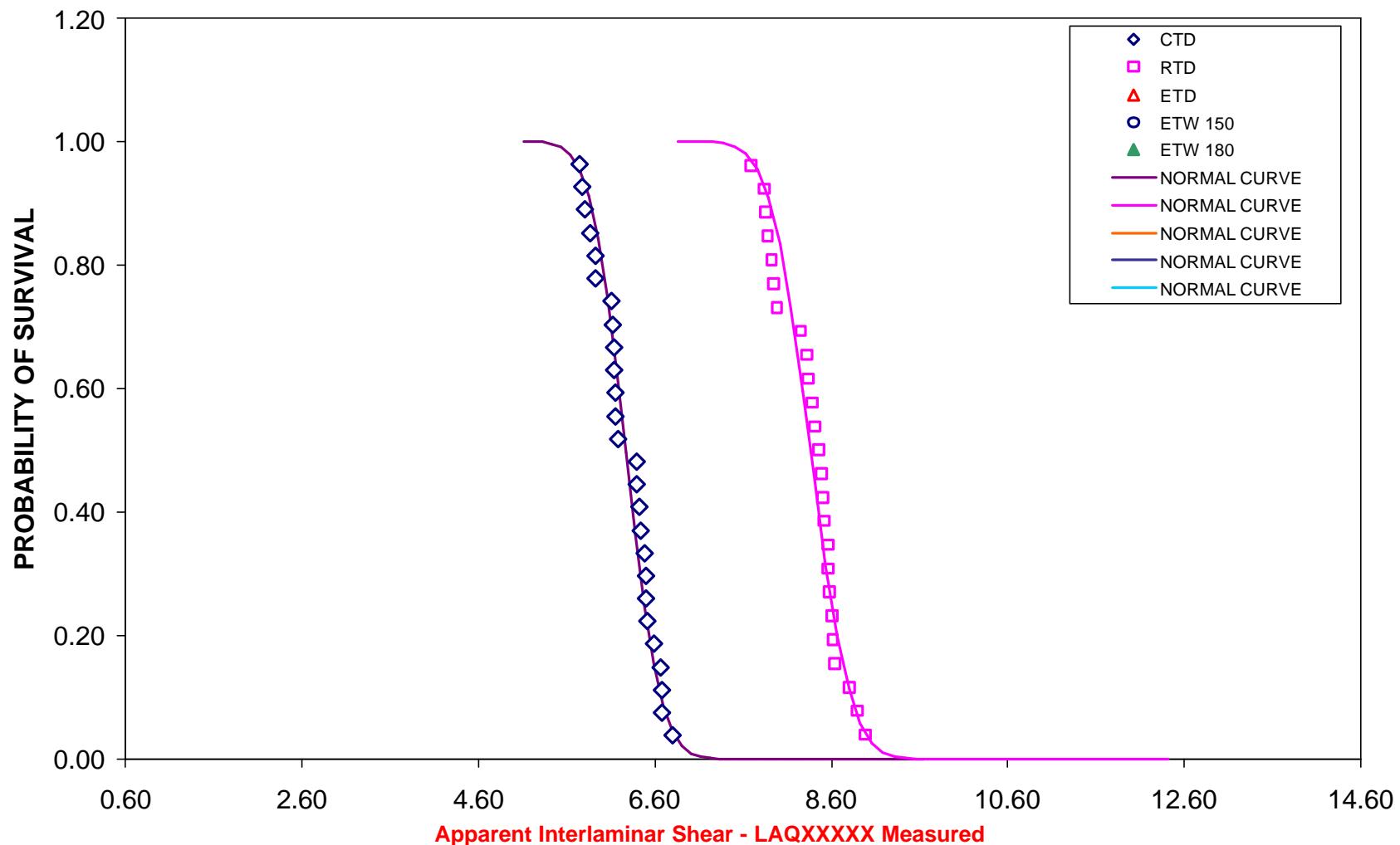
3.3.2 Plot of Pooled Data

DISTRIBUTION OF POOLED DATA

SP381/ 7781 E-Glass Cloth

Cirrus

Laminate Tension - LAUXXXXX Measured
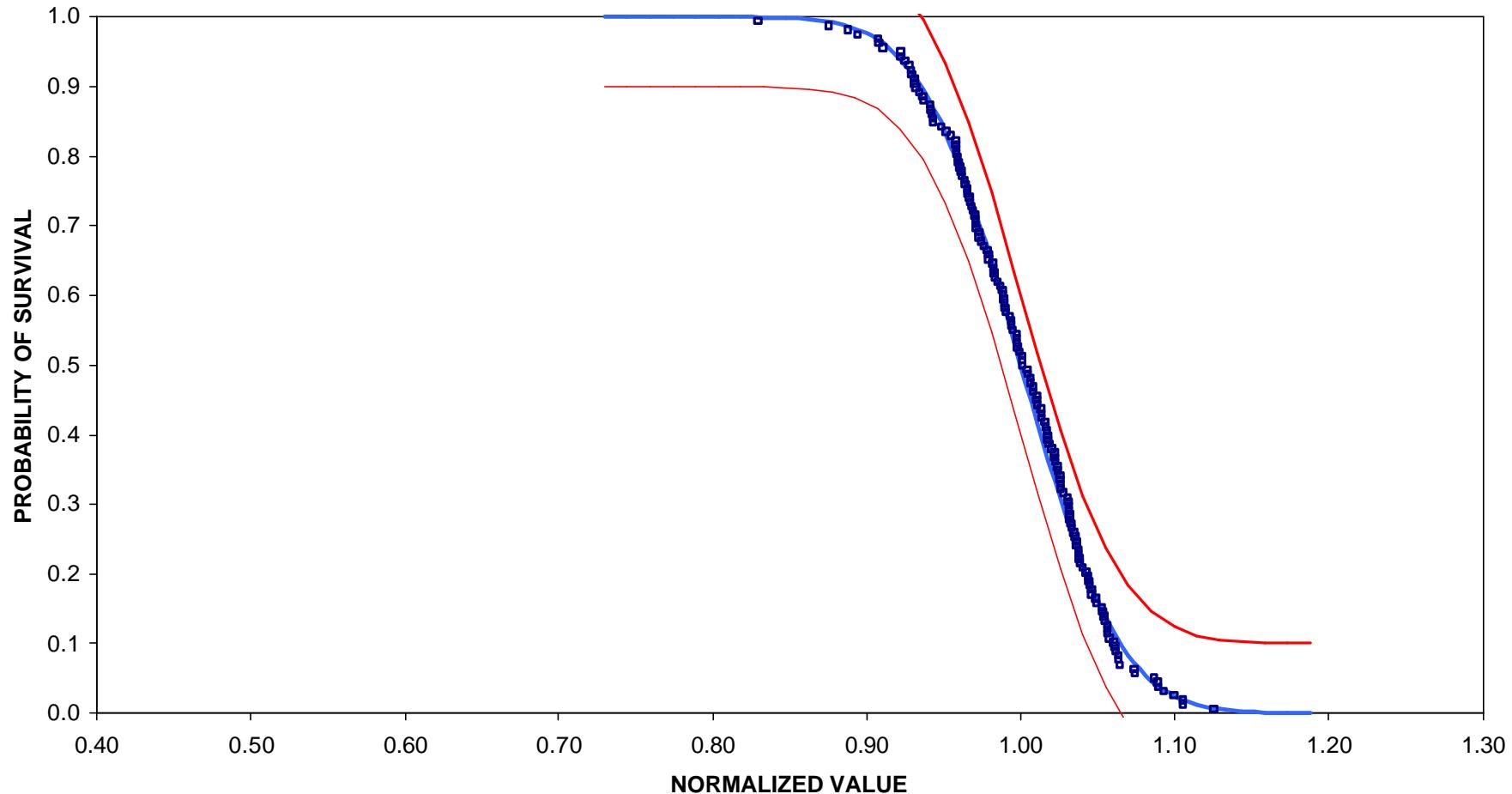
DISTRIBUTION OF POOLED DATA

SP381/ 7781 E-Glass Cloth

Cirrus

Laminate Tension - LAUXXXXX Normalized
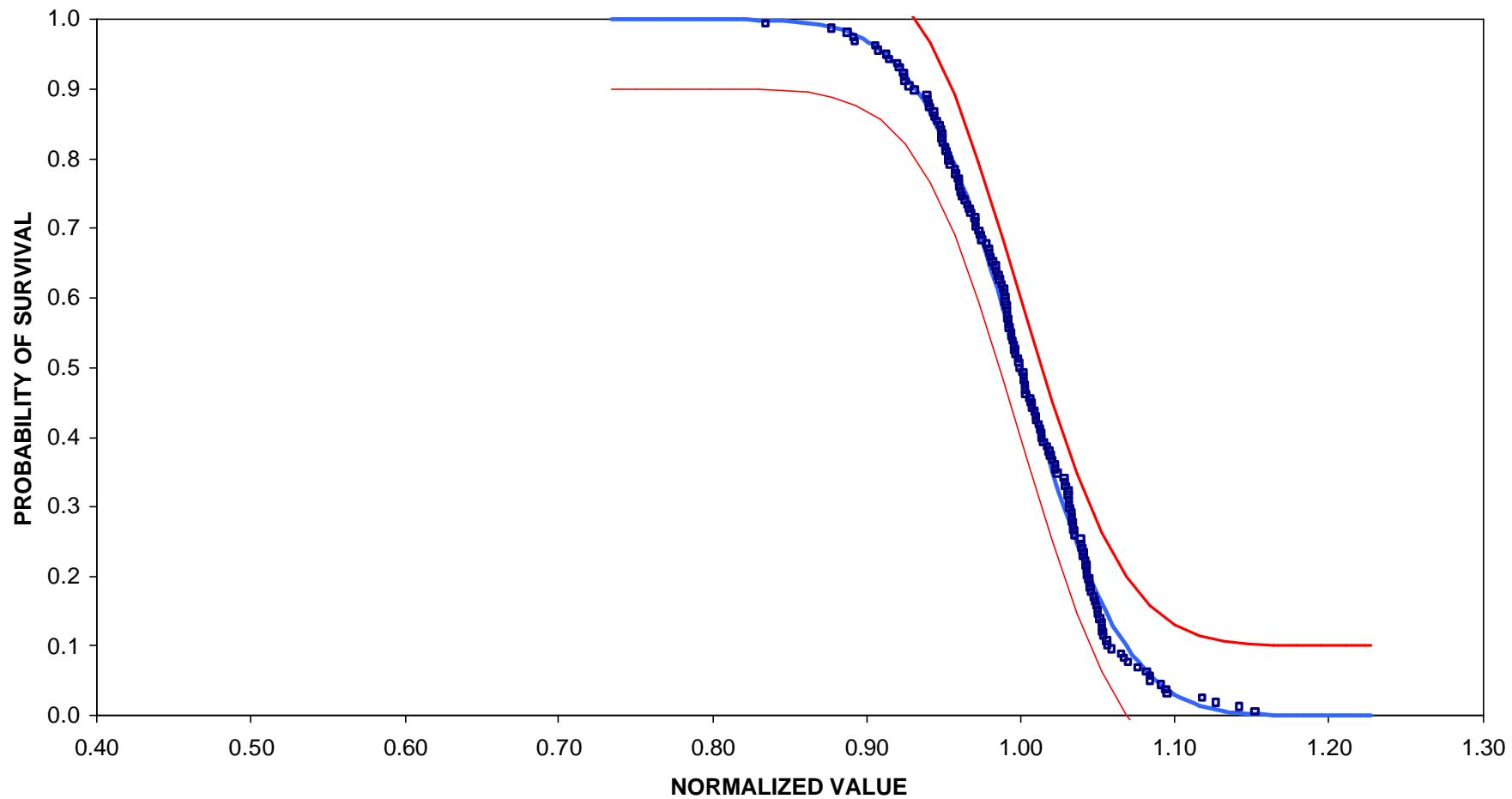
DISTRIBUTION OF POOLED DATA

SP381/ 7781 E-Glass Cloth

Cirrus

Laminate Compression - LAKXXXXX Measured
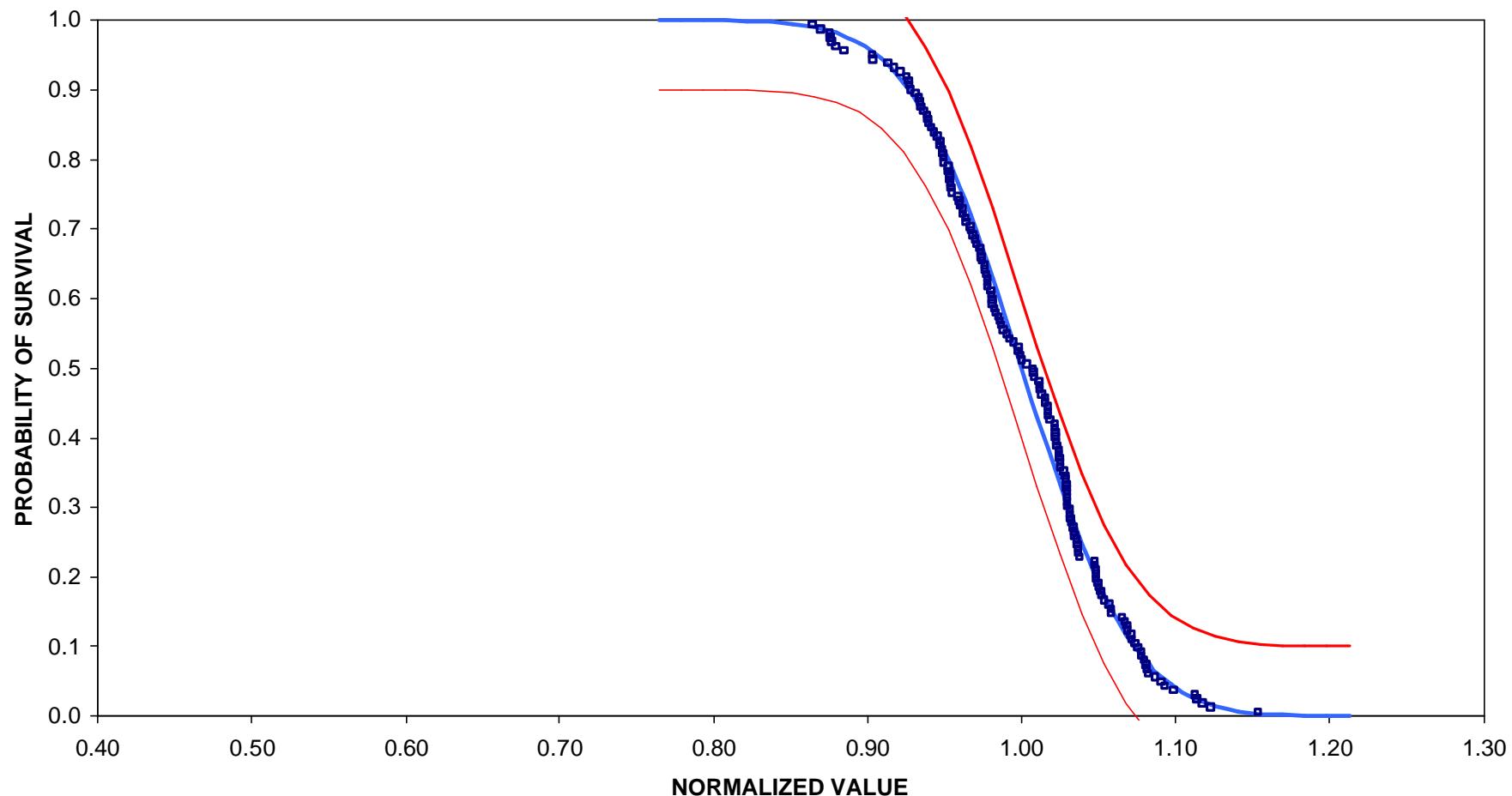
DISTRIBUTION OF POOLED DATA

SP381/ 7781 E-Glass Cloth

Cirrus

Laminate Compression - LAKXXXXX Normalized
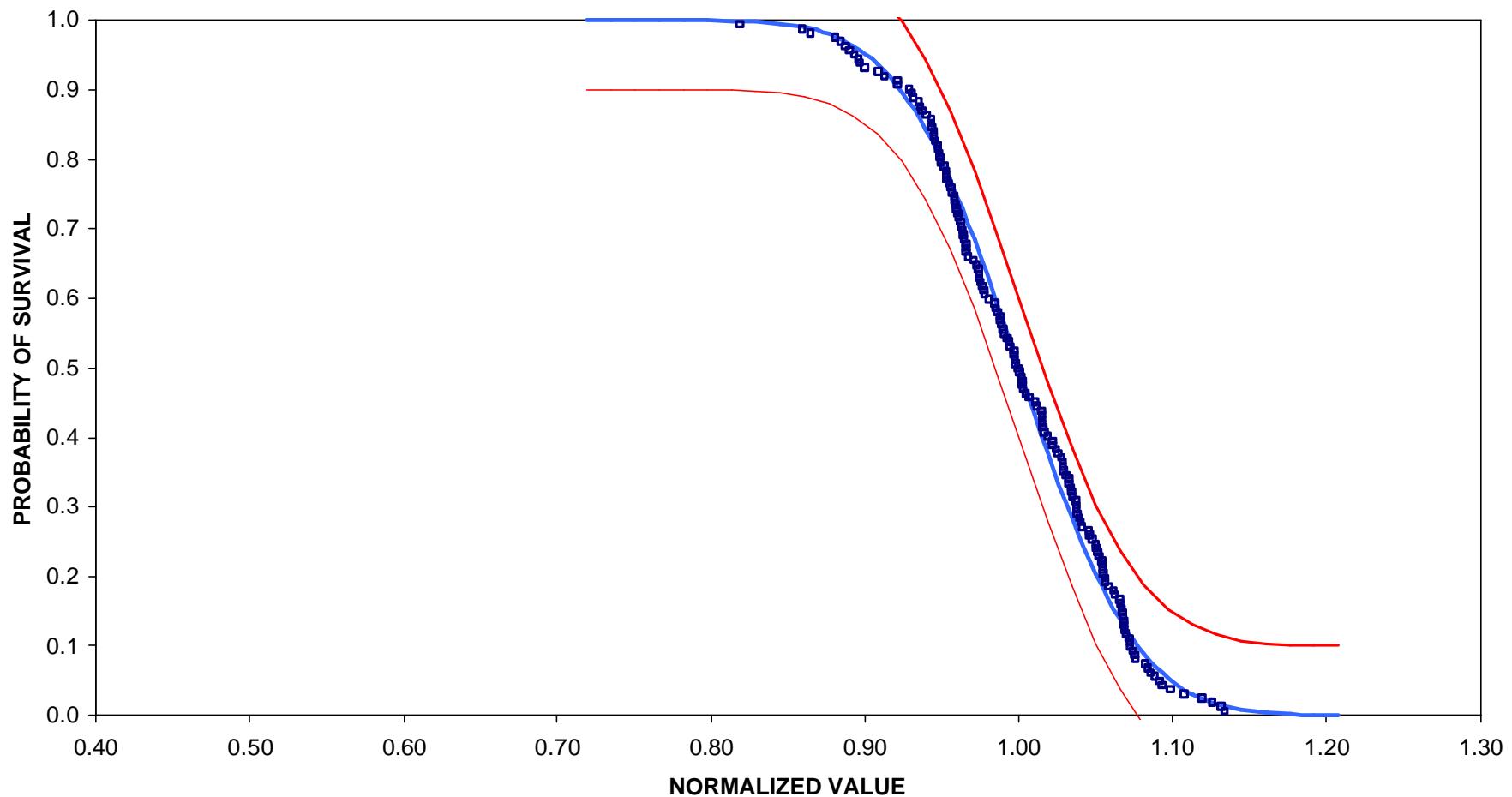
DISTRIBUTION OF POOLED DATA

SP381/ 7781 E-Glass Cloth

Cirrus

**In-Plane Shear - LANXXXXX Measured**
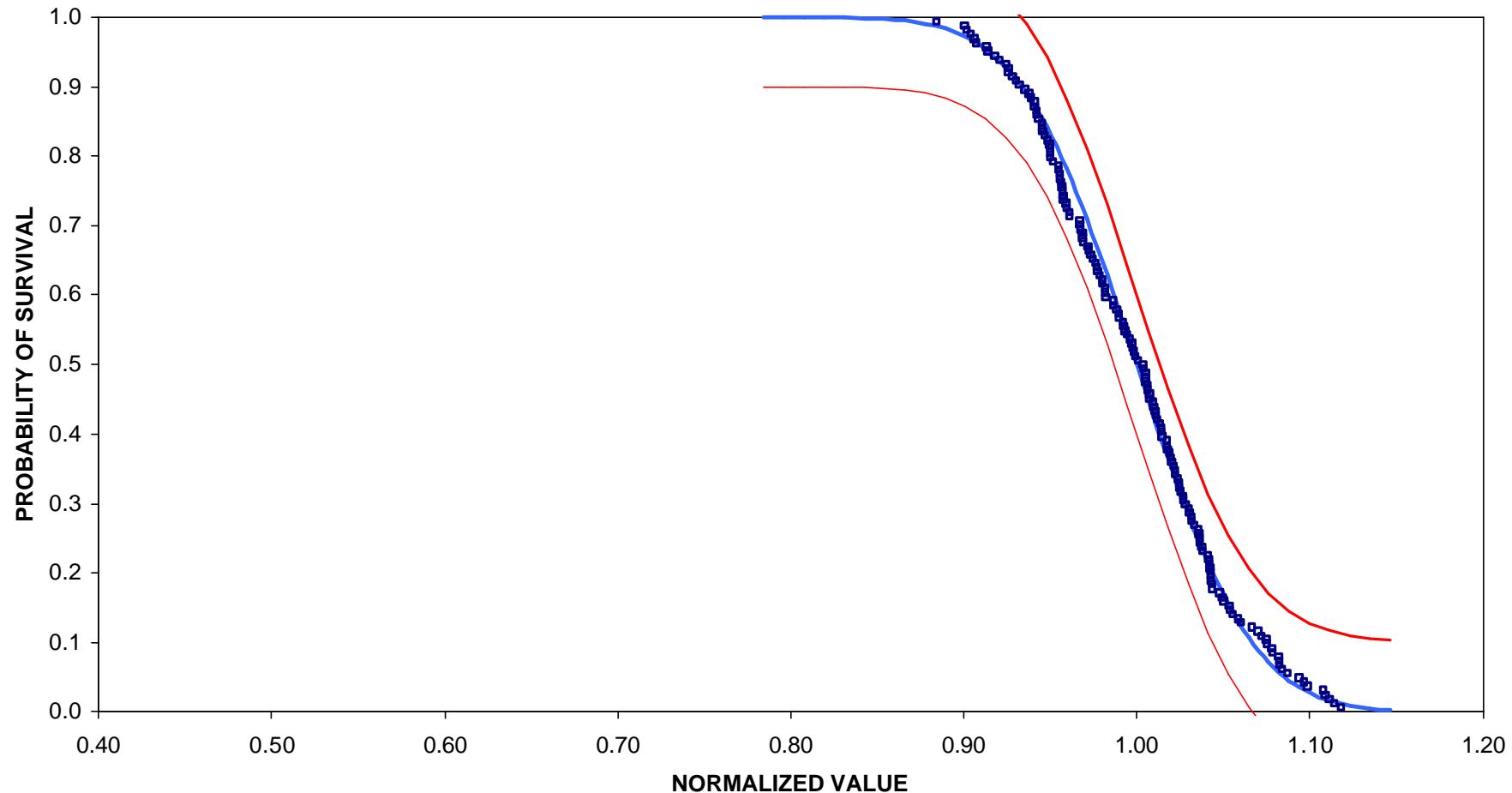
DISTRIBUTION OF POOLED DATA

SP381/ 7781 E-Glass Cloth

Cirrus

Apparent Interlaminar Shear - LAQXXXXX Measured
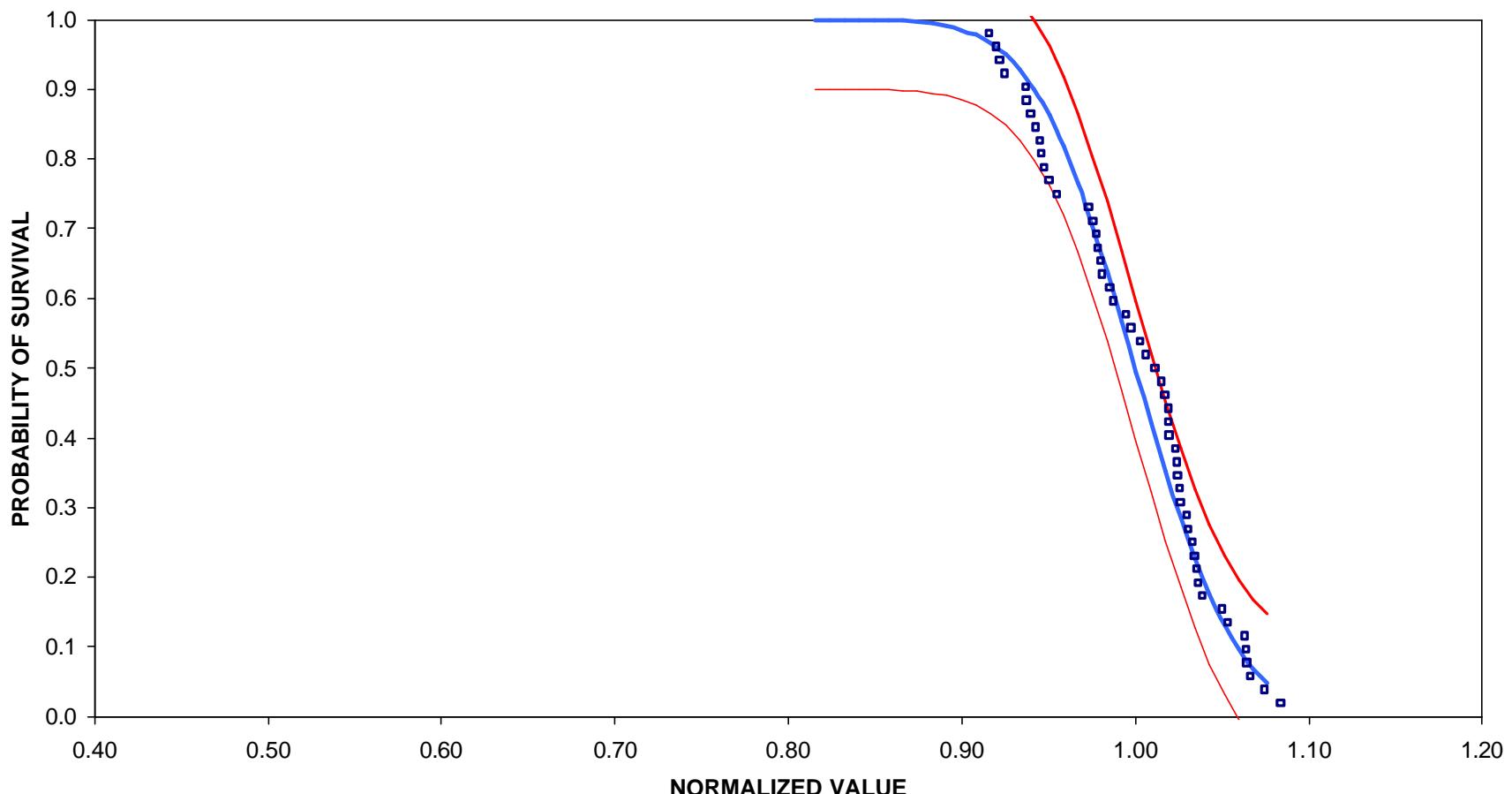
3.4 Moisture Conditioning History Charts

Conditioning History
Cirrus

Conditioning History
Cirrus

Conditioning History
Cirrus

Conditioning History
Cirrus

Conditioning History
Cirrus

Conditioning History
Cirrus

Conditioning History
Cirrus

Conditioning History
Cirrus

Conditioning History
Cirrus

Conditioning History
Cirrus

Conditioning History
Cirrus

**Conditioning History**
**Cirrus**
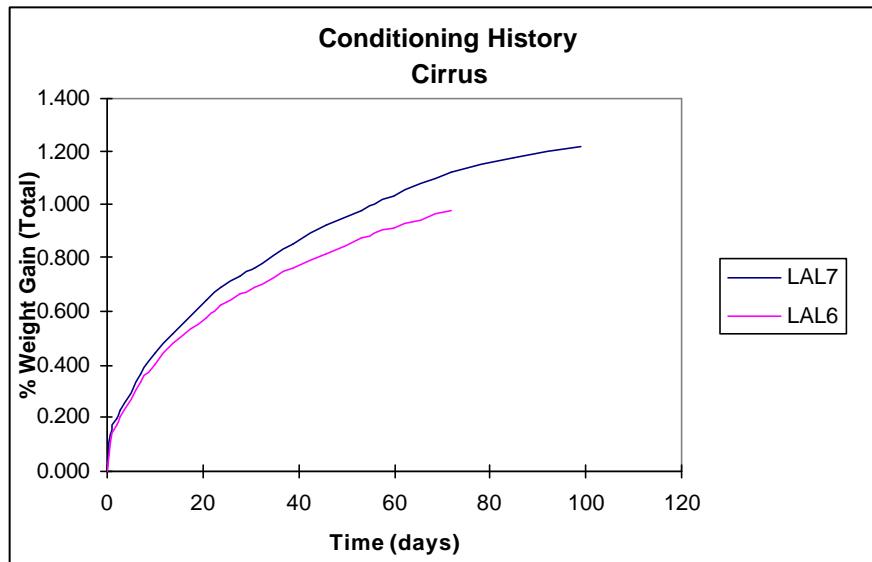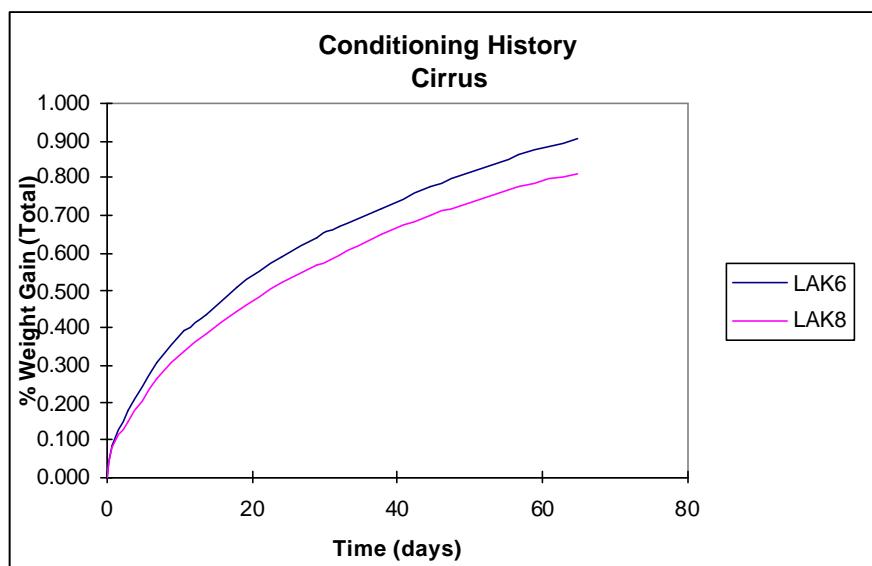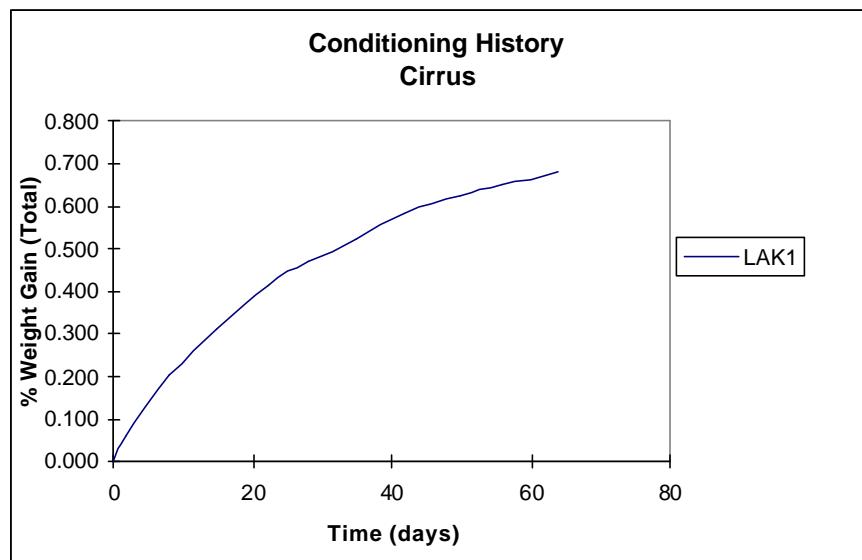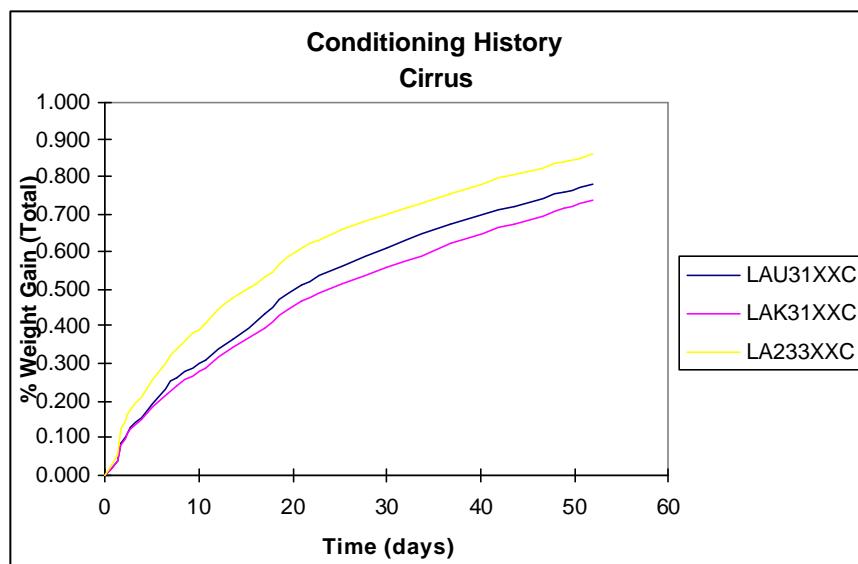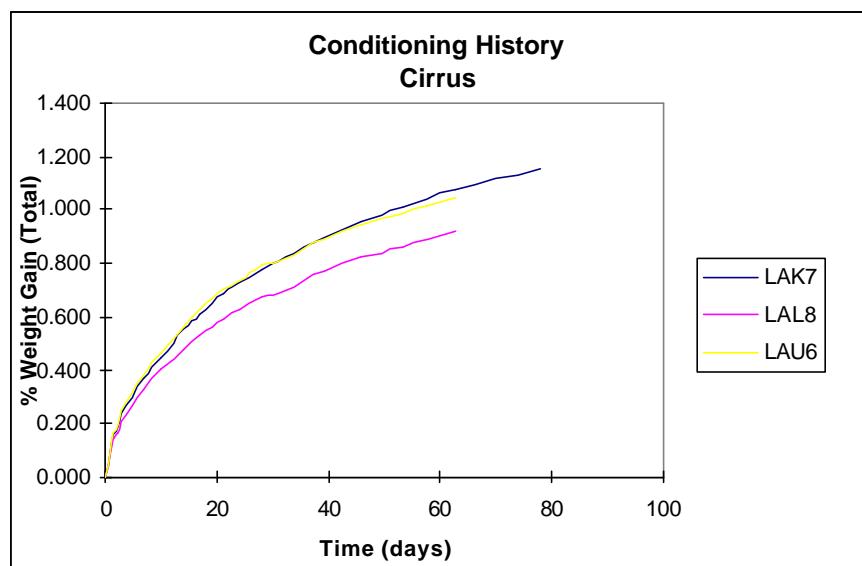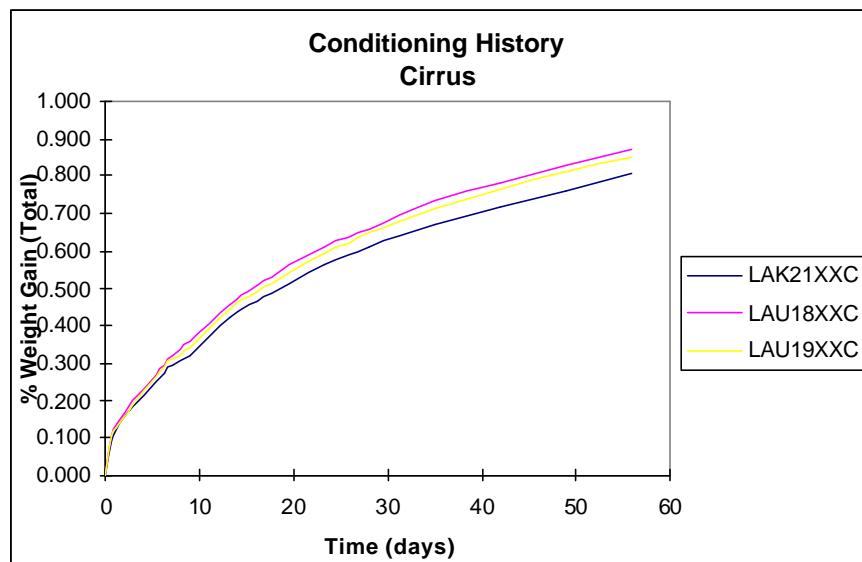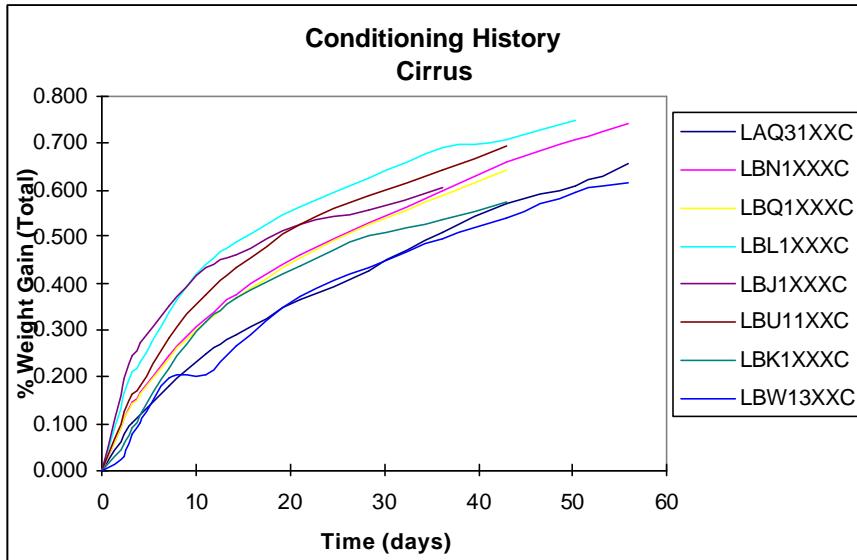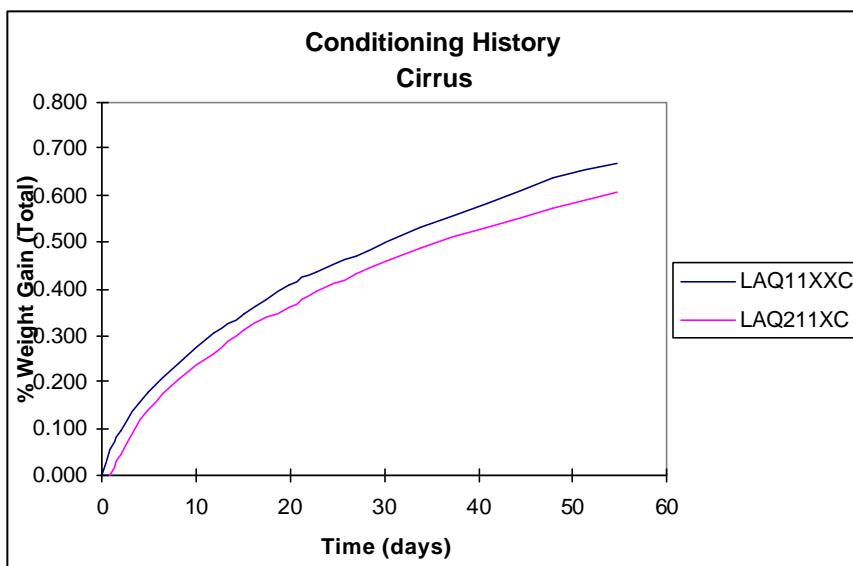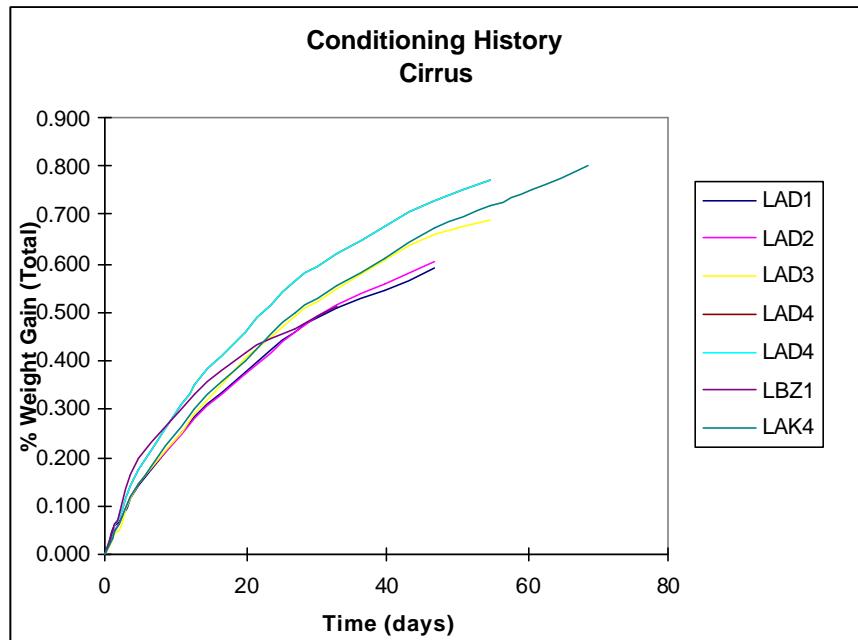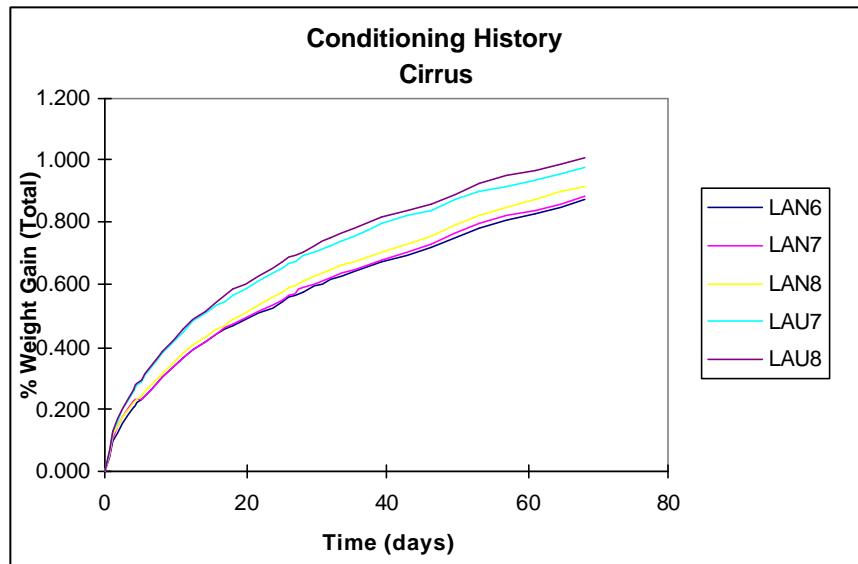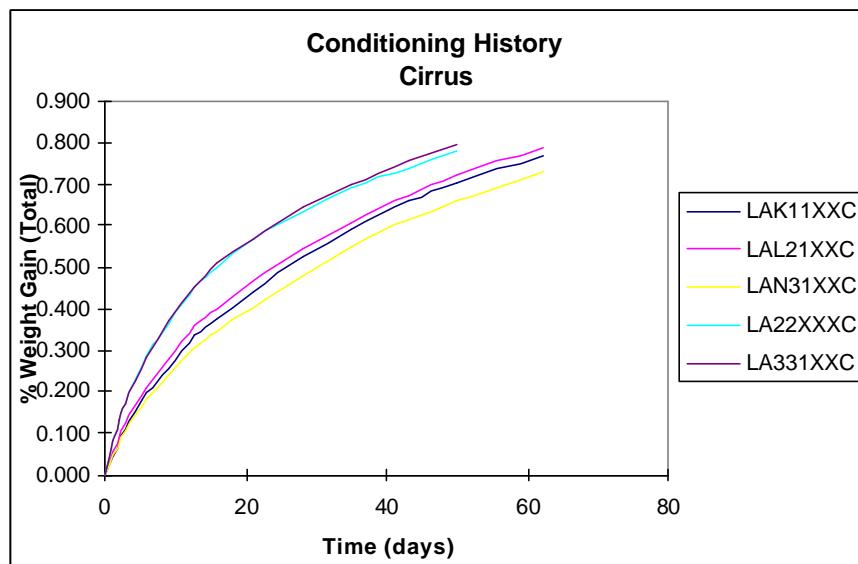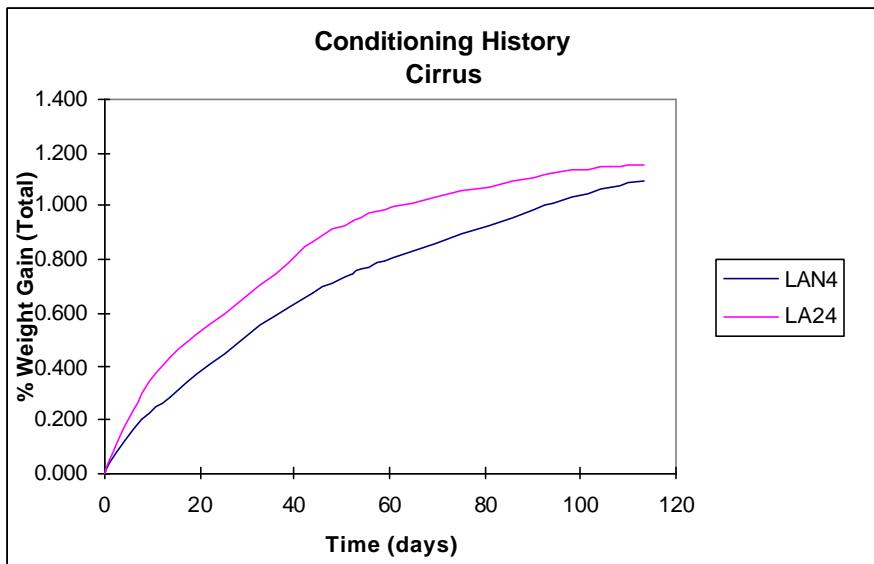
3.5 Physical Test Results

Physical Test Summary
3M SP381/7781 E-Glass Cloth

	Composite Density [g/cc]	Resin Content [wt%]	Fiber Volume [vol%]	Void Content [vol%]
90° Tension (LAUXXXXX)				
No. of Specimens	16	16	16	16
Mean	1.829	35.027	45.718	1.585
Standard Deviation	0.021	2.002	1.914	0.809
0° Compression (LAKXXXXX)				
No. of Specimens	5	5	5	5
Mean	1.838	35.094	45.905	1.048
Standard Deviation	0.034	2.035	2.296	0.440
In-Plane Shear (LANXXXXX)				
No. of Specimens	9	9	9	9
Mean	1.823	35.771	45.050	1.288
Standard Deviation	0.023	1.116	1.314	0.597
Interlaminar Shear (LAQXXXXX)				
No. of Specimens	2	2	2	2
Mean	1.987	28.362	55.072	0.869
Standard Deviation	0.206	7.890	11.694	1.229
Bearing (LA#XXXXX)				
No. of Specimens	18	18	18	18
Mean	1.813	35.722	44.837	1.879
Standard Deviation	0.025	1.365	1.545	0.477
Overall No. of Specimens	**50**	**50**	**50**	**50**
Overall Mean	**1.829**	**35.151**	**45.673**	**1.555**
Overall Std. Deviation	**0.050**	**2.400**	**3.065**	**0.694**

DMA Results -- Onset Storage Modulus

DRY

As Fabricated		
Sample #	Tg [°C]	Tg [°F]
LAD1-A	143.23	289.81
LAD2-A	145.30	293.54
LAD3-A	146.49	295.69
LAD4-A	146.01	294.82
LAD5-A	144.38	291.89
	Average [°F]	293.15
	Standard Dev. [°F]	2.35
	Coeff. Of Var. [%]	0.80

WET

Moisture Equilibrium at 85% RH		
Sample #	Tg [°C]	Tg [°F]
LAD3-C	118.58	245.44
LAD4-C	115.89	240.61
	Average [°F]	243.02
	Standard Dev. [°F]	3.41
	Coeff. Of Var. [%]	1.40

92

STORAGE MODULUS

Onset X = 145.301 °C
Onset Y = 4.0370e+009 Pa

Y1 = 4.4156e+009 Pa
X1 = 103.096 °C

Y2 = 2.0133e+009 Pa
X2 = 158.762 °C

Peak = 161.662 °C

TAN δ

Y1 = 0.150
X1 = 144.048 °C
Y2 = 0.146
X2 = 178.086 °C

Area = 0.492 x min
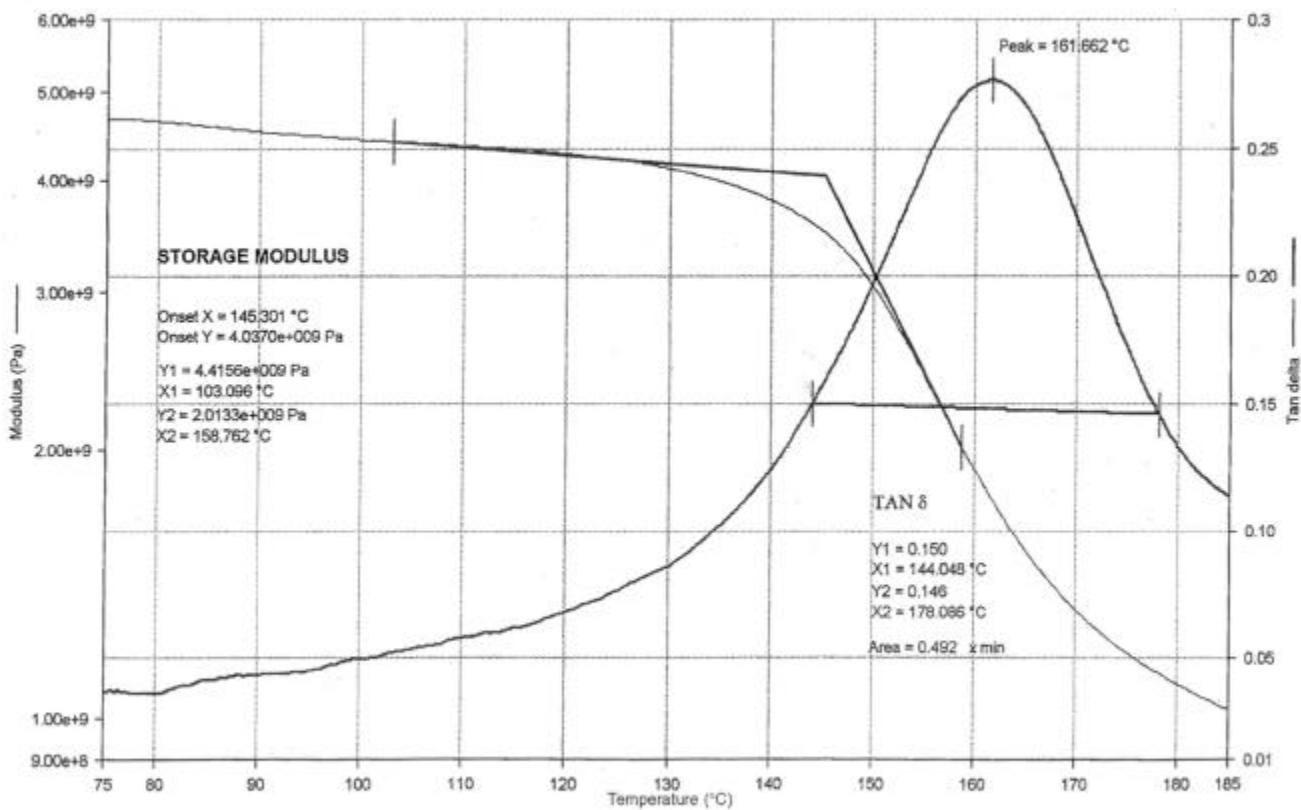
Representative DMA curve for 7781 / SP381, 'as fabricated' condition.

68

93
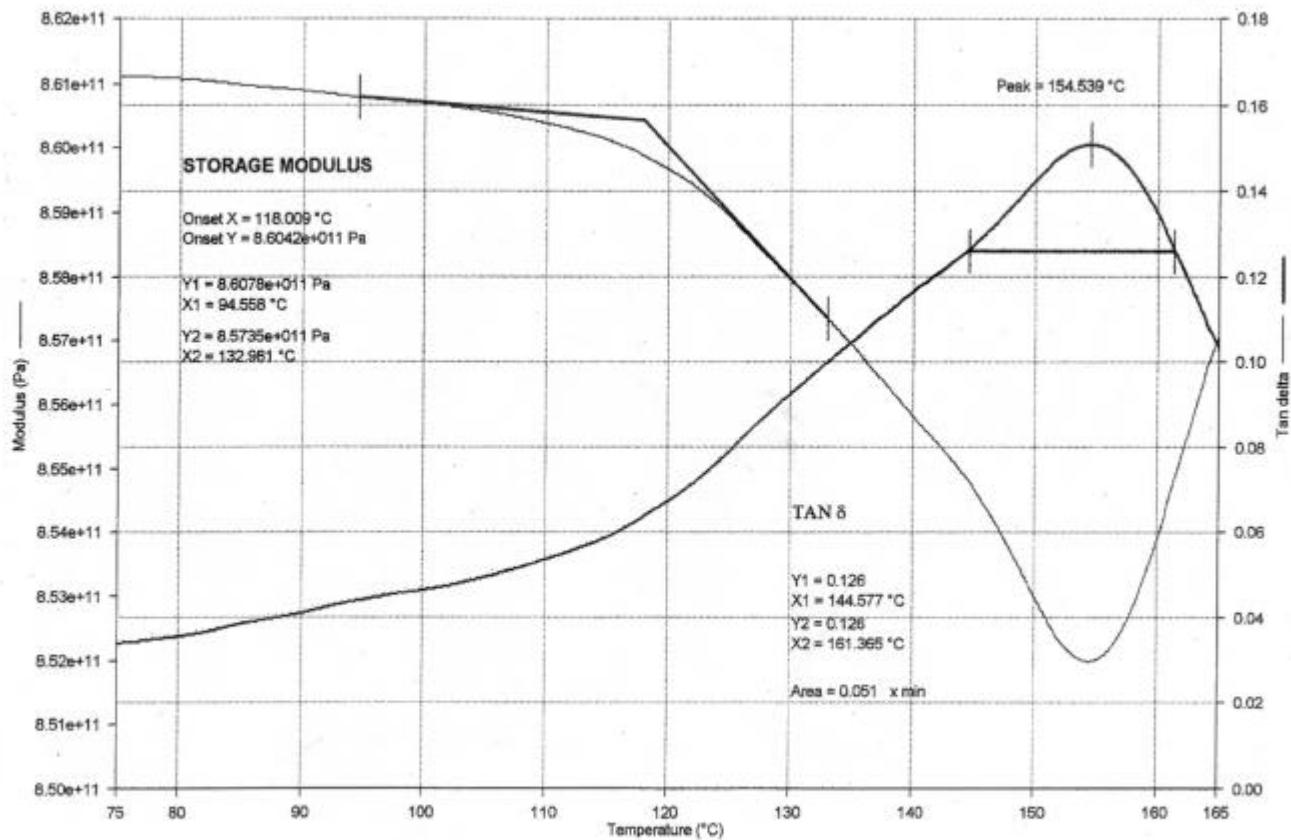
Representative DMA curve for 7781 / SP381, 'saturated' condition.

69

94

4.0 TESTING AND REPORTING COMMENTS

Conformity data is documented and archived as part of the Cirrus certification program. FAA project No. TC 1425CH-A.