National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland
20771

NASA

Reply to Attn of: 313

February 12, 1993

TO: 752.2/Plating and Plastics Section/Dr. Blake

FROM: 313/Materials Branch

SUBJECT: Alternate Test Methods for Determining Mechanical Properties of Graphite Epoxy Materials

INTRODUCTION

The work performed for this memorandum investigated the use of three devices which could potentially reduce both the cost and turn around time for testing of graphite epoxy (Gr/Ep) tensile coupons. Gr/Ep test coupons are typically tabbed to facilitate load transfer to the test coupon and are strain gauged to determine stiffness and strain at failure of the test coupon. The implementation of the aforementioned devices would eliminate the need for both the tabs and the strain gauges.

The tensile loading of tabless coupons was performed using hydraulic grips with hybrid wedge surfaces to transfer load the test coupons. The strain in the test coupons was monitored using a laser extensometer. The coupon stiffness was measured prior to tensile testing with a sonic resonance measurement system. This memorandum reports the results of these tests and compares the strength results to that of previous tests and the strain results to those obtained using strain gauges.

CONCLUSIONS & RECOMMENDATIONS

The sonic resonance method determined the stiffness of all laminates except the $[90]_{16}$ coupons. The accuracy and precision observed in these measurements were similar to those made with strain gauges. The low stiffness of the $[90]_{16}$ laminate prevented the stiffness measurement using the sonic resonance technique.

The laser extensometer determined the stiffness and strain ~~to~~ AT failure of Gr/Ep tensile coupons with the accuracy of the strain gauges but with a lower degree of precision.

Strengths achieved using the hydraulic grips exceeded predicted strengths for most of the Gr/Ep laminates. The $[0]_{16}$ coupons failed at approximately half the predicted load due to matrix splitting in the grips. The average $[90]_{16}$ coupon strength was 15% below the minimum predicted load. All other laminates failed at loads greater than or equal to the predicted loads.

It is recommended that additional coupons, taken from the same panel, be tested with and without tabs to verify the capability of the hydraulic grips. It is also recommended that $[0]_4$ and $[0]_6$ coupons be submitted (with and without tabs) to determine if the hydraulic grips are capable of testing zero degree un-tabbed tensile coupons to predicted strength levels.

TEST SPECIMENS & PROCEDURES

Six lots of tabless, non-strain gauged specimens (60 specimens total) with various laminate lay-ups were provided by Code 752.2 personnel. The ply orientations of the specimens along with predicted strength and stiffness values are presented in Table 1. All specimens were made from AMOCO T50/1962 prepreg material. Specimens in lots 2, 4 and 6 were nominally nine inches long and 1 inch wide. The nominal width of specimens in lots 1, 3 and 5 was either 1 or 1/2 inch. The lot 5 specimens were six inches long. Exact specimen dimensions are presented in Tables 2 and 3. It should be noted that the tabbed specimens requested as controls were not provided.

The stiffness of each specimen was determined using vibrational data acquired with a sonic resonance impulse excitation measurement system (Grindo-Sonic, J.W. Lemmens, St. Louis, MO). This device measures the frequency of fundamental flexural, torsional or longitudinal mode vibration of the test object following an impulse excitation. For this study only the fundamental flexural and longitudinal frequencies were measured. The specimen geometry did not lend itself to torsional vibration measurements. The flexural measurements were made while supporting the specimens at their fundamental nodal points (Figure 1) above an acoustic detector. The specimen was excited by lightly tapping with a small hammer at the center of the specimen. Longitudinal measurements were made while suspending the specimen lengthwise above the detector (held with thumb and index finger across the width at mid span) and tapping the upper end. The specimen stiffnesses were then calculated based on observed frequencies, specimen geometry and density as described in ASTM C747-74. The actual calculations were performed using software provided by the device manufacturer (EMOD, ver 9.12).

The tabless specimens were gripped using hydraulic grips fitted with a recently available grip face (Surfalloy, MTS, Minneapolis, MN). The Surfalloy grip face is manufactured using plasma deposition and is much less aggressive (i.e. creates less damage in the test specimen) than the typical grip faces. Typical wedge type grips faces generally have rows of diamond shaped teeth which dig into the test material. Both grip faces are shown in Figure 2. Premature failure of graphite epoxy specimens is generally prevented by the presence of tapered tabs constructed from a compliant material and attached to both faces at either end of the specimens. These tabs allow the load to be gradually transferred from the grips to the specimen and eliminate the creation of local damage.

When the Surfalloy grips are hydraulically loaded the force required to secure the specimen in the grips, without slipping, can be balanced against the applied load necessary to fail the test specimen. This optimized gripping force minimizes the damage created by the grips. Initial testing revealed that while the Surfalloy grips where an improvement over traditional grips, failure still occurred in the grips due to local damage created by the grip faces. After experimenting with several interfaces (paper, cardboard, Mylar) it was found that two plies of 600 grit sandpaper were a sufficient interface to shift failures out of the grips and into ungripped area of the specimen. It was this configuration that was used to test most of the specimens reported on in this memorandum.

All strength testing was performed on an Instron 1125 universal test machine at a crosshead speed of 0.02 inches per minute. Load and strain data were recorded using an HP 3852 data acquisition unit with a Macintosh IIcx instrument controller. All data was stored to disk and is available in Apple format if desired. Tensile strain measurements were made on selected specimens using single element strain gauges (Micro Measurements P/N CEA-06-375UW-120). At least one specimen from each lot was test with a biaxial strain gauge (Micro Measurements P/N CEA-06-375UW-120).

Strain measurements were made on all specimens using a non contacting laser extensometer (OPTRA LE3000, Optra Inc., Beverly, MA). Extension measurements are made by reflecting a dual laser signal off the specimen surface at two locations (i.e. the gauge length). The movement of the specimen is determined by the movement of the interference fringe patterns created on the specimen surface. The existing specimen surfaces are used without any modification. The laser extensometer has a gauge length of one inch and a stated measurement precision of 10 μe with a measurement accuracy of <50μe (additional specifications are available on request). The extensometer was mounted to the Instron such that the mid-gauge length of the laser focused on the center of the specimen approximately 2 inches below the upper grip. The current configuration of the laser fixturing prevented the laser from being mounted any lower. The laser is sensitive to twisting and out of plane movement of the test specimen and so is ideally suited for use with hydraulic grips which limit both of these deformations.

RESULTS

Results of the sonic resonance impulse excitation testing are presented in Tables 2-1 through 2-5. The measured frequencies are presented along with calculated elastic moduli for flexural and longitudinal modes. The assumed Poisson's ratio for all calculations was 0.3. Due to the low stiffness of the Lot 3 specimens ([90] lay-up) no sonic resonance data was obtained.

The results of initial tests with the hydraulic grips are presented in Figure 3. All of the data acquired for this graph was taken using specimens gripped with the Surfalloy grips and two plies of 600 grit sandpaper. The error in the applied grip pressure is approximately +/- 0.5 MPa. The MPa units are used because these increments are more easily read on the hydraulic pressure gauge. The graph plots the applied grip pressure versus the load where slippage of the specimen was observed to occur. Limited testing with the 1/2 inch wide specimens indicates this relationship is independent of the area gripped. The maximum rated grip pressure, 21 MPa, dictates that the greatest load attainable with this set-up is 10,000 pounds.

Results of strength tests are presented in Tables 3-1 through 3-5. The failure loads were taken as the maximum observed load. The failure stress, observed strain at failure (laser & strain gauge), tensile modulus (calculated using laser and strain gauge data) and observed failure mode/failure location are also presented in Tables 3-1 through 3-5. The stress was calculated using the measured specimen dimensions. The failure modes where somewhat consistent within each lot. The lot 1 specimens failed due to matrix splitting at loads well below those predicted by strengths given in Table 1. Failure of specimens from lots 2, 3 and 4 were mixed between grip failures and failures in the gauge length. The failure mode of the lot 6 specimens was unusual in that it occurred due to interlaminar failure at the 90 degree plies. Failure appears to have initiated at the edges and proceeded inward (Figure 4).

Determination of tensile modulus and strain at failure using the laser data required some manipulation of laser strain data. The nature of the laser extensometer is such that imperfections in the specimen surface will cause the laser reflection to fade which causes the strain monitor to lose its place and subsequently shift the strain to an arbitrary value. After further deformation the reflection will increase in strength and the data acquired after this shifting will continue record the material extension. The resulting load (stress) versus strain curve has a saw tooth appearance (Figure 5). If the output is closely watched by the operator, the strain monitor can be reset to zero after the signal has regained strength. This zero reset will give a convenient reference for the post acquisition data manipulation. After the test is completed and the data stored to disk, the strain segments are spliced together simply by moving the data after a shift to the end of the data acquired prior to the shift. It should be noted that this shifting ocurred in only 25% of the specimens tested.

One or two coupons from each lot were used to measure the Poisson's ratio. The results are listed in Table 4. While there appears to be little difference between the measured values for the various laminate orientations, there is general agreement with the predicted values. The similarity in results may be to the location of the strain gauges, which were mounted near the grips, not at midspan.

The ply orientations of the lot 6 specimens was not known. An attempt to determine the ply orientations was made by measuring the fiber areas in individual plies using image analysis software (Image, NIH). The preliminary results of image analysis test are presented in Figure 6. This testing is incomplete as the software (hardware ?) developed a bug during testing which I have been unable to eliminate. The areas of the three known ply orientations were taken from cross sections of specimens 2-6 and 4-9. The standard deviation of the known values are approximately 150 pixels. The number 4, 8, 9 & 13 plies were observed to be 90 degree plies. From the data taken to date the panel appears to be a [0/30/90/-30]2S laminate.

DISCUSSION

The average tensile modulus and standard deviation determined using strain gauges, sonic resonance and the laser extensometer for each of the specimen lots are presented in Table 5. There is general agreement between the measured and predicted (Table 1) values for the elastic moduli. The strain gauge data is assumed to be accurate as this is the technique generally used to obtain stiffness values in Gr/Ep materials. There is excellent agreement between the values determined using impulse excitation and the strain gauges. With the exception of the lot 2 specimens, there is also good agreement (within 5%) between the stiffness determined using flexural and longitudinal vibrations. It is not clear why the moduli determined from the longitudinal excitation deviates from that of the flexural mode in the lot 2 specimens, the average of these two modes would agree quite well with the stiffness determined with strain gauge data. This agreement demonstrates that accurate stiffness values can be obtained prior to or without tensile testing. The stiffness of the lot 6 coupons is slightly lower than that predicted for a

$[0/30/90/-30]_{2S}$ lay-up and that observed in the lot 2 specimens.

The stiffness values determined using the laser extensometer were in excellent agreement with the stiffness values determined using the strain gauges. The significantly greater standard deviation in the laser data indicates that a larger sample population is required if the laser is used to determine the laminate stiffness. It is possible that the scatter in the laser data may be reduced in future testing after the parameters controlling the laser instrument's performance are more clearly understood. The average strain to failure determined using the laser data was also in good agreement with the values determined using the strain gauges. These results clearly indicate that the time and expense of strain gauge application can be circumvented if the end user of the strain data can live with slightly larger scatter in the test data.

The final issue addressed in this testing is the application of the load without the use of adhesively bonded tabs. The strength results of the lot 2, 3 and 4 specimens exceed the predicted strengths for their respective lay-ups. If the lot 6 specimens are indeed made from a [0/30/90/-30]2S laminate, then the failure stress agrees with the predicted strength. While the [90] specimens average a slightly lower than predicted strength, this strength may be dependent on the specimen preparation and subsequent handling that could damage the specimens. The failure of some low strength [90] specimens did occur in the gauge length.

The only lay-up that could not be tested to predicted strength levels is the $[0]_{16}$ coupons. The predicted strength level would require a tensile load of 12,800 pounds, which exceeds the 10,000 pound no slip gripping capability of the hydraulic grips. This restriction might be circumvented by using a laminate with less plies than the $[0]_{16}$ specimens. The minimum load achieved with the one inch wide $[0]_{16}$ specimens was 5500 pounds. This translates to a laminate with 6 plies. It is possible that even with the thinner laminate the coupon may still fail prematurely due to matrix splitting. The splitting failure in the grip is due to transverse loads generated by restricting lateral movement of the specimen that the matrix is unable to support. The thinner section may result in lower loads required to produce splitting. An alternate specimen configuration might be to add a couple of 90 degree plies to absorb the transverse loads.

In summary the testing reported in this memorandum demonstrates that mechanical properties of Gr/Ep materials can be obtained without tabbing or strain gauging the test coupons. The elimination of these two operations will undoubtedly reduce both the cost and turn around time for testing of the Gr/Ep tensile coupons. Please feel free to contact me if you have any questions or concerns.

Michael J. Viens

cc:
313/Staff
313/file
313.4/Parker
723/Wagner

Table 1. Specimen Orientations and Predicted Properties

Lot Number	Lay-Up	Panel	Predicted Strength (ksi)	Predicted Stiffness (Msi)	Source
1	[0]16	Unknown	155	31.3	1
			206	37.0	2
			152	27.4	3
			160	33.0	4
2	[0/30/90/-30]2S	P44	65	17	4
3	[90]16	Unknown	5.3	1.06	1
			5.5	1.03	2
			4.4	1.04	3
			5.0	1.00	4
4 & 5	[45/0/-45/90]2S	P55 & P51	49.1	12.6	1
			45.0	12.0	4
			39.3	13.8	5
6	Unknown	P53			

1. Composite Optics Inc.
2. AMOCO
3. LaRC
4. GSFC DDF, Composites Structural Materials Design & Selection Handbook, 10/90
5. GSFC/Code 313, memo from Mr Viens to Mr. Matsumura; dtd. 7/16/91

Table 2-1. Lot #1 T50/1962 [0]16, Panel Unknown

Specimen ID	Thickness (in)	Width (in)	Length (in)	Mass (g)	Density (g/cc)	R[Flex] (Hz)	R[Long] (kHz)	E[Flex] (Msi)	E[Long] (Msi)
#1-1	0.079	0.999	9.006	18.227	1.565	444.0	25.07	28.81	29.89
#1-2	0.083	1.000	9.006	19.371	1.581	470.0	25.15	29.56	30.40
#1-3	0.087	1.001	9.002	20.382	1.587	490.0	24.80	29.29	29.63
#1-4	0.086	1.001	9.004	20.151	1.586	487.0	25.12	29.63	30.41
#1-5	0.088	0.998	9.003	20.566	1.587	499.0	25.11	29.71	30.40
#1-6	0.088	1.001	9.004	20.687	1.592	499.0	25.05	29.81	30.34
#1-7	0.083	0.500	9.000	9.740	1.591	469.0	24.97	29.54	30.09
#1-8	0.082	0.500	8.999	9.725	1.608	473.0	25.44	31.10	31.56
#1-9	0.086	0.501	9.001	9.958	1.567	481.0	25.04	28.56	29.85
#1-10	0.084	0.500	9.000	9.845	1.589	474.0	24.91	29.42	29.91
#1-11	0.087	0.500	9.001	10.034	1.564	482.0	24.77	27.92	29.11
#1-12	0.083	0.500	9.000	9.699	1.585	468.0	25.11	29.29	30.30
Avg.					**1.584**			29.39	30.16
Std. Dev.					**0.013**			0.77	0.59

Table 2-2. Lot #2 T50/1962 [0/30/90/-30]2S, Panel P44

Specimen ID	Thickness (in)	Width (in)	Length (in)	Mass (g)	Density (g/cc)	R[Flex] (Hz)	R[Long] (kHz)	E[Flex] (Msi)	E[Long] (Msi)
#2-1	0.080	1.005	9.001	19.110	1.611	363.0	18.54	19.30	16.82
#2-2	0.080	1.005	9.004	18.981	1.600	360.3	18.55	18.90	16.76
#2-3	0.080	1.005	9.003	18.994	1.601	358.7	18.50	18.74	16.65
#2-4	0.080	1.006	9.003	19.008	1.601	360.4	18.50	18.91	16.64
#2-5	0.080	1.005	9.004	18.992	1.601	359.4	18.52	18.82	16.68
#2-6	0.080	1.004	9.004	18.996	1.603	361.9	18.63	19.10	16.90
#2-7	0.080	1.005	9.005	18.962	1.598	359.5	18.56	18.81	16.73
Avg.					**1.602**			**18.94**	**16.74**
Std. Dev.					**0.004**			**0.20**	**0.10**

Table 2-3 Lot #4 T50/1962 [45/0/-45/90]2S, QI, Panel P55

Specimen ID	Thickness (in)	Width (in)	Length (in)	Mass (g)	Density (g/cc)	R[Flex] (Hz)	R[Long] (kHz)	E[Flex] (Msi)	E[Long] (Msi)
#4-1	0.079	1.002	9.002	18.780	1.608	289.0	15.57	12.52	11.84
#4-2	0.079	1.002	9.002	18.747	1.605	289.0	15.60	12.50	11.86
#4-3	0.079	1.003	9.003	18.657	1.606	285.6	15.53	12.38	11.77
#4-4	0.078	0.996	9.000	18.353	1.602	281.5	15.55	12.13	11.76
#4-5	0.079	1.001	9.001	18.814	1.613	289.1	15.53	12.56	11.81
#4-6	0.080	1.001	9.001	18.842	1.595	289.9	15.52	12.18	11.67
#4-7	0.079	1.003	9.002	18.781	1.607	288.4	15.53	12.46	11.77
#4-8	0.079	1.002	9.001	18.709	1.602	286.6	15.54	12.27	11.75
#4-9	0.080	1.002	9.002	18.856	1.595	291.4	15.62	12.31	11.81
#4-10	0.080	1.003	9.001	18.869	1.594	291.3	15.58	12.29	11.75
Avg.					**1.603**			**12.36**	**11.78**
Std. Dev.					**0.006**			**0.15**	**0.05**

Table 2-4 Lot #5 T50/1962 [45/0/-45/90]2S, QI, Panel P51

Specimen ID	Thickness (in)	Width (in)	Length (in)	Mass (g)	Density (g/cc)	R[Flex] (Hz)	R[Long] (kHz)	E[Flex] (Msi)	E[Long] (Msi)
#5-1	0.060	1.005	6.001	9.439	1.592	485.0	23.32	11.95	11.70
#5-2	0.059	1.005	6.001	9.407	1.613	483.6	23.40	12.46	11.94
#5-3	0.059	1.003	6.001	9.409	1.617	483.1	23.37	12.46	11.93
#5-4	0.059	0.995	6.002	9.331	1.616	483.1	23.40	12.46	11.96
#5-5	0.060	0.500	6.002	4.685	1.588	479.3	23.24	11.65	11.57
#5-6	0.060	0.488	6.003	4.562	1.584	480.4	23.23	11.68	11.53
#5-7	0.060	0.502	6.002	4.721	1.594	485.8	23.38	12.02	11.75
#5-8	0.060	0.503	6.003	4.709	1.599	482.0	23.33	12.08	11.75
#5-9	0.059	0.756	6.005	6.995	1.594	472.2	23.02	11.76	11.41
Avg.					**1.600**			**12.06**	**11.73**
Std. Dev.					**0.013**			**0.33**	**0.20**

Table 2-5. Lot #6 T50/1962 [Unknown], Panel P53

Specimen ID	Thickness (in)	Width (in)	Length (in)	Mass (g)	Density (g/cc)	R[Flex] (Hz)	R[Long] (kHz)	E[Flex] (Msi)	E[Long] (Msi)
#6-1	0.087	1.000	8.999	20.289	1.581	359.8	17.74	15.72	15.10
#6-2	0.087	1.001	9.000	20.205	1.573	358.0	17.70	15.49	14.96
#6-3	0.086	1.001	9.002	19.973	1.573	355.3	17.83	15.62	15.18
#6-4	0.086	1.002	9.003	20.076	1.579	355.5	17.69	15.67	15.01
#6-5	0.085	1.001	9.003	19.908	1.586	355.0	17.97	16.11	15.56
#6-6	0.088	1.002	9.000	20.415	1.570	361.8	17.81	15.43	15.11
#6-7	0.086	1.002	9.002	20.014	1.574	357.2	17.94	15.81	15.39
#6-8	0.088	0.995	8.999	20.358	1.577	362.0	17.80	15.51	15.16
#6-9	0.085	1.002	9.003	19.776	1.583	350.4	18.00	15.85	15.58
#6-10	0.087	1.004	8.999	20.361	1.581	361.9	17.90	15.85	15.35
Avg.					**1.578**			**15.71**	**15.24**
Std. Dev.					**0.005**			**0.21**	**0.22**

Table 3-1. Lot #1 T50/1962 [0]16, Panel Unknown

Specimen ID	Thickness (in)	Width (in)	Failure Load (lbs)	Failure Stress (ksi)	Failure Strain Laser (με)	Failure Strain Gauge (με)	Tensile Modulus Laser (Msi)	Tensile Modulus Gauge Msi)	Failure Mode/Location
#1-1	0.079	0.999	7054	89.38	3359	3825	24.20	28.39	Matrix Splitting
#1-2	0.083	1.000	5808	69.98	3417	2473	18.70	28.61	Matrix Splitting
#1-3	0.087	1.001	7430	85.32	4347	3010	26.97	28.81	Matrix Splitting
#1-5	0.088	0.998	7178	81.73	2565	2927	30.55	30.47	Matrix Splitting
#1-6	0.088	1.001	5506	62.51	2389		28.76		Matrix Splitting
#1-10	0.084	0.500	3501	83.36	3324		28.78		Matrix Splitting
Avg.				**78.71**	**3234**	**3059**	**26.33**	**29.07**	
Std. Dev.				**10.27**	**701**	**563**	**4.31**	**0.95**	

Table 3-2. Lot #2 T50/1962 [0/30/90/-30]2S, Panel P44

Specimen ID	Thickness (in)	Width (in)	Failure Load (lbs)	Failure Stress (ksi)	Failure Strain Laser (με)	Failure Strain Gauge (με)	Tensile Modulus Laser ~~(Msi)~~	Tensile Modulus Gauge ~~Msi)~~	
#2-1	0.080	1.005	7983	99.29	5620	5456	18.25	18.44	Failed in Grip
#2-2	0.080	1.005	7838	97.49	5554	5533	17.42	17.76	Failed In Grip
#2-3	0.080	1.005	8012	99.65	5010	5702	19.42	17.51	Failed in Gauge Length
#2-4	0.080	1.006	8025	99.71	6031	5704	16.38	17.59	Failed at Edge of Grip
#2-5	0.080	1.005	8515	105.91	6206	6052	17.67	17.72	Failed in Grip
#2-6	0.080	1.004	6984	86.95	5593		17.10		Failed in Grip
#2-7	0.080	1.005	8898	110.67	6089		17.78		Failed in Gauge length
Avg.				**99.95**	**5729**	**5689**	**17.72**	**17.80**	
Std. Dev.				**7.37**	**414**	**230**	**0.95**	**0.37**	

Table 3-3. Lot #3 T50/1962 [90]16, Panel Unknown

Specimen ID	Thickness (in)	Width (in)	Failure Load (lbs)	Failure Stress (ksi)	Failure Strain Laser (µe)	Failure Strain Gauge (µe)	Tensile Modulus Laser (Msi)	Tensile Modulus Gauge Msi)	
#3-1	0.087	1.003	342	3.92	3927	3951	1.01	0.973	Failed in Grip
#3-2	0.086	1.002	338	3.92	4007	3639	0.95	1.081	Failed in Gauge Length
#3-3	0.087	1.002	331	3.79		3819		0.984	Failed at Edge of Grip
#3-4	0.087	1.003					1.10	1.013	Failed in Grip
#3-5	0.087	1.004	365	4.18	4724	4347	0.89	0.964	Failed in Grip
#3-7	0.087	0.503	120	2.76	3636		0.84		Failed in Gauge Length
#3-8	0.087	0.494	63	1.47	1340		1.07		Failed in Gauge Length
#3-9	0.086	0.499	204	4.75	3605		1.10		Failed in Gauge Length
#3-10	0.086	0.501	203	4.71	4510		1..017		Failed in Grip
#3-11	0.086	0.501	173	4.02	5559		0.75		Failed at Edge of Grip
Avg.				**3.72**	**3914**	**3939**	**0.96**	**1.00**	
Std. Dev.				**1.03**	**1226**	**301**	**0.13**	**0.05**	

Table 3-4. Lot #4 T50/1962 [45/0/-45/90]2S, QI, Panel P55

Specimen ID	Thickness (in)	Width (in)	Failure Load (lbs)	Failure Stress (ksi)	Failure Strain Laser (με)	Failure Strain Gauge (με)	Tensile Modulus Laser (Msi)	Tensile Modulus Gauge Msi)	
#4-1	0.079	1.002	5763	72.80	5712	5871	13.40	12.62	Failure in Gauge Length
#4-2	0.079	1.002	5510	69.61	5423	5484	15.46	12.63	Failure in Gauge Length
#4-3	0.079	1.003	6355	80.71	8385	6431	10.34	12.68	Failure in Gauge Length
#4-4	0.078	0.996	3848	49.53	3703	4080	12.89	12.27	Failed in Grip
#4-5	0.079	1.001	5942	75.14	6086	6002	13.66	12.63	Failed in Grip
#4-6	0.080	1.001	5006	62.51	4832	5508	12.27	12.77	Failure in Gauge Length
#4-7	0.079	1.003	5525	69.73	6526		10.47		Failure in Gauge Length
#4-8	0.079	1.002	4643	58.65	4885		11.72		Failed in Grip
#4-9	0.080	1.002	4677	58.35	5755		10.20		Failed in Grip
#4-10	0.080	1.003	4431	55.22			11.32		Failed in Grip
Avg.				**65.23**	**5701**	**5563**	**12.17**	**12.60**	
Std. Dev.				**9.88**	**1300**	**806**	**1.70**	**0.17**	

Table 3-5. Lot #6 T50/1962 [Unknown], Panel P53

Specimen ID	Thickness (in)	Width (in)	Failure Load (lbs)	Failure Stress (ksi)	Failure Strain Laser (με)	Failure Strain Gauge (με)	Tensile Modulus Laser (Msi)	Tensile Modulus Gauge Msi)	
#6-1	0.087	1.000	6310	72.53	4760	4673	14.26	15.83	Interlaminar Failure
#6-2	0.087	1.001	5963	68.47	4943	4329	14.77	16.03	Interlaminar Failure
#6-3	0.086	1.001	5964	69.28	5628	4449	12.55	15.89	Interlaminar Failure
#6-4	0.086	1.002	5602	65.01	4356	4165	15.14	15.79	Interlaminar Failure
#6-5	0.085	1.001	6430	75.57		4750	17.51	16.16	Interlaminar Failure
#6-6	0.088	1.002	5702	64.67	4500	4185	15.98	15.51	Interlaminar Failure
#6-7	0.086	1.002	5334	61.90	4188		15.26		Interlaminar Failure
#6-8	0.088	0.995	5534	63.20	4142		15.55		Interlaminar Failure
#6-9	0.085	1.002	5058	59.74	3839		15.48		Interlaminar Failure
#6-10	0.087	1.004	5049	57.80	3140		18.09		Failed in Grip
Avg.				**65.82**	**4388**	**4425**	**15.46**	**15.87**	
Std. Dev.				**5.62**	**703**	**246**	**1.56**	**0.22**	

Table 4. Poisson's Ratios

Specimen ID	Lay-Up	Poisons Ratio	Predicted Poisons Ratio	Source*
#1-5	[0]16	0.342	0.27	1
#2-5	[0/30/90/-30]2S	0.344		
#3-2	[90]16	~0	0.007	3
#4-5	[45/0/-45/90]2S	0.323	0.371	5
#4-7	[45/0/-45/90]2S	0.328	0.298	1
#6-5	[Unknown]	0.361		
#6-6	[Unknown]	0.344		

* Sources as listed in Table 1.

Table 3-5. Lot #6 T50/1962 [Unknown], Panel P53

Specimen ID	Thickness (in)	Width (in)	Failure Load (lbs)	Failure Stress (ksi)	Failure Strain Laser (με)	Failure Strain Gauge (με)	Tensile Modulus Laser (Msi)	Tensile Modulus Gauge Msi)	
#6-1	0.087	1.000	6310	72.53	4760	4673	14.26	15.83	Interlaminar Failure
#6-2	0.087	1.001	5963	68.47	4943	4329	14.77	16.03	Interlaminar Failure
#6-3	0.086	1.001	5964	69.28	5628	4449	12.55	15.89	Interlaminar Failure
#6-4	0.086	1.002	5602	65.01	4356	4165	15.14	15.79	Interlaminar Failure
#6-5	0.085	1.001	6430	75.57		4750	17.51	16.16	Interlaminar Failure
#6-6	0.088	1.002	5702	64.67	4500	4185	15.98	15.51	Interlaminar Failure
#6-7	0.086	1.002	5334	61.90	4188		15.26		Interlaminar Failure
#6-8	0.088	0.995	5534	63.20	4142		15.55		Interlaminar Failure
#6-9	0.085	1.002	5058	59.74	3839		15.48		Interlaminar Failure
#6-10	0.087	1.004	5049	57.80	3140		18.09		Failed in Grip
Avg.				**65.82**	**4388**	**4425**	**15.46**	**15.87**	
Std. Dev.				**5.62**	**703**	**246**	**1.56**	**0.22**	

Table 5. Average Tensile Moduli (Msi) as Determined by Independent Techniques

Lot #	Laminate Lay-Up	Laser Extensometer	Strain Gauge	Acoustic Vibration Flexural	Acoustic Vibration Longintudinal
1	[0]16	26.33 (4.31)	29.07 (0.95)	29.39 (0.77)	30.16 (0.59)
2	[0/30/90/-30]2S	17.72 (0.95)	17.8 (0.37)	18.94 (0.20)	16.74 (0.10)
3	[90]16	0.96 (0.13)	1.00 (0.05)		
4	[45/0/-45/90]2S	12.17 (1.70)	12.60 (0.17)	12.36 (0.15)	11.78 (0.05)
5	[45/0/-45/90]2S			12.06 (0.33)	11.73 (0.20)
6	[Unknown]	15.46 (1.56)	15.87 (0.22)	15.71 (0.21)	15.24 (0.22)

Numbers in parenthesis represent one standard deviation.

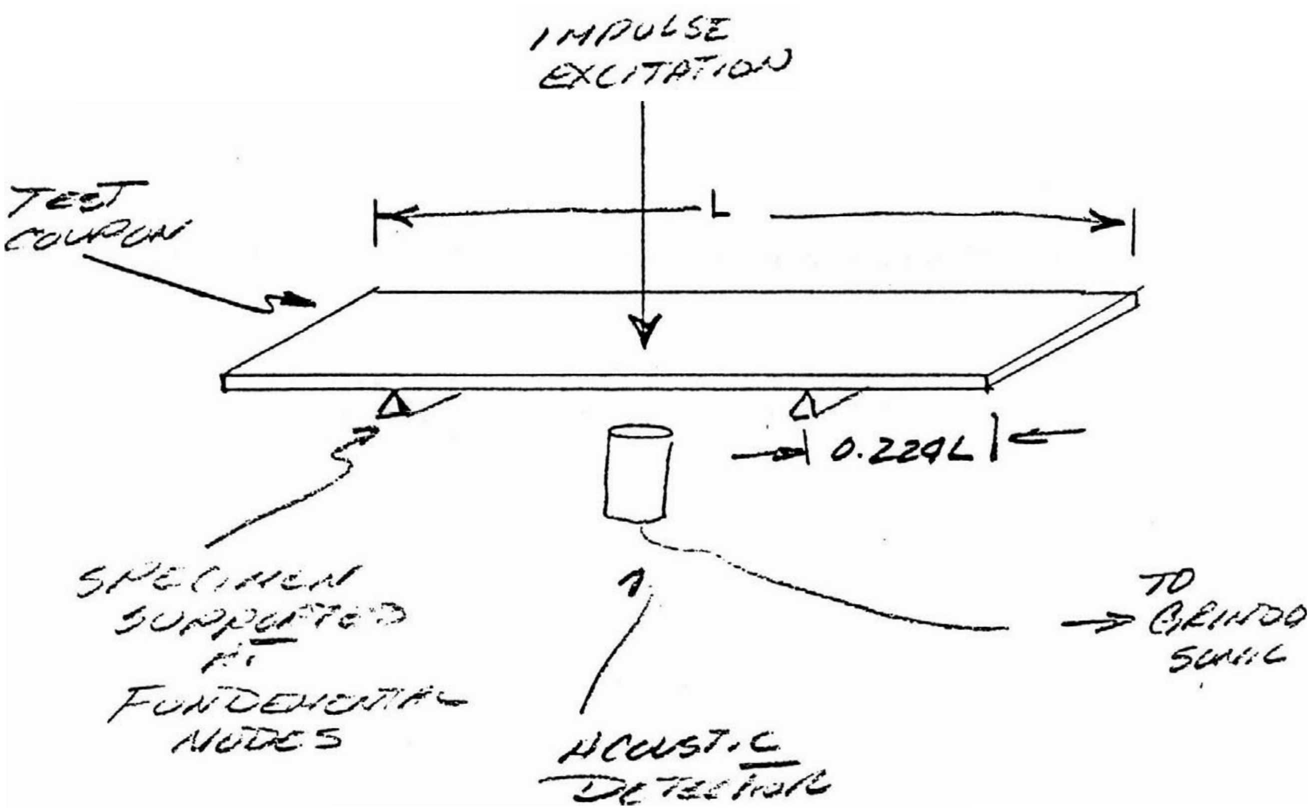

Figure 1. Sketch of the sonic resonance test setup.

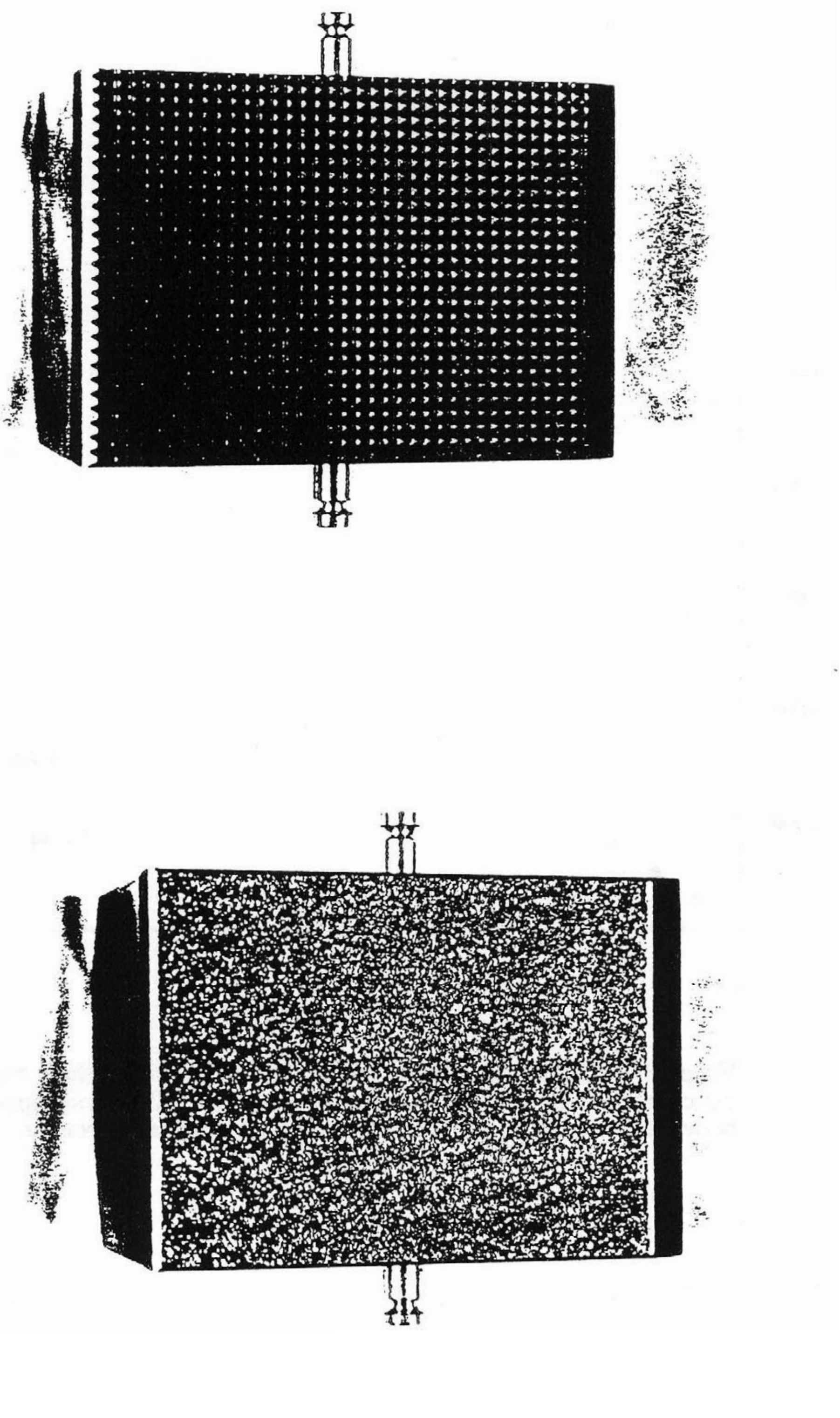

Figure 2. Hydraulic grip faces. A) Traditional diamond shaped grips.
B) Surfalloy grip face.

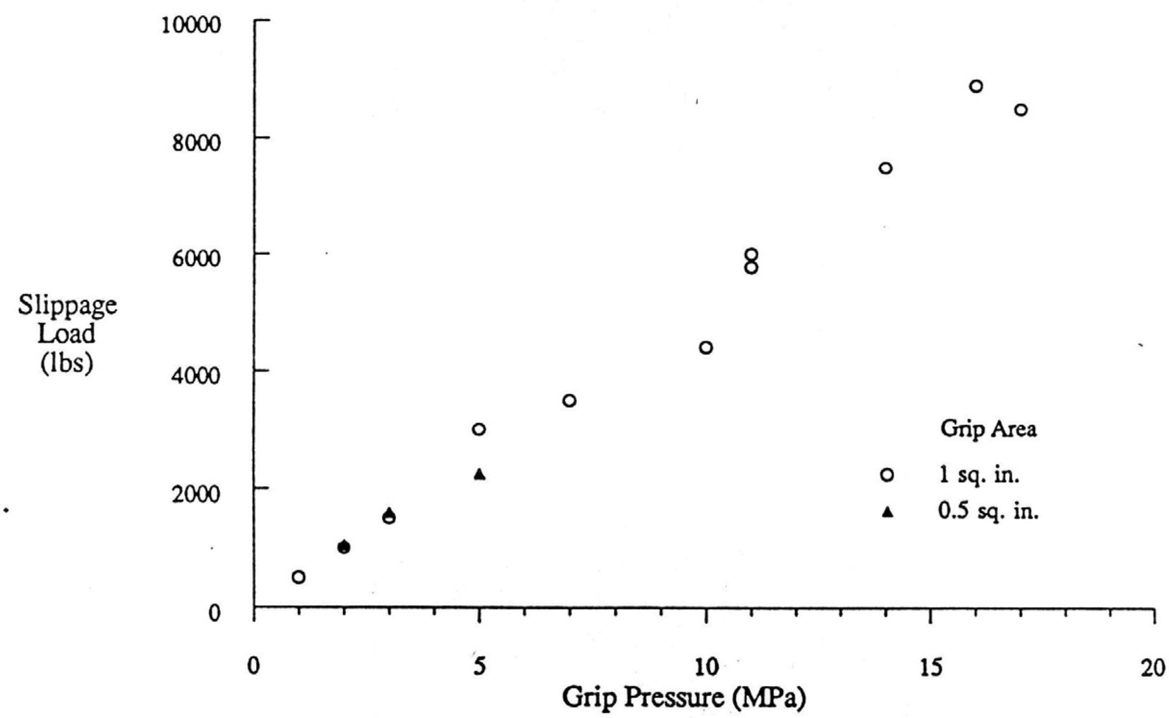

Figure 3. Relationship between applied hydraulic grip pressure and load at which test specimen begins to slip. Two layers of 600 grit sandpaper are between the Surfalloy grips and the graphite epoxy test specimen.

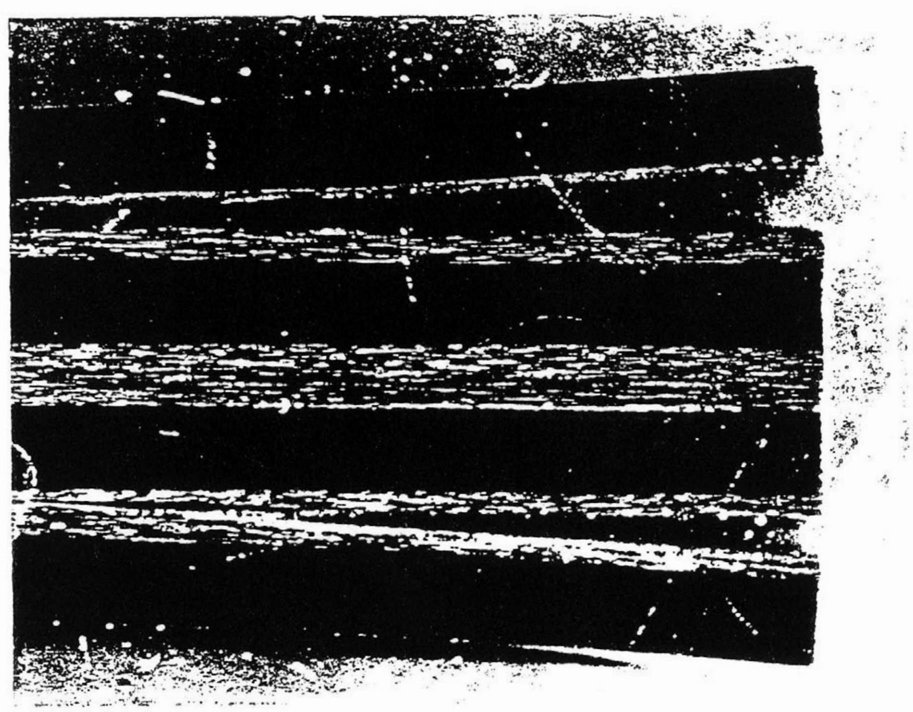

Figure 4. Photograph taken of cross section of specimen 6-3. View shown is along the long axis of the test coupon, i.e. the tensile loading direction. This photo shows the interlaminar failure of the lot 6 specimen in the 90 degree plies. Magnification ~ 30X.

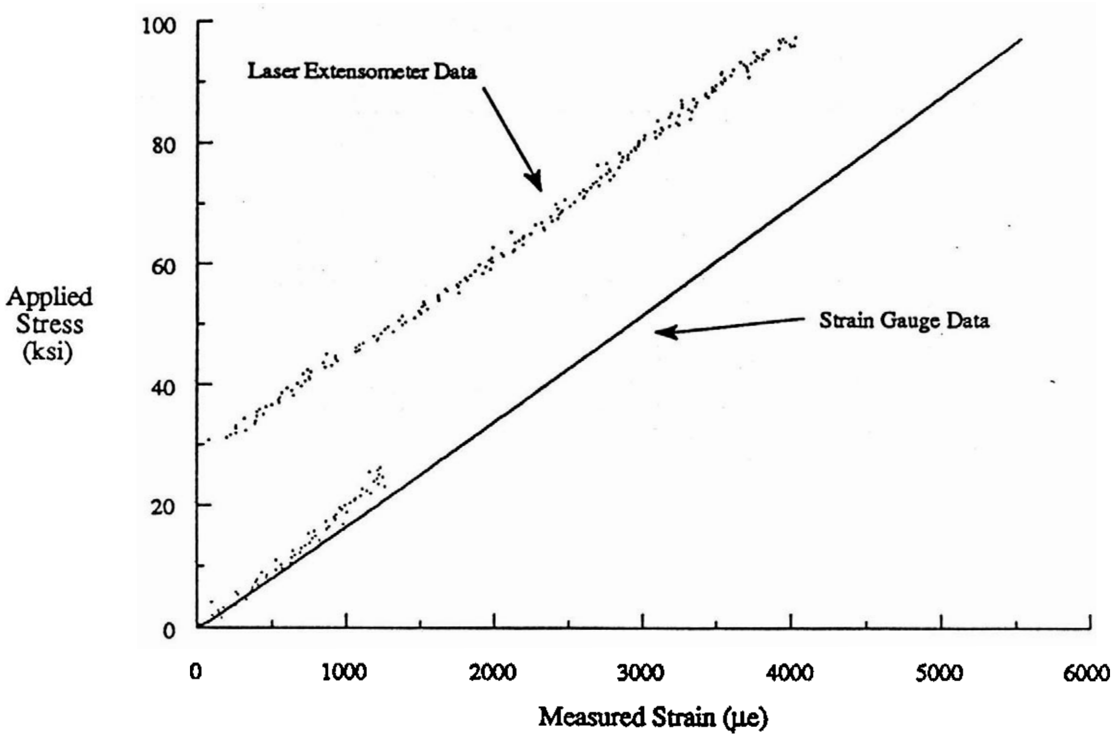

Figure 5. Typical stress versus strain data showing the laser monitor being reset during loading.

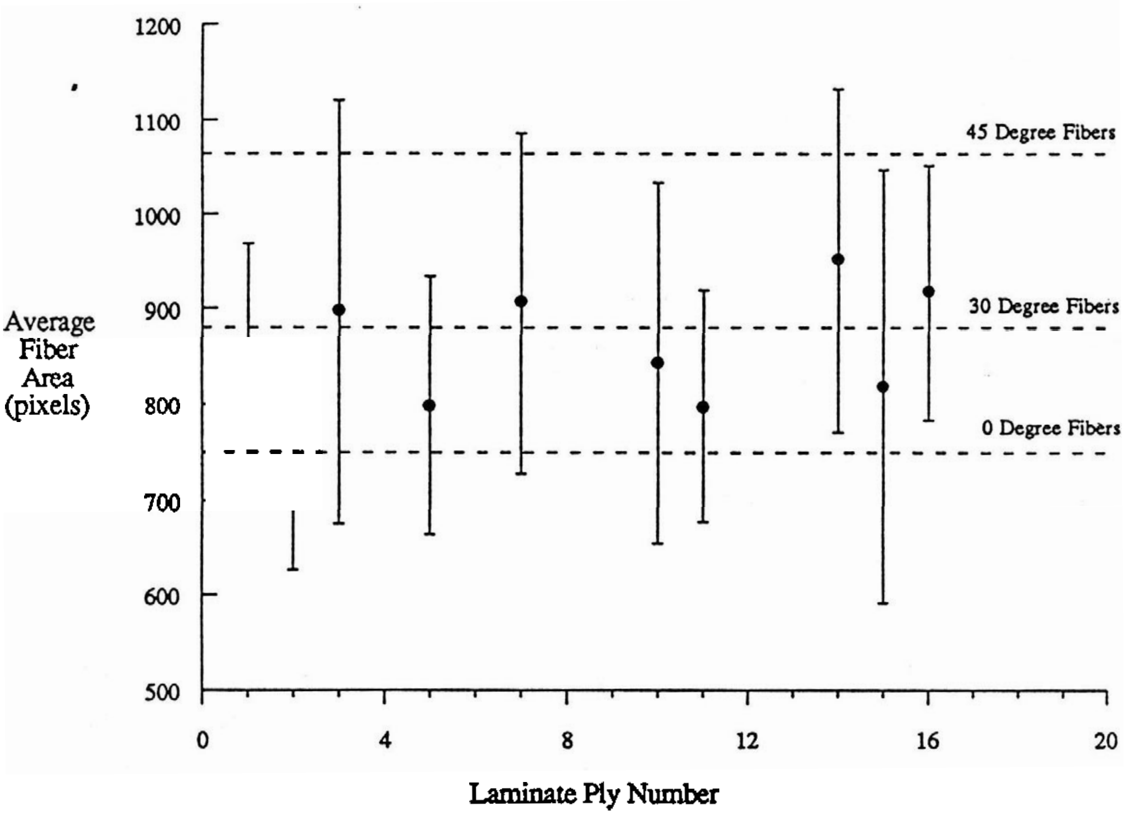

Figure 6. Fiber area measurements for individual plies of specimen 6-3. Known fiber areas (dash lines) were determined from individual plies on specimens 2-6 and 4-9. The 4th, 8th, 9th and 13th plies are 90 degree plies.