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MECHANICAL PROPERTIES OF E293/1581 FIBERGLASS-EPOXY COMPOSITE AND OF SEVERAL ADHESIVE SYSTEMS

D. C. Watson
Materials Integrity Branch
Systems Support Division

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Final Report for Period June 1980 - September 1981

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Mechanical properties have been generated on E293/1581 fiberglass-epoxy composite and several different adhesive systems. Three flat panels of this composite were supplied. Several panels having adhesive joints were also supplied having the E293/E-glass fabric composite laminates bonded; to itself, to steel, and to aluminum honeycomb material. Several types of adhesives, both film and foam adhesives, were used in bonding the single lap joint panels and the composite-honeycomb sandwich panel. Tensile, flexure,

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and interlaminar shear data were obtained on specimens removed from the flat panels parallel to the warp fabric direction and at room temperature and 280°F (138°C). Single lap shear tests were conducted on specimens removed from the adhesively bonded panels. Three point flexure and edgewise compression tests were conducted on specimens removed from the composite-aluminum honeycomb sandwich panel.

PREFACE

This report was prepared by the Materials Integrity Branch (AFWAL/MLSA), Systems Support Division, Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, under Project 2418, "Aerospace Structural Materials," Task 241807, "Systems Support," Work Unit 24180703, "Engineering & Design Data."

The work reported herein was performed during the period June 1980 to September 1981, under the direction of the author, David C. Watson (AFWAL/MLSA), materials engineer. The report was released by the author in December 1981.

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TABLE OF CONTENTS

SECTION		PAGE
I	BACKGROUND	1
II	TEST PROGRAM AND PROCEDURES	2
	1. Material	2
	2. Specimen Geometry and Test Procedures	6
III	RESULTS AND DISCUSSION	11
	1. Fiberglass/Epoxy Panels	11
	2. Adhesively Bonded Panels	18
IV	CONCLUSIONS	22
	APPENDIX A - E Glass Fiber/E-293 Epoxy Laminate and Adhesive Bond Panels Fabrication Procedures and Test Specimen Location	23
	APPENDIX B - Test Data	32
	REFERENCES	44

LIST OF ILLUSTRATIONS

FIGURE		PAGE
1	Typical Cross-Sections of Fabricated Panels	4
2	Flexural Test Setup for Three Point Loading of Sandwich Material Specimen	9
3	Edgewise Compression Specimen in Test Apparatus	9
4	Tensile Stress-Strain Curves for E293/1581 Fiberglass Epoxy; Warp Direction	15
1A	Test Specimen Location in 18" by 18" Panels	28
2A	Test Specimen Location in Fiberglass Composite to Composite Lap Shear Bond Panels	29
3A	Test Specimen Location in Fiberglass Composite to Steel Lap Shear Bond Panels B201, B202, B203, B204, B205, B206, B207, B208	30
4A	Test Specimen Location in Fiberglass Composite to Aluminum Honeycomb Core Adhesive Bonded Panel	31

LIST OF TABLES

TABLE		PAGE
1	Physical Properties Data	3
2	Statistical Analysis Results	13
3	Summary of the Combined Test Results on E293/1581 Fiberglass/Epoxy	14
B-1	Tensile Test Results in Room Temperature, Laboratory Air	33
B-2	Tensile Test Results at 280°F (138°C)	34
B-3	Flexural Test Results	35
B-4	Apparent Interlaminar Shear Test Results in Room Temperature, Laboratory Air	36
B-5	Apparent Interlaminar Shear Test Results at 280°F (138°C)	37
B-6	Panel Averages of Mechanical Properties of E293/1581 Fiberglass/Epoxy	38
B-7	Single-Lap-Shear Test Results of Film Adhesives for Fiberglass to Fiberglass Bond	39
B-8	Single-Lap-Shear Test Results of Foam Adhesives for Fiberglass to Fiberglass Bond	40
B-9	Single-Lap-Shear Test Results for Fiberglass to Metal Bond	41
B-10	Three Point Flexure Test Results for Fiberglass to Aluminum Honeycomb Bonded Panel	42
B-11	Edgewise Compression Test Results for Fiberglass to Aluminum Honeycomb Bonded Panel	43

SECTION I

BACKGROUND

Since about 1965 the Systems Support Division, Materials Laboratory, Air Force Wright Aeronautical Laboratories has been supporting Arnold Engineering Development Center (AEDC), AFSC, in their efforts to replace steel components with fiberglass composite materials in the 16S Propulsion Wind Tunnel. The supersonic compressor circuit of this wind tunnel has five stages, C-1 to C-5. This use of composite materials to replace metallic rotor blades reduces the rotating mass and accompanying stresses in the rotor and thereby increases the overall life, and performance of the compressor stages. During the mid to late 1960's, the metal blades of the C-1 and C-2 compressor stages were replaced with fiberglass-epoxy matrix composite blades. These blades have operated successfully in this application. Since the failure of the C-4 steel rotor disc in 1973, several programs have been conducted in support of AEDC's efforts to replace steel blades and blade spacers in the C-3 and C-4 compressor stages with fiberglass/epoxy or fiberglass/polymide composite components depending on the operating temperature.

In addition, after about 15 years of operation of the C-1 stage, new blades were required. One reason for this was foreign object damage which was due to ingestion of materials inadvertently being left in the up-stream cell areas. Since a new manufacturer was contracted to make these replacement blades, AEDC again requested support from the Materials Laboratory. The purpose of this support was to evaluate the materials response to the new company's processing/fabrication techniques to produce E-glass fiber/E293 epoxy composite components. Three flat panels of this composite were supplied to AFWAL/MLSA for determination of mechanical properties. In addition, several panels with adhesive joints were supplied having E-glass/E293 composite laminates bonded; to itself, to steel, and to aluminum honeycomb material. Several different adhesives were screened to determine their applicability to these new rotor blades.

SECTION II

TEST PROGRAM AND PROCEDURES

1. MATERIAL

Three composite panels, approximately 18 X 18 inches (457 X 457 mm). and several adhesively bonded panels were fabricated by the Homestead Tool and Machine Inc. under an Air Force contract with Arnold Engineering Development Center (AFSC). The fabrication methods were representative of those used for the C-1 stage blades. The detailed fabrication procedures used for all the panels are presented in Appendix A, and were taken from documentation supplied with the panels.

The three test panels were identified as panel numbers 006, 007, and 008. These panels consisted of 15 plies of style 1581 woven E-glass fabric/E-293 epoxy matrix. The warp direction of the prepreg plies were laid up in the same orientation, and the panels were press cured. Physical property data obtained from two samples from each panel are presented in Table 1. The lower void content from sample number 6R1 can be accounted for by the higher cure pressure used on panel 006, see paragraph 2.c. in Appendix A. Photo micrographs of a typical cross section from each of three samples are shown in Figure 1. The voids visible in Figure 1 were randomly distributed on the machined specimen surfaces as observed by low magnification (30X). The three test panels were visually inspected for gross defects using back lighting on a tracing table. The machined test specimens were also visually inspected for delaminations and gross defects prior to testing.

In addition to the three panels used for the determination of selected mechanical properties, several adhesively bonded panels were provided for shear strength determinations. Several types of adhesives were used to bond the fiberglass/epoxy composite to composite, to steel and to aluminum honeycomb. The composite to composite and steel to composite bonded panels were fabricated for single-lap-shear testing. The composite to aluminum honeycomb panel, 17¼ X 18 inches (438 X 457 mm). was a composite-honeycomb-composite sandwich type construction having six

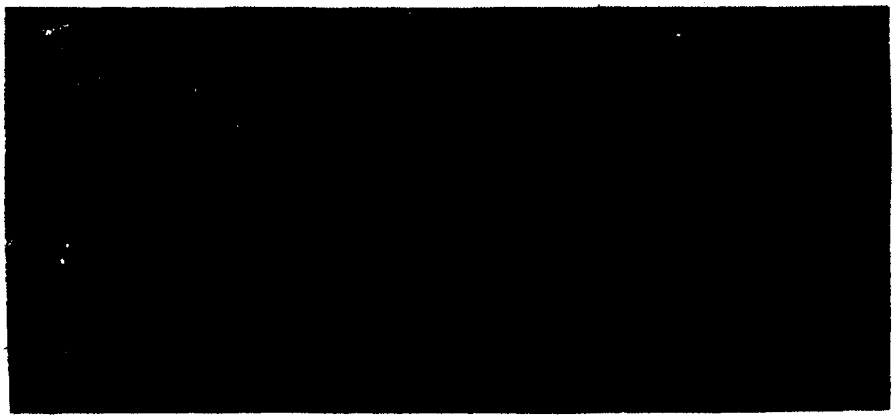
TABLE 1

PHYSICAL PROPERTIES DATA

Panel Number	Specific Gravity	% Resin Content (by weight)	% Resin Volume	% Fiber[1] Volume	% Void[1] Content by Volume	Glass[2] Transition Temperature
6R1	1.86	33.73	50.19	47.41	2.40	154 °C
6R2	N.A.	30.78	-----	-----	----	------
7R1	1.85	32.08	47.48	48.33	4.19	146 °C
7R2	1.87[2]	29.89	44.72	50.42	4.86	------
8R1	1.85	32.58	48.16	47.89	3.99	147 °C
8R2	1.87[2]	30.40	45.48	50.06	4.46	------

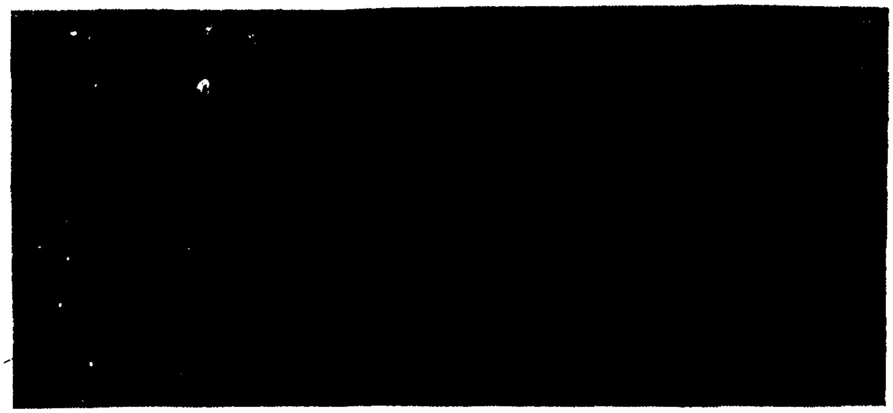
NOTE: [1] 1.25 g/cc resin density and 2.60 g/cc fiber density values were used to calculate % Fiber Volume and % Void Content.

[2] One data point; all other information is an average of three data points.



(a) Sample 6R1, Panel 006, 60X

(b) Sample 7R1, Panel 007, 60X



(c) Sample 8R1, Panel 008, 60X

Figure 1. Typical Cross-Sections of Fabricated Panels

different adhesive systems that were laid down in 3 inch wide strips. The thickness of this sandwich panel was approximately 1 inch (25mm). The adhesively bonded panels were inspected using an ultrasonic C-scan NDT technique prior to machining into specimens. The following is a summary of the panels and adhesive systems furnished:

Composite to Composite (Film Adhesives)

Panel I.D.	Adhesive System
B-101	FM96
B-102	FM96U
B-103	AF143
B-104	HT424

Composite to Steel (Film Adhesives)

Panel I.D.	Adhesive System and Condition
B-201	FM96 - acid etch, no primer
B-202	FM96 - no etch, no primer
B-203	FM96 - acid etch, spray primed
B-204	FM96 - no etch, spray primed
B-205	HT424 - acid etch, spray primed
B-206	AF143 - acid etch, spray primed
B-207	FM96U - no etch, dip primed
B-208	no adhesive, acid etch, spray primed

Composite to Composite (Foam Adhesives)

Panel I.D.	Adhesive System
B-301	3M-3015
B-302	FM41
B-303	HT424 foam
B-304	Hysol-3050
B-305	HT424 foam

Composite to Aluminum Honeycom Sandwich Panel

Area I.D.	Adhesive System
1	FM41 foam
2	3M-3015 foam
3	HT424 foam, two layers
4	HT424 foam, one layer
5	Hysol-3050 foam
6	FM96 U film

2. SPECIMEN GEOMETRY AND TEST PROCEDURES

a. Fiberglass/Epoxy Panels

Tensile, flexure, and short-beam-shear specimens were cut out of the three panels and finished machined on a Tensile-Cut belt sander. The specimen locations are shown in Figure 1-A. The tests on these specimens were conducted on an Instron Testing Machine, Model TTCM. The crosshead speeds were 0.05 inch/minute (1.27 mm/min.) for the tensile and short-beam-shear testing and 0.2 inch/minute (5.1 mm/min.) for the flexure tests.

(1) Tensile

When testing woven fiberglass/polymer matrix composite materials, the testing laboratory within the Systems Support Division has used both the dogbone-shaped specimen per American Society for Testing & Materials (ASTM) test method D638-77a, type I, and the constant cross section specimen per ASTM test method D3039-76. Since sufficient amount of material was supplied, tensile tests were conducted on both specimen geometries to determine any effect on the tensile strength results. The dogbone-shaped specimen had a reduced section of 0.5 inch (13mm) width by 2.25 inch (57.15 mm) length and 3.0 inch (76 mm) fillet radii. The straight-sided specimen was 1 inch (25 mm) wide and 9 inches (229 mm) long. and had 1/16 inch (1.6 mm) thick by 2 inch (51 mm) long woven glass/ phenolic doubling tabs bonded to the grip ends. Both specimen types were gripped using wedge action grips. The upper grip was attached to a universal joint type alignment coupling. Specimen strain was obtained using an Instron 2 inch (51 mm) clip-on type extensometer.

(2) Flexure

Flexural testing was conducted in accordance with ASTM test method D790-71, using Method I, three-point loading. The flexural specimens were 5 inches (127 mm) by 1 inch (25 mm). The loading fixture was adjusted to a 4 inch (102 mm) span which resulted in a span-to-depth ratio of about 29:1. Mid-span deflection was determined from the motion of the loading nose relative to the specimen supports using the load/time strip chart recording since the test machine crosshead speed was known. This deflection was used to determine the flexural modulus from each test.

(3) Interlaminar Shear

The interlaminar shear (short-beam-shear) testing was done in accordance with ASTM test method D2344-76. The span-to-depth ratio for the first four tests was set to equal 5:1, but this resulted in flexural failures. The ratio was changed to 4:1 which yielded a majority of valid interlaminar shear failures. The specimen dimensions were 0.250 inch (6.35mm) wide and 0.925 inch (23.5mm) long.

b. Adhesively Bonded Panels

(1) Single-Lap-Shear

Specimens were removed from the panels, as shown in Figures 2-A and 3-A to yield four single-lap-joint specimens per adhesive/surface preparation/material combination. The specimens were 1 inch (25mm) wide and had an overlap length of approximately 1.6 inch (41mm). The testing procedures described in ASTM standard practice D3163-73 were followed even though this standard is not intended for use on anisotropic adherends such as reinforced plastic laminates. To insure proper loading conditions, a tab of proper thickness was adhesively bonded to each end of the specimens so that the lap-joint line was coincident with the center line of the loading train. The specimen ends were gripped using the Instron wedge action grips. These tests were conducted on an Instron Testing Machine, Model TTCM, at a crosshead rate of 0.05 inch/minute (1.27mm/min.).

(2) Composite to Aluminum Honeycomb Sandwich Panel

Two flexural and two edgewise-compression specimens were removed from each of the six adhesive areas in the panel as shown in Figure 4-A. The flexural specimen dimensions were 1.1 inch (28mm) thick by 1 inch (25mm) wide by 12 inches (305mm) long, and the compression specimens were two inches (51mm) square by 1 inch (25mm) thick. The tests on these specimens were performed on a Wiedemann/Baldwin, Model FGT, Testing Machine.

The flexural tests were conducted using a three-point loading method, shown in Figure 2, and following the procedures of ASTM standard method C393-62 with the exception that the specimen width and length were less than specified. In an attempt to avoid compression failures in the top facing under the center load point during the 280°F (138°C) temperature tests, an aluminum sheet, 1/8 inch (3.2mm) thick by 1 inch (25mm) square, was placed between the loading bar and specimen surface. The loading fixture was set to a span of 11 inches (279mm).

The edgewise-compression tests were performed following ASTM test method C364-61. The test machine's crosshead speed was maintained at 0.02 inch/minute (0.51mm/min.). Strain gages were bonded to both faces of the specimen. The grips, shown in Figure 3, were used to secure the specimens during the tests and maintain a uniform loading condition.

c. Testing Environment

The above tests were conducted at room temperature, laboratory air, and at 280°F (138°C). The ambient laboratory temperature and relative humidity were recorded on a Honeywell Hygrometer equipped with a temperature pen. The laboratory temperature remained between

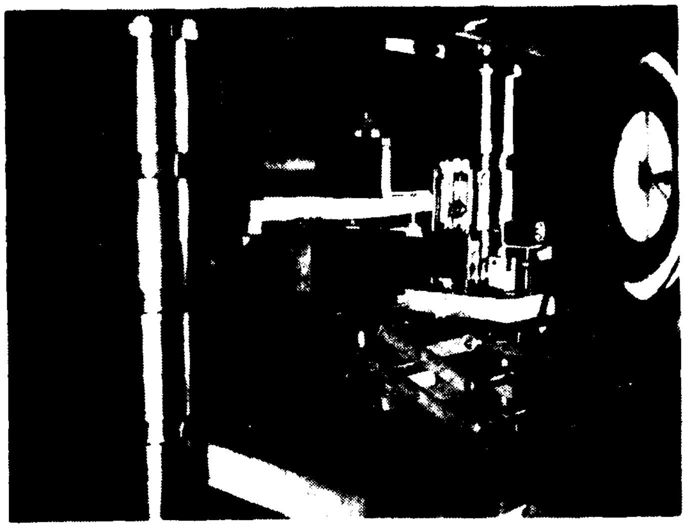


Figure 2. Flexural Test Setup for Three Point Loading of Sandwich Material Specimen

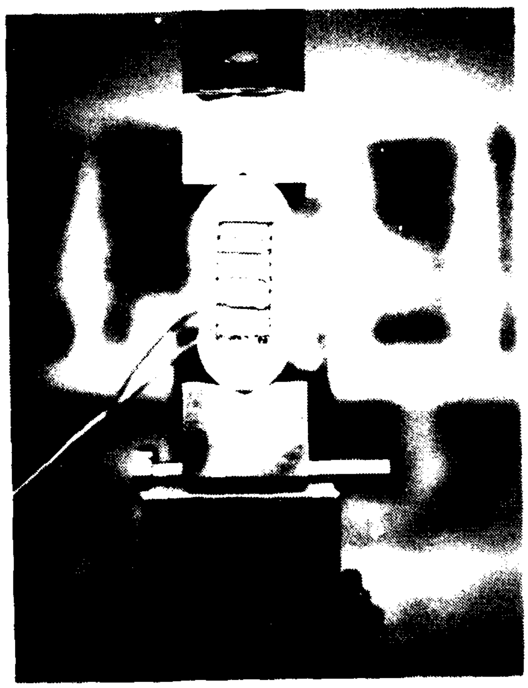


Figure 3. Edgewise Compression Specimen in Test Apparatus

70°F (21°C) and 76°F (24°C) except for a short period when it decreased to 65°F (18°C). The relative humidity varied between 25% and 60%. All of the specimens were at these conditions until testing. None of the specimens were put in a desiccator for removal of moisture.

The elevated temperature tests were conducted in a Conrad-Missimer, Model FTU1.8, air circulating test chamber. Temperature control was maintained with a Gardsman indicating pyrometric controller using a Chromel/alumel control thermocouple taped to the test specimen, except for the interlaminar shear tests. For these shear tests, the thermocouple was placed near the specimen but not taped to it. Another thermocouple was taped to the specimens, except for interlaminar shear, and connected to a Fluke Model 2190A digital thermometer to monitor the test temperature. This unit has an accuracy of ± 0.7°F(± 0.4°C) for the temperature range used. The indicated test temperature was maintained within ± 3°F (± 1.7°C). The test specimens were held at the test temperature for at least 30 minutes prior to testing.

SECTION III

RESULTS AND DISCUSSION

1. FIBERGLASS/EPOXY PANELS

The tensile, flexure, and interlaminar shear test results at room temperature and 280°F (138°C) are tabulated in Tables B-1 to B-5. The panel to panel average results are presented in Table B-6.

Tables B-1 and B-2 show the tensile properties obtained from both of the test specimen geometries, dog-bone and the constant cross section specimen. Also, these two tables indicate the failure locations within the specimens. All of the dog-bone specimens failed at the end of the reduced test section at or near the tangent point to the fillet radii. About all of the constant cross section specimens failed at or near the tab edge or inside the gripping tabs. This may be the result of using a 1/16 inch (1.6mm) thick tab material rather than the much thicker tab recommended in ASTM test method D3039-76.

The room temperature flexure specimens failed in flexure as expected; however, all of the 280°F (138°C) test specimens failed as a result of compression in the outer plies beneath the loading pin. Some of the elevated temperature specimens also showed a flexural failure mode in conjunction with compression, but it was not apparent which failure occurred first. Since the 280°F (138°C) tests resulted in compression failures, the average results are not presented in Table B-6 and no statistical analysis was performed using these data.

The majority of the interlaminar shear specimens failed in shear; however, some failed by flexural failure of the outer plies. The data from the specimens that failed in flexure are not included in the average shear strength values listed in Table B-6. Also, specimen number 7-S-1 was rejected as an outlier using the method of processing data for extreme values presented in Reference 1.

The above results were statistically evaluated using the following procedures:

a. All of the data from the three panels were combined for each of the mechanical properties; ultimate tensile strength (both specimen geometries), flexural strength, and interlaminar shear strength. Chi-Square goodness of fit tests (References 1, 2 and 3) were conducted to determine if these data groups were normally distributed at a significance level of $\alpha = 0.05$.

b. After it was determined that each of the strength property data were normally distributed, "F" and "t" tests (Reference 2) were conducted to determine if selected data groups did or did not have significantly different means and variances. The groups of data that were compared are shown in Table 2. Since the samples were not removed randomly from the panels nor the order of testing randomized, the results of these tests are not exact (Reference 2).

c. The data groups that showed no significant difference in either the variances or the means, using a 95% confidence level, were combined to form a population. The results are shown in Table 3. The elastic modulus values associated with the strength property data was also combined and presented Figure 4 illustrates the tensile stress-strain behavior of the fiberglass/E293 epoxy composite.

d. Since the two-parameter Weibull distribution is being used as a failure distribution for static strength data of composite materials, the Weibull parameters for each strength data set were determined using the maximum likelihood estimator (Reference 3). The estimators of the shape, $\hat{\alpha}$, and scale $\hat{\beta}$, parameters are shown in Table 3 for those data that were shown to fit the Weibull distribution.

e. The Chi-square goodness of fit test (References 3 and 4) was used to determine if each strength data set did fit the two-parameter Weibull distribution at a significance level of $\alpha = 0.05$.

TABLE 2

STATISTICAL ANALYSIS RESULTS

Mechanical Property	Specimen Type	Comparison Type	Temperature:	Room Temperature		280°F (138°C)	
			Statistical Test : (1)	F-test	t-test	F-test	t-test
Ultimate Tensile Strength	Dog-bone	Panel 006 data compared to panel 007		NO	NO	NO	NO
"	" "	Combined data from panels 006 & 007 compared to panel 008		NO	NO	NO	NO
"	Constant Cross Sect.	Panel 006 data compared to panel 007		NO	NO	NO	YES
"	" "	Combined data from panels 006 & 007 compared to panel 008		NO	NO	—	—
"	" "	Panel 007 data compared to panel 008		—	—	NO	NO
"	" "	Combined data from panels 007 & 008 compared to panel 006		—	—	NO	YES
"	" "	Bottom grip tab failures compared to top grip tab failures (deleting 280°F data from panel 006)		NO	NO	NO	NO
"	" "	Failures at tab-edge compared to failures inside the grip tab (deleting 280°F data from panel 006)		NO	NO	NO	NO
"	N.A.	Dog-bone type compared to constant cross section specimen (using combined data)		NO	NO	NO	NO
"	Dog-bone	Present data compared to the 1965 data (using combined data)		NO	NO	NO	NO
Flexural Strength	N.A.	Panel 006 data compared to panel 007		NO	NO	—	—
"	N.A.	Panel 007 data compared to panel 008		NO	NO	—	—
Interlaminar shear strength	N.A.	Panel 006 data compared to panel 007 and to panel 008		YES	—	—	—
"	N.A.	Panel 007 data compared to panel 008		NO	NO	NO	NO

(1) A "NO" indicates that no significant differences exist for that statistical test using a 95% confidence level. A "YES" indicates that a significant difference did exist.

TABLE 3

SUMMARY OF THE COMBINED TEST RESULTS ON
E293/1581 FIBERGLASS/EPOXY

Test type and property	Test Temperature	Average	Standard Deviation	Number of Tests	M.L.E. Weibull Parameters shape $\hat{\alpha}$	scale $\hat{\beta}$
TENSILE						
Ultimate stress, Ksi (MPa)	73°F (23°C)	45.5 (314)	3.2 (22.1)	30	15.8	47.0 (324)
	280°F (138°C)	32.0 (221)	1.8 (12.4)	25	--	
Initial modulus, Msi (GPa)	73°F (23°C)	3.65 (25.2)	0.36 (2.5)	30	---	
	280°F (138°C)	2.80 (19.3)	0.22 (1.5)	24	—	
Secondary modulus,Msi(GPa)	73°F (23°C)	2.81 (19.4)	0.19 (1.3)	28	-	
	280°F (138°C)	2.52 (17.4)	0.14 (1.0)	15	—	
3 POINT FLEXURE						
Ultimate stress, Ksi (MPa)	73°F (23°C)	67.5 (465)	2.9 (20.0)	15	25.0	68.8 (474)
Initial molulus, Msi (GPa)	73°F (23°C)	3.55 (24.5)	0.13 (0.9)	15	—	—
	280°F (138°C)	2.62 (18.1)	0.17 (1.2)	14	—	—
APPARENT INTERLAMINAR SHEAR						
Ultimate stress, Ksi (MPa)	73°F (23°C)	7.82 (53.9)	0.38 (2.6)	16	25.6	7.99 (55.1)
	280°F (138°C)	2.18 (15.0)	0.16 (1.1)	20	14.8	2.25 (15.5)

M.L.E. - Maximum likelihood estimator

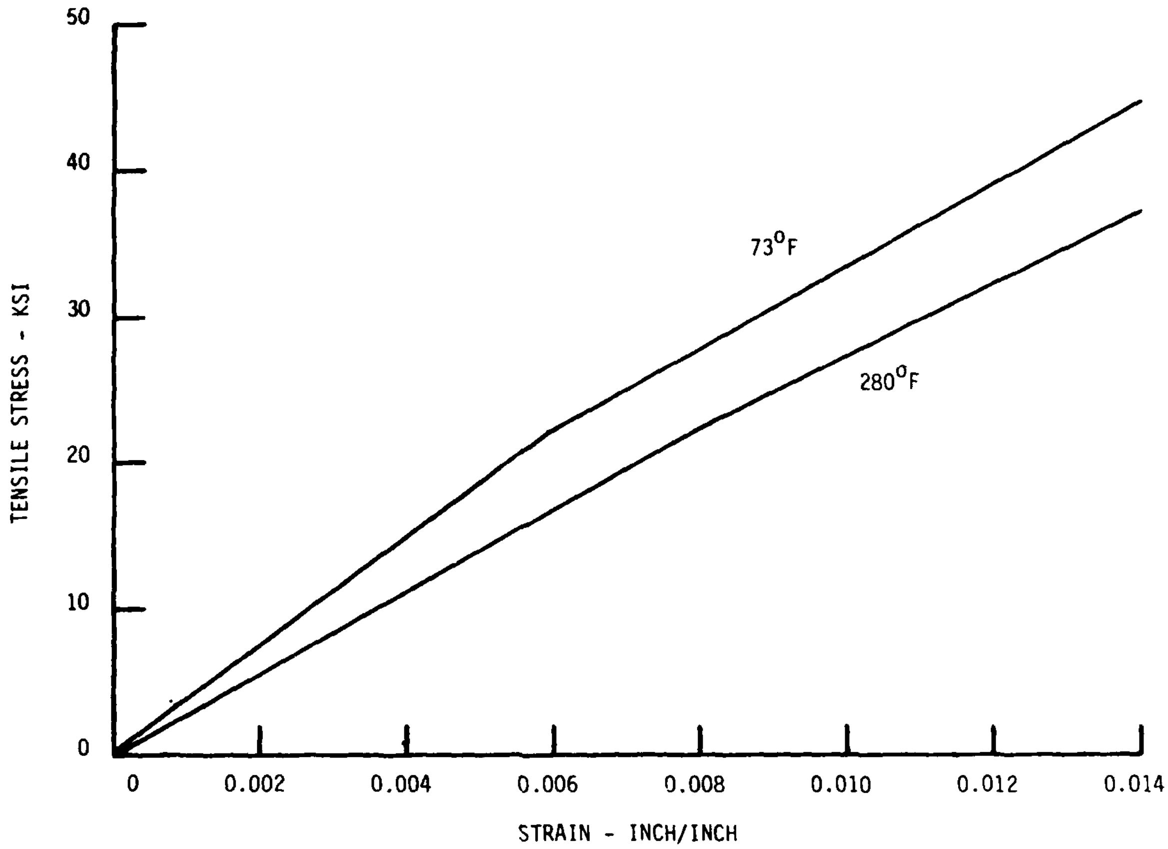


Figure 4. Tensile Stress - Strain Curves for E293/1581 Fiberglass Epoxy; Warp Direction

The results of the statistical evaluation shown in Table 2 are summarized below:

a. Chi-Square test for normality --

The combined 280°F (138°C) interlaminar shear strength data from the three panels were the only data group not normally distributed. However, if the data from panel 006 are deleted, the combined 280°F (138°C) shear strength data from panels 007 and 008 were normally distributed.

b. "F" test --

The room temperature interlaminar shear strength data from panel 006 compared to panel 007 or panel 008 data differed significantly with regard to variability. All of the other data group variances did not show a significant difference.

c. "t" test --

(1) For the constant cross section specimen, the average ultimate tensile strength at 280°F (138°C) from panel 006 was significantly greater than the tensile strength values obtained from panels 007 and 008.

(2) For the constant cross section specimen, there was no significant difference in the average ultimate tensile strength that can be attributed to the location of the failure. The 280°F (138°C) data from panel 006 were not included.

(3) The two tensile specimen geometries resulted in no significant difference in either the room temperature or 280°F (138°C) average ultimate tensile strength. Again the 280°F (138°C) data from panel 006 constant cross section specimen were not included.

(4) There was no significant difference between the present average ultimate tensile strength data and the 1965 data (Reference 5).

d. Chi-Square test for two parameter Weibull distribution --

The combined 280°F (138°C) ultimate tensile strength data (panel 006 data from the constant cross section specimen deleted) and the 280°F (138°C) interlaminar shear strength data from the three panels did not conform to the Weibull distribution. However, deleting the 280°F (138°C) shear strength data from panel 006, resulted in the elevated temperature shear data from the other two panels conforming to the Weibull distribution.

Based on the above Chi-Square test results, the 280°F (138°C) interlaminar shear strength data from panel 006 belongs to a different population than the same data from panels 007 and 008. The 280°F (138°C) shear strength data from panel 006 are about 30% greater than the data from panels 007 and 008. From the data shown in Table 1, the void content of panel 006 was 2.4%, while the void contents from panels 007 and 008 were about 4.5%. Considering the difference in void contents, the 280°F shear strength results are consistent with the experimental observations presented in Reference 6; i.e., horizontal shear strength decreases approximately linearly with increasing void content. However, the average room temperature shear strength data do not conform with this observation from Reference 6. The average room temperature shear strength from panel 006 show only a 3 to 7% increase over the other two panels' data and the data variability from panel 006 is significantly less. A possible explanation for this difference between the room temperature and 280°F shear strength results is that the room temperature shear strength data from Panel 006 represent only six data points because of the flexural failure mode occurring in the first four tests.

Another difference associated with panel 006 occurred in the 280°F (138°C) ultimate tensile strength data. The results were obtained from the constant cross section specimens and showed panel 006 having 13 to 18% greater tensile strength than those from the other two panels at 280°F (138°C). However, there were no significant differences when comparing the other ultimate tensile strength data; i.e., data from the dog-bone type specimen at both room temperature and 280°F (138°C), and the room temperature data from the constant cross section specimen.

The difference in void contents of the panels would not be expected to produce this difference in the elevated temperature tensile strength since tensile strength is a fiber dominated property. Also, no information presented in Reference 6 showed any relationship between void content and tensile strength. No explanation of the discrepancy in the 280°F (138°C) ultimate tensile strength data from panel 006, constant cross section specimen, can be made.

2. ADHESIVELY BONDED PANELS

No statistical evaluations were conducted on the results obtained from the adhesively bonded panels since only one or two tests were conducted per adhesive/surface preparation/test condition. Therefore, the following discussions on the adhesively bonded panels test results are limited to trends in the shear strength data. The comparisons made in the following discussions are limited to this evaluation since the fabrication/surface preparation procedures used, see Appendix A, may or may not be optimum for the adhesive systems.

a. Fiberglass to fiberglass composite bond, single-lap-shear test results:

The adhesive shear strength results for the film adhesives and the foam adhesives are shown in Tables B-7 and B-8. For the film adhesives, the FM96 and AF143 systems yielded approximately the same results and the highest shear strength at both room temperature and 280°F (138°C). The HT424 adhesive showed the largest decrease in shear strength due to the increase in test temperature.

Of the foam adhesives, the 3M-3015 system had the highest shear strength at 280°F (138°C), while the Hysol 3050 system had the highest shear strength at room temperature. The HT 424 foam adhesive showed very little loss in strength as a result of increasing the test temperature.

b. Fiberglass composite to steel bond, single-lap-shear test results:

The shear strength results for the composite to steel single-lap-shear tests are presented in Table B-9. For the FM96 adhesive, four different surface preparations were used in fabricating the panels. These limited number of data show that the AF143 adhesive to thave the highest shear strength at both room temperature and 280°F (138°C). However, the shear data from the other three adhesive systems (FM96 & HT424 both with an acid etch and FM96U with no acid etch) were comparable with AF143 at room temperature but not at 280°F (138°C). The HT424 adhesive showed the largest decrease in shear strength due to the temperature increase. The results from the different surface preparations with the FM96 adhesive show the following:

(1) The acid etch increased the room temperature shear strength approximately 30%, but the etch decreased the 280°F (138°C) shear strength approximately 15%.

(2) The spray prime had little effect at either test temperature. Note that the majority of the specimens tested at 280°F (138°C) failed by interlaminar shear in the composite laminate which indicates that the shear strength of the adhesive bond was greater than the reported values in Table B-9.

c. Fiberglass composite to aluminum honeycomb sandwich panel:

The three-point flexural test results for the composite to aluminum honeycomb sandwich panel are shown in Table B-10. Three types of failure modes occurred in these tests; i.e., adhesive shear failure at the bond, compression failure of composite facing, and interlaminar shear failure in the composite facing. The four test specimens removed from the HT424 adhesive area failed by interlaminar shear in the composite. Three out of four of the other adhesive specimens tested at room temperature failed by shear in the adhesive and three out of four specimens tested at 280°F (138°C) failed by compression in the facing.

Because of these different failure modes, the following discussion compares the amount of core shear stress developed at failure of the beam. This will present a feel for the relative performance of honeycomb sandwich panels having these adhesive systems and loaded in three-point flexure. At room temperature the FM41 (adhesive shear failure) and FM96U (facing compression failure) adhesives withstood a core shear stress greater than 550 psi (3.8 MPa) while all the other adhesives' core shear stresses were below 500 psi (3.4 MPa). At the 280°F (138°C) test temperature, the Hysol 3050 (adhesive shear failure) system withstood the highest core shear stress of about 400 psi (2.7 MPa); however, the FM41, 3M-3015 and FM96U (all facing compression failures) adhesives were not much below this shear stress at approximately 350 psi (2.4 MPa). The 3M-3015 (adhesive shear failure at room temperature and facing compression failure at 280°F) system resulted in no loss in core shear stress due to the increase in test temperature, while the HT424 (composite interlaminar shear failure) showed the largest decrease with increasing test temperature. The location of the composite interlaminar shear failures in the HT424 adhesive specimens shifted from near the loading point at room temperature to one fiberglass ply from the adhesive bond (tensile side of beam) at 280°F (138°C).

The edgewise compression test results for the composite to aluminum honeycomb sandwich panel are shown in Table B-11. These tests were essentially compression testing of the fiberglass epoxy facings. Nearly all of the failures were the result of crushing the facing material at the grip ends. The only result worth noting is the considerably lower compression strength values for the HT 424 adhesive area obtained at 280°F (138°C). This result is consistent with the above trend observed under the three-point flexure tests.

d. In summary considering all of the previous shear test results, single-lap-shear and honeycomb sandwich panels, the following adhesives had the best shear properties for a 280°F (138°C) application and using the fabrication/surface preparation procedures shown in Appendix A:

1. Film adhesive - AF143, FM96 and FM96U
2. Foam adhesive - 3M-3015 and Hysol 3050

The film adhesives may be useful for either single lap shear joints or a composite to aluminum honeycomb sandwich panel. The foam adhesives would be better applied to a honeycomb sandwich panel type application since the single lap shear strength properties were about one-fourth to one-fifth those of the film adhesives.

SECTION IV

CONCLUSIONS

1. There were no significant differences in the room temperature or 280°F (138°C) ultimate tensile strength data as a result of using two different tensile specimen geometries. However, both specimen types resulted in the failures occurring at the end of the test sections (at or near the fillet radii for the dog-bone shape specimens and at or near the grip tab edge for the constant cross section specimens).

2. There was no significant difference between the present ultimate tensile strength data and those reported in 1965.

3. One of the three test panels was fabricated using a higher press pressure (65 psi versus 50 psi) which resulted in a lower void content (2.4% versus 4.5%) for that panel. The 280°F (138°C) interlaminar shear strength for the panel was 30% greater than the data from the other two panels. The Chi-Square test showed this data from the lower void content panel to belong to a different population than the other two panels' data.

4. For this particular 280°F (138°C) application and fabrication/surface preparation procedures, the following adhesives showed the best shear strength properties:

(1) Film adhesive - AF143, FM96 and FM96U

(2) Foam adhesive - 3M-3015 and Hysol 3050

APPENDIX A

E-GLASS FIBER/E-293 EPOXY LAMINATE AND ADHESIVE BOND PANELS FABRICATION PROCEDURES AND TEST SPECIMEN LOCATION

The following information was provided with the test panels by Homestead Tool and Machine, Inc., Coleman, MI:

1. PREPREG MATERIAL

Three rolls of prepreg woven cloth were obtained from Ferro Corp. The E-glass was woven into the 1581 style fabric. The resin system was E293 and the percent resin contents were as follows:

roll #1 - 33.0%
roll #2 - 32.9%
roll #3 - 37.3%

No other physical properties of the prepreg material were provided by Homestead Tool.

2. 18" X 18" X 15" PLY TEST PANELS

a. For the three panels, the prepreg cloth plies were stacked with the warp fibers oriented in one direction. Panel 006 and 008 were layed up with prepreg from roll #3, and panel 007 was layed up with roll #1 prepreg cloth.

b. The panels were cured in a press. The stack of 15 plies of prepreg cloth was placed on a 20" X 20" X 2" aluminum plate that had seven electric cartridge heaters. Above the stack of prepreg cloth were the following (beginning at the prepreg cloth): one ply of cured silicone/fiberglass sheet, a 15 ply plate of cured 20" X 20" fiberglass/epoxy, 19" X 19" silicone air bag, and a 20" X 20" X 2" aluminum plate (no heaters). Both the top and bottom aluminum plates were supported by four - four inch square tubes. Temperature control of the lower aluminum plate was manual for the three panel cures. However, a proportional controller was used for temperature control for the subsequent bonded panels. A pressure regulator was used in conjunction with the air bag to apply pressure to the test panels.

c. The cure schedule was as follows:

The temperature was increased to 350°F in 30 to 45 minutes, held at 350°F for 1 to 1 1/2 hours, and then cooled. The pressure for panel 006 was 65 psi and 50 psi for panels 007 and 008. The temperature went up to 400°F during the curing of panel 008.

d. The panels were post cured in an oven at 350°F for 3 1/2 hours.

3. FIBERGLASS COMPOSITE TO COMPOSITE/FILM ADHESIVE/SINGLE-LAP-SHEAR BOND PANELS

a. The fiberglass/epoxy panels were fabricated as above using 15 plies of cloth from roll #2 and press cured using 80 psi and held at 350°F for 2 hours. The nylon peelply was removed, the bond area sanded with 100 grit emery and air blown to remove the dust.

b. The following adhesives were used for the lap shear bonds:

Panel B-101; FM96 - modified epoxy on nylon carrier, film weight of 0.075 lb/sq. ft., Lot B2334

Panel B-102; FM96U - unsupported modified epoxy film, film weight of 0.075 lb/sq. ft., Lot L68C-32

Panel B-103; AF143 - film weight of 0.10 lb/sq. ft., Lot 121R

Panel B-104; HT424 - aluminum filled, modified epoxy - phenolic resin coated on a glass carrier, film weight of 0.10 lb./sq.ft., Lot T-B-8336

c. These panels were put in a four place bond jig and placed in the press, described previously, in the same location as the test panels. The cure schedule was the following: 50 psi, one hour heat up to 350°F, held at 350°F for 1 hour, 1 hour cool down, and post cured in an oven at 350°F for 3 hours.

4. FIBERGLASS COMPOSITE TO STEEL/FILM ADHESIVE/SINGLE-LAP-SHEAR BOND PANELS

a. The prepreg fiberglass cloth, 23 or 25 plies, from roll #3 were stacked in the four place bond jig.

b. The adhesive was placed against the metal surface, followed by one ply of cloth, another layer of adhesive and the remaining plies of cloth.

c. The metal sheets were 11 guage hot rolled steel, 0.08% carbon. The steel sheets were grit blasted, blown off and stored in a moisture proof bag until bonding. All of the sheets; except those used in bonding panels B-202, 204, and 207; were acid etched for 10 minutes, rinsed under tap water, air dried, and stored in a moisture proof bag. All of the sheets; except those used in bonding panels B-201 and B-202; were sprayed with BR227 primer, batch B-630, to achieve a primer thickness of 0.7 to 1.1 mil. However, the sheets for panels B-207 were dipped primed with BR227, with a resulting thickness of 2.0 to 3.0 mils.

d. The following adhesives and conditions were used for these lap shear bonds:

Panel B201; FM96 - film weight of 0.075 lb/sq. ft., 23 plies fiberglass, acid etch, no primer.

Panel B202; FM96 - same film weight, 23 plies fiberglass, no acid etch, no primer.

Panel B203; FM96 - same film weight, 23 plies fiberglass, acid etch, spray primed.

Panel B204; FM96 - same film weight, 23 plies fiberglass, no acid etch, spray primed.

Panel B205; HT424 - film weight of 0.10 lb/sq. ft., 25 plies of fiberglass, acid etch, spray primed.

Panel B206; AF143 - film weight of 0.10 lb/sq. ft., 25 plies of fiberglass, acid etch, spray primed.

Panel B207; FM96U - film weight of 0.075 lb/sq. ft., 25 plies of fiberglass, no acid etch, dip primed.

Panel B208; no adhesive, 25 plies of fiberglass, acid etch, spray primed.

e. The four place bond jig with the panels were placed in the press. The cure schedule was the following: 50 psi, one hour - 20 minutes heat up to 325°F, held at 325°F for one hour - 10 minutes, one hour cool down, and post cured in an oven at 350°F for 3 hours.

5. FIBERGLASS COMPOSITE TO COMPOSITE/FOAM ADHESIVE/SINGLE-LAP-SHEAR BOND PANELS

a. The fiberglass/epoxy panels were fabricated in the press described in 2.b. above using 15 plies of prepreg cloth from roll #2. The cure schedule was 50 psi, one hour at 350°F and post cured for three hours at 350°F. The bond areas were sanded with 100 grit emery and air blown to remove dust.

b. The following adhesives were used for the lap shear bonds:

Panel B-301; 3M-3015-50 mils thickness, 2 layers of adhesive.

Panel B-302; Am. Cyan. - FM41 - modified epoxy, 0.115 inch thickness, one layer of adhesive.

Panel B-303; Am. Cyan. - HT424 foam - aluminum filled modified epoxy - phenolic, 50 mils thickness, two layers of adhesive.

Panel B-304; Hysol-3050 - contains asbestos fibers, 50 mils thickness, two layers of adhesive.

Panel B-305; Am. Cyan. - HT 424 foam - 50 mils thickness, two layers of adhesive.

c. The panels were laid up with the above adhesives in the four place bond jig to achieve an approximate 0.100 inch bond thickness. They were cured in the press to the following schedule: 20 psi, 50 minutes up to 325°F, held at 325°F for one hour - 20 minutes, one hour cool down, and post cured in an oven at 350°F for 4 hours.

6. FIBERGLASS COMPOSITE TO ALUMINUM HONEYCOMB SANDWICH PANEL

a. One panel, 18" X 17¼", was laid up as follows:

(1) Five plies of prepreg cloth from roll #1.

(2) Three cured panels, 6" X 17¼", having five plies of cloth.

(3) Three inch wide layer or layers of different adhesives were placed in six areas, 3" X 17¼".

(4) 5052 aluminum honeycomb core, 1/8 inch cell size, 0.91 inch thick, and density of 8.3 lbs/cu. ft.

(5) Repeat of three inch wide adhesives.

(6) Ten plies of prepreg cloth from roll #1.

(7) The warp direction of the plies of cloth were parallel to the 17¼" length.

b. The adhesives used were the following:

Area #1 - FM41 foam, one layer

Area #2 - 3M-3015 foam, one layer

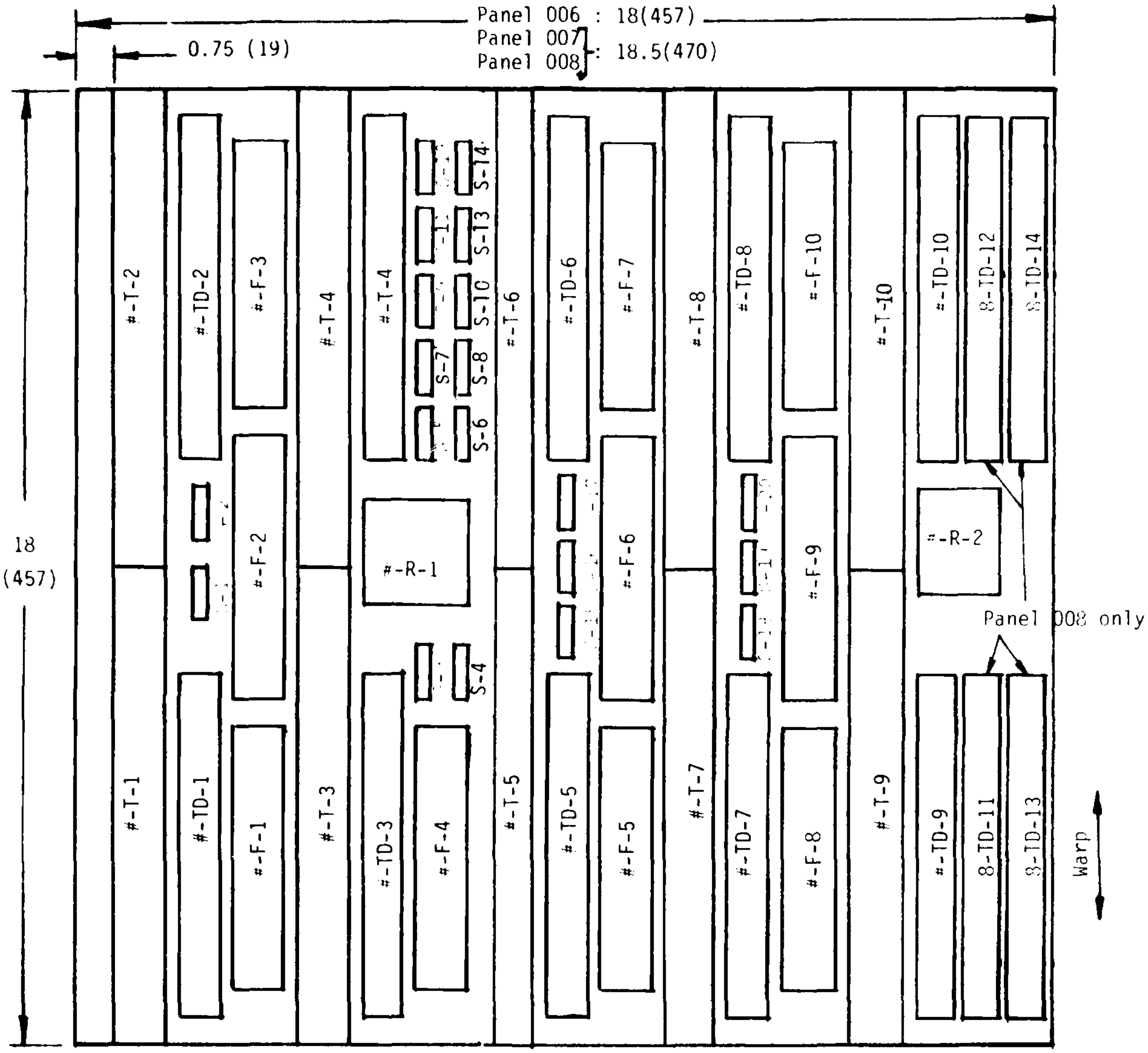
Area #3 - HT424 foam, two layers

Area #4 - HT424 foam, one layer

Area #5 - Hysol-3050 foam, one layer

Area #6 - FM96U film, two layers on side with precured panel and one layer on side with 10 plies of cloth.

c. This panel was press cured with the following schedule: 50 psi air bag pressure, side with 10 plies of prepreg cloth was next to heated platen, one hour up to 340°F, held at 340°F for one hour - 15 minutes, cool down and post cured for three hours at 350°F.

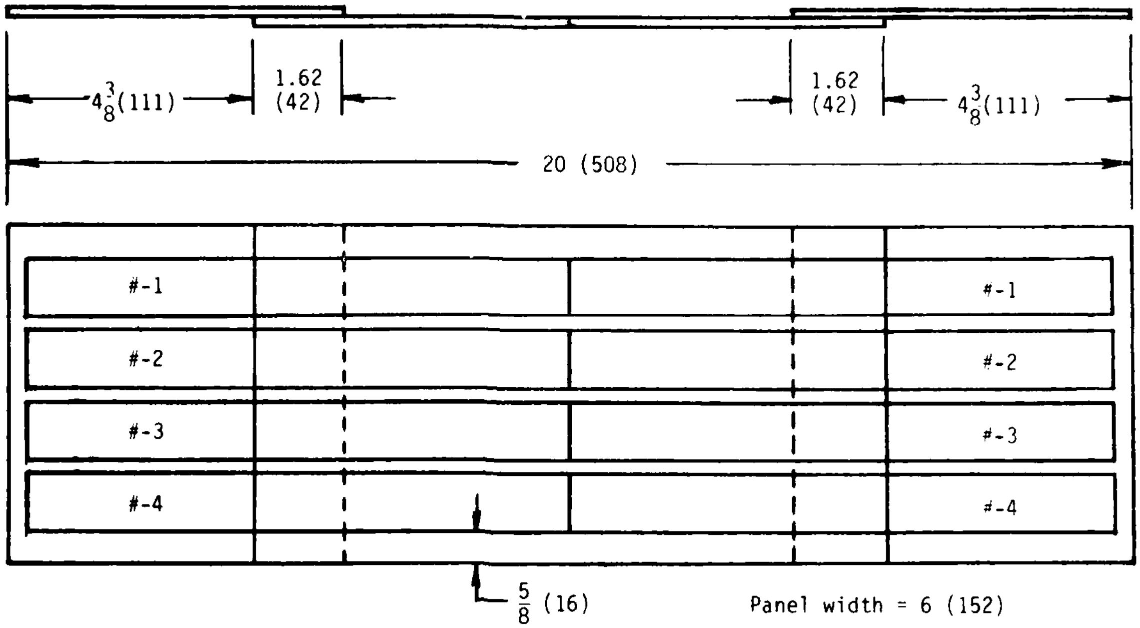


\# = Panel Number (6, 7, or 8)
T = Straight Sided Tensile
TD = Dog-Bone Tensile
Dimensions in inches (mm)

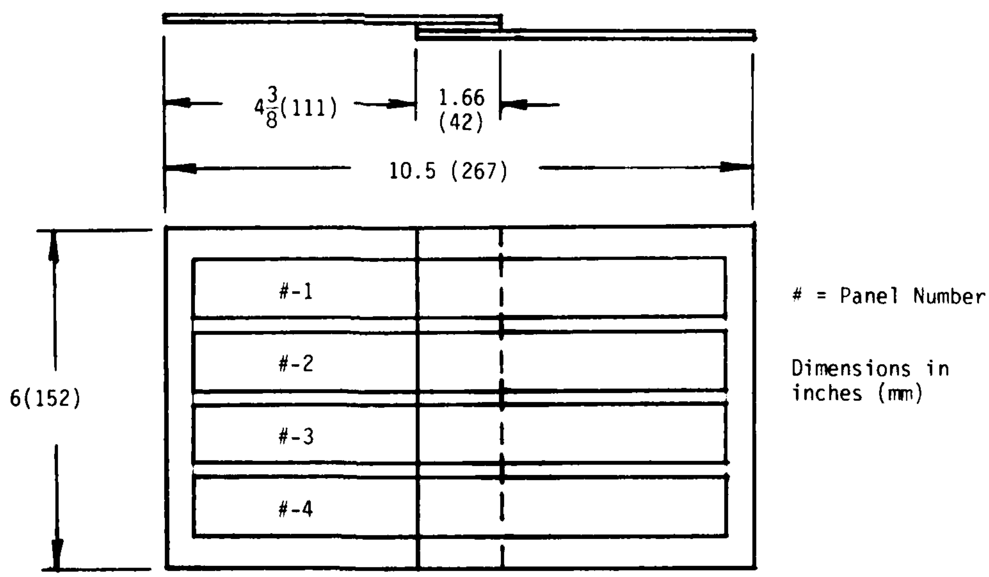
F = Flexure
S = Interlaminar Shear
R = Physical Properties

Average Thickness (3 panels) : 0.138 inch (3.50 mm)

Figure 1A. Test Specimen Location in 18" by 18" Panels



a) Double Adhesive Bond Panels B101, B102, B103, B104 (Film) and B302, B304 (Foam)



b) Single Foam Adhesive Bond Panels B301, B303, B305

Figure 2A. Test Specimen Location in Fiberglass Composite to Composite Lap Shear Bond Panels

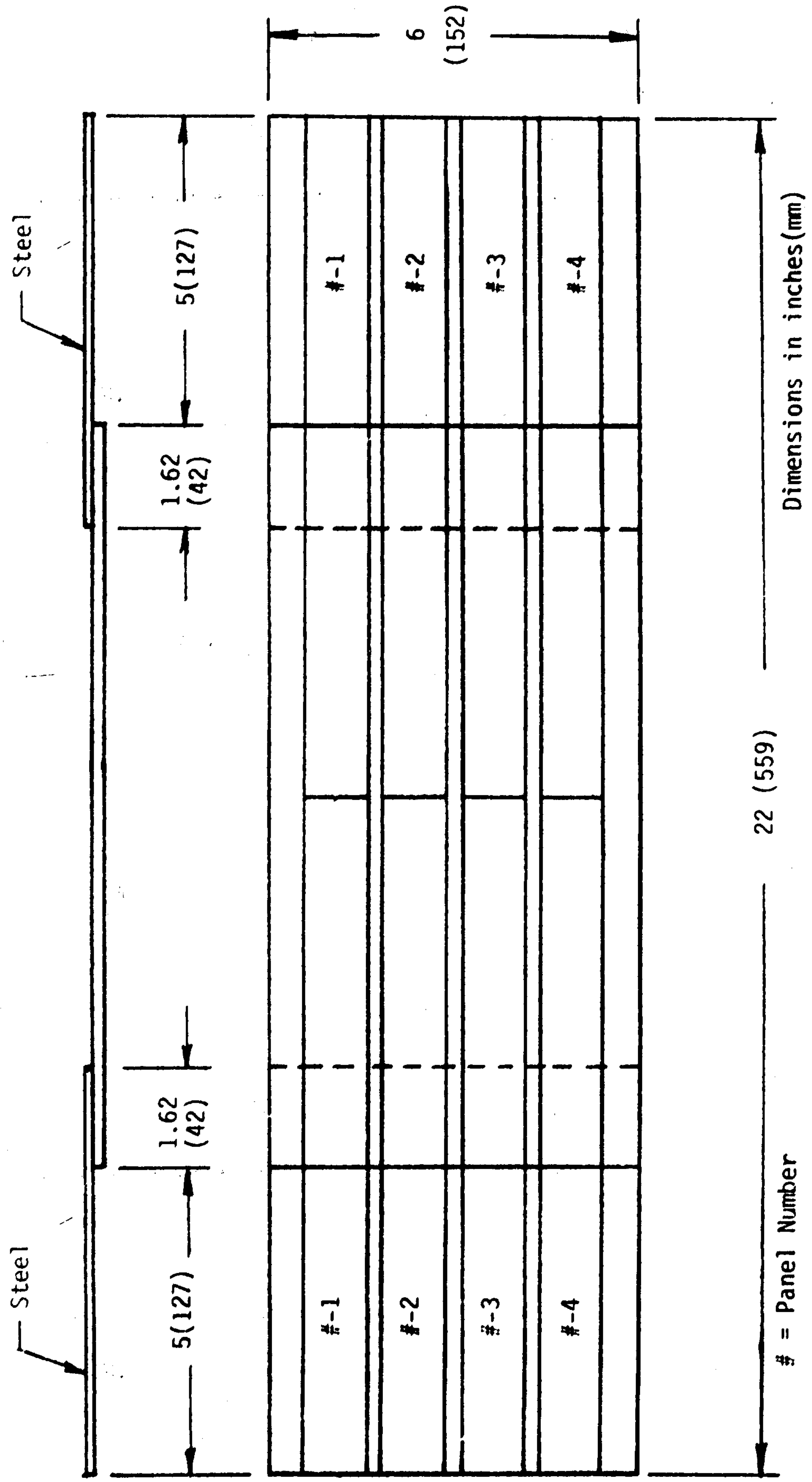


Figure 3A. Test Specimen Location in Fiberglass Composite to Steel Lap Shear Bond Panels B201, B202, B203, B204, B205, B206, B207, B208

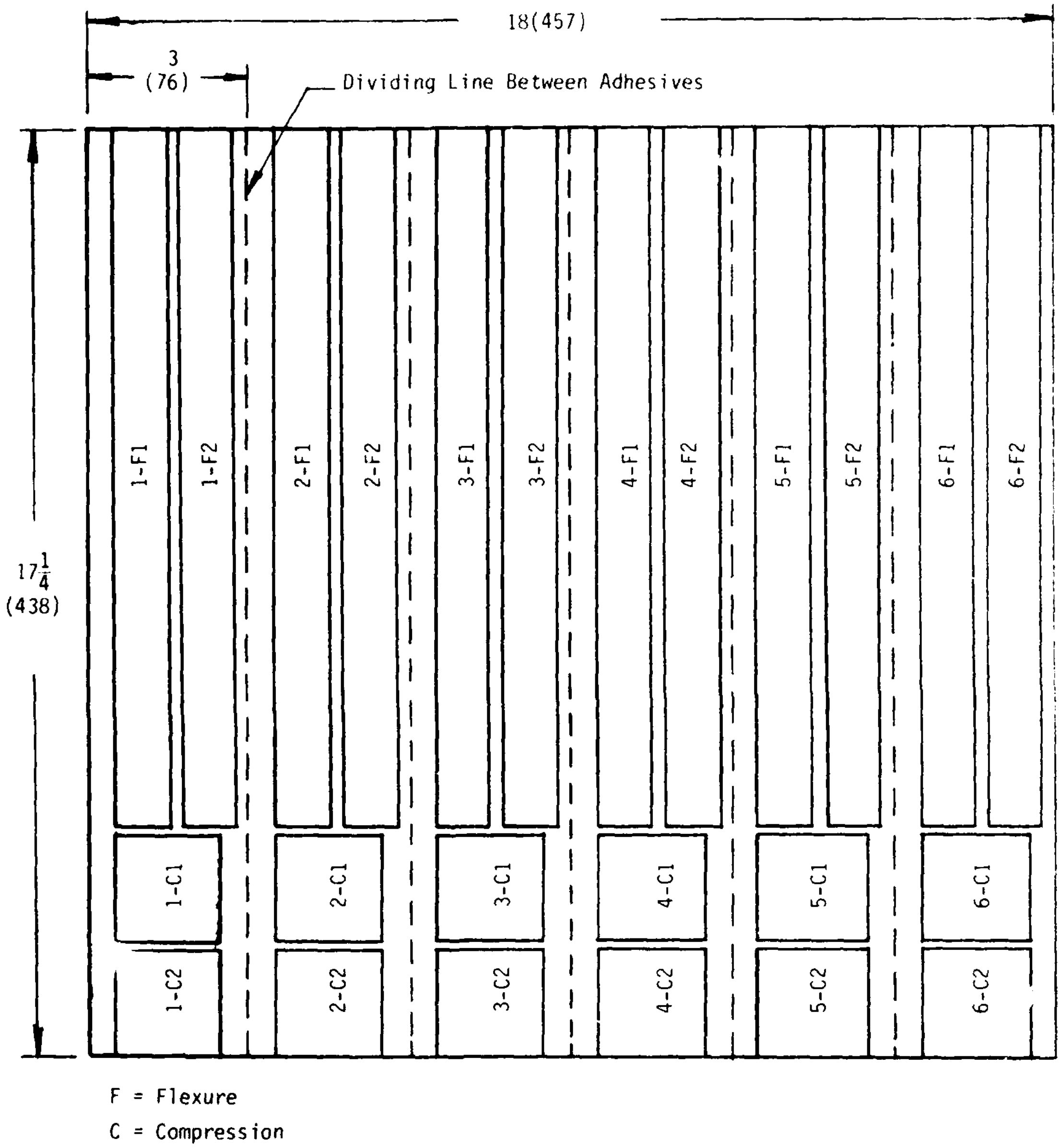


Figure 4A. Test Specimen Location in Fiberglass Composite to Aluminum Honeycomb Core Adhesive Bonded Panel

APPENDIX B

TEST DATA

TABLE 81

TENSILE TEST RESULTS IN ROOM TEMPERATURE, LABORATORY AIR

Panel No.	Sample No. (a)	Ultimate Strength KSI	Ultimate Strength (MPa)	Initial Elastic Modulus MSI	Initial Elastic Modulus (GPa)	Secondary Elastic Modulus MSI	Secondary Elastic Modulus (GPa)	Failure Location (b)
006	6-TD-1	46.6	(321)	4.09	(28.2)	2.73	(18.8)	A
	6-TD-4	47.3	(326)	3.60	(24.8)	2.58	(17.8)	A
	6-TD-5	43.2	(298)	3.50	(24.1)	2.60	(17.9)	A
	6-TD-8	40.6	(280)	3.75	(25.9)	2.63	(18.1)	A
	6-TD-9	46.3	(319)	3 68	(25.4)	2.76	(19.0)	A
006	6-T-1	49.2	(339)	4.26	(29.4)	3.53	(24.3)	B
	6-T-4	50.2	(346)	3.21	(22.1)	(c)		B
	6-T-5	47.8	(330)	3.37	(23.2)	2.80	(19.3)	D
	6-T-8	46.2	(318)	3.27	(22.5)	2.84	(19.6)	C
	6-T-9	40.8	(281)	3.52	(24.3)	2.79	(19.2)	B
007	7-TD-1	49.3	(340)	3.79	(26.1)	2.88	(19.9)	A
	7-TD-4	42.3	(292)	3.63	(25.0)	2.69	(18.5)	A
	7-TD-5	43.1	(297)	3.79	(26.1)	2.57	(17.7)	A
	7-TD-8	46.2	(319)	3.51	(24.2)	2.84	(19.6)	A
	7-TD-9	43.1	(297)	3.90	(26.9)	2.81	(19.4)	A
007	7-T-4	45.0	(310)	4.32	(29.8)	3.00	(20.7)	B
	7-T-6	43.4	(299)	3.96	(27.3)	2.95	(20.3)	D
	7-T-8	43.8	(302)	3.91	(27.0)	2.89	(19.9)	D
	7-T-9	51.4	(354)	3.54	(24.4)	3.00	(20.7)	D
008	8-TD-8	47.2	(325)	3.64	(25.1)	2.64	(18.2)	A
	8-TD-9	41.9	(289)	3.70	(25.5)	2.67	(18.4)	A
(d)	8-TD-11	44.7	(308)	4.01	(27.6)	2.95	(20.3)	A
	8-TD-12	41.7	(288)	3.75	(25.9)	2.85	(19.7)	A
	8-TD-13	51.2	(353)	3.39	(23.4)	2.69	(18.5)	A
	8-TD-14	46.9	(323)	2.84	(19.6)	2.69	(18.5)	A
008	8-T-1	39.5	(272)	2.89	(19.9)	(c)		B
	8-T-4	44.6	(308)	3.22	(22.2)	2.93	(20.2)	D
	8-T-5	48.6	(335)	3.59	(24.8)	2.80	(19.3)	B
	8-T-8	47.4	(327)	4.20	(29.0)	2.75	(19.0)	D
	8-T-9	45.3	(312)	3.58	(24.7)	2.84	(19.6)	D

(a) TD - Dog-bone tensile specimen
T - Constant cross section specimen

(b) A - End of reduced section, at or near tangent with fillet radius
B - At or near tab edge toward test section
C - 1/2 inch from tab edge toward test section
D - Within tab, 1/16 to 3/16 inch from tab edge

(c) No secondary slope of load-strain curve.

(d) Operator error occurred in the testing of specimens 8-TD-1, 8-TD-4 & 8-TD-5

TABLE B2

TENSILE TEST RESULTS AT 280°F (138°C)

Panel No.	Sample No. (a)	Ultimate Strength KSI	(MPa)	Initial Elastic Modulus MSI	(GPa)	Secondary Elastic Modulus MSI	(GPa)	Failure Location (b)
006	6-TD-2	29.6	(204)	3.25	(22.4)	2.76	(19.0)	A
	6-TD-3	35.5	(245)	2.84	(19.6)	2.39	(16.5)	A
	6-TD-6	32.8	(226)	2.98	(20.5)	2.62	(18.1)	A
	6-TD-7	34.0	(234)	2.94	(20.3)	2.57	(17.7)	A
	6-TD-10	33.4	(230)	2.63	(18.1)	(c)		
006	6-T-2	36.8	(254)	2.98	(20.5)	(c)		B
	6-T-3	34.1	(235)	3.31	(22.8)	2.69	(18.5)	D
	6-T-6	39.0	(269)	2.86	(19.7)	2.32	(16.0)	B
	6-T-7	34.4	(237)	2.93	(20.2)	2.68	(18.5)	D
	6-T-10	37.7	(260)	2.81	(19.4)	2.50	(17.2)	D
007	7-TD-2	32.4	(223)	2.96	(20.4)	2.39	(16.5)	A
	7-TD-3	31.4	(217)	2.95	(20.3)	2.48	(17.1)	A
	7-TD-6	30.9	(213)	2.56	(17.7)	(c)		A
	7-TD-7	32.0	(221)	3.06	(21.1)	2.58	(17.8)	A
	7-TD-10	33.1	(228)	2.53	(17.4)	(c)		A
007	7-T-2	33.0	(228)	3.27	(22.5)	(c)		D
	7-T-3	31.3	(216)	2.83	(19.5)	(c)		D
	7-T-5	34.7	(239)	2.52	(17.4)	(c)		D
	7-T-7	33.4	(230)	2.47	(17.0)	(c)		D
	7-T-10	29.2	(201)	2.60	(17.9)	2.45	(16.9)	B
008	8-TD-2	28.9	(199)	2.63	(18.1)	(c)		A
	8-TD-3	30.6	(211)	(d)		(d)		A
	8-TD-6	33.4	(230)	2.70	(18.6)	(c)		A
	8-TD-7	35.0	(241)	2.53	(17.4)	(c)		A
	8-TD-10	31.4	(217)	2.70	(18.6)	(c)		A
008	8-T-2	31.0	(214)	2.83	(19.5)	2.52	(17.4)	
	8-T-3	30.6	(211)	2.99	(20.6)	(c)		D
	8-T-6	30.6	(211)	2.84	(19.6)	(c)		D
	8-T-7	29.2	(201)	2.74	(18.9)	2.30	(15.8)	B
	8-T-10	32.5	(224)	2.88	(19.8)	2.48	(17.1)	B

(a) TD - Dog-bone tensile specimen
T - Constant cross section specimen

(b) A - End of reduced section, at or near tangent with fillet radius
B - At or near tab edge toward test section
D - Within tab, 1/16 to 3/16 inch from tab edge

(c) No secondary slope of load-strain curve.

(d) Operator error

TABLE B3

FLEXURAL TEST RESULTS

Panel No.	Test Temperature °F	(°C)	Sample No.	Flexural Strength KSI	(MPa)	Initial Elastic Modulus MSI	(GPa)	Failure Mode (a)
006	74	(23)	6-F-1	66.1	(456)	3.65	(25.2)	F
			6-F-3	63.5	(438)	3.38	(23.3)	F
			6-F-6	69.4	(479)	3.53	(24.3)	F
			6-F-8	68.6	(473)	3.53	(24.3)	F
			6-F-10	68.9	(475)	3.60	(24.8)	F
007	74	(23)	7-F-1	65.3	(450)	3.48	(24.0)	F
			7-F-3	63.0	(434)	3.39	(23.4)	F
			7-F-6	65.5	(452)	3.45	(23.8)	F
			7-F-8	71.2	(491)	3.56	(24.5)	F
			7-F-10	73.1	(504)	3.66	(25.2)	F
008	74	(23)	8-F-1	68.9	(475)	3.81	(26.3)	F
			8-F-3	65.5	(452)	3.72	(25.6)	F
			8-F-6	64.8	(447)	3.36	(23.2)	F
			8-F-8	68.2	(470)	3.56	(24.5)	F
			8-F-10	69.9	(482)	3.64	(25.1)	F
006	280	(138)	6-F-2	37.0	(255)	2.74	(18.9)	C&F
			6-F-4	37.0	(255)	2.80	(19.3)	C&F
			6-F-5	39.6	(273)	2.87	(19.8)	C&F
			6-F-7	40.6	(280)	2.67	(18.4)	C
			6-F-9	37.0	(255)	2.63	(18.1)	C
007	280	(138)	7-F-2	31.0	(214)	2.44	(16.8)	C
			7-F-4	30.8	(212)	2.30	(15.9)	C
			7-F-5	30.4	(210)	2.78	(19.2)	C&F
			7-F-9	31.8	(219)	2.55	(17.6)	C
008	280	(138)	8-F-2	30.4	(210)	2.36	(16.3)	C&F
			8-F-4	29.0	(200)	2.57	(17.7)	C&F
			8-F-5	34.1	(235)	2.70	(18.6)	C
			8-F-7	34.1	(235)	2.76	(19.0)	C
			8-F-9	33.7	(232)	2.59	(17.9)	C&F

(a) F - Flexure failure of outer plies (tensile side)
C - Compression failure of outer plies at loading pin

TABLE B4

APPARENT INTERLAMINAR SHEAR TEST RESULTS
IN ROOM TEMPERATURE, LABORATORY AIR

Panel no.	Sample no.	Apparent Shear Strength KSI	(MPa)	Failure Mode (a)
006	6-S-1	7.04	(48.5)	F
	6-S-3	7.65	(52.8)	F
	6-S-5	7.47	(51.5)	F
	6-S-7	7.47	(51.5)	F
	6-S-9	8.18	(56.4)	S
	6-S-11	8.21	(56.1)	S
	6-S-13	8.19	(56.5)	S
	6-S-15	8.35	(57.6)	S
	6-S-17	8.06	(55.6)	S
	6-S-19	8.28	(57.1)	S
007	7-S-1	6.61	(45.6)	S
	7-S-3	7.89	(54.4)	F
	7-S-5	7.53	(51.9)	S
	7-S-7	7.36	(50.8)	S
	7-S-9	7.44	(51.3)	S
	7-S-11	7.27	(50.1)	S
	7-S-13	7.39	(51.0)	S
	7-S-15	8.03	(55.4)	S
	7-S-17	8.22	(56.7)	S
	7-S-19	7.89	(54.4)	S
008	8-S-1	7.92	(54.6)	F
	8-S-3	8.31	(57.3)	S
	8-S-5	8.22	(56.7)	S
	8-S-7	7.92	(54.6)	S
	8-S-9	4.80	(33.1)	F
	8-S-11	7.61	(52.5)	S
	8-S-13	7.41	(51.1)	S
	8-S-15	8.18	(56.4)	S
	8-S-17	8.24	(56.8)	S
	8-S-19	8.06	(55.6)	S

(a) S - Shear failure
F - Flexure failure of the outer plies (tensile side)

TABLE B5

APPARENT INTERLAMINAR SHEAR TEST RESULTS
AT 280°F (138°C)

Panel no.	Sample no.	Apparent Shear Strength KSI	(MPa)	Failure Mode
006	6-S-2	2.76	(19.0)	Shear
	6-S-4	2.89	(19.9)	"
	6-S-6	2.89	(19.9)	"
	6-S-8	2.96	(20.4)	"
	6-S-10	2.97	(20.5)	"
	6-S-12	2.82	(19.4)	"
	6-S-14	2.83	(19.5)	"
	6-S-16	3.03	(20.9)	"
	6-S-18	2.85	(19.7)	"
	6-S-20	2.89	(19.9)	"
007	7-S-2	2.01	(13.9)	Shear
	7-S-4	2.31	(15.9)	"
	7-S-6	2.23	(15.4)	"
	7-S-8	2.19	(15.1)	"
	7-S-10	2.19	(15.1)	"
	7-S-12	2.10	(14.5)	"
	7-S-14	1.96	(13.5)	"
	7-S-16	2.33	(16.1)	"
	7-S-18	2.12	(14.6)	"
	7-S-20	2.06	(14.2)	"
008	8-S-2	2.01	(13.9)	Shear
	8-S-4	2.22	(15.3)	"
	8-S-6	2.26	(15.6)	"
	8-S-8	2.18	(15.0)	"
	8-S-10	2.14	(14.8)	"
	8-S-12	1.96	(13.5)	"
	8-S-14	1.92	(13.2)	"
	8-S-16	2.43	(16.8)	"
	8-S-18	2.46	(17.0)	"
	8-S-20	2.42	(16.7)	"

TABLE B6

PANEL AVERAGES OF MECHANICAL PROPERTIES OF E293/1581 FIBERGLASS/EPOXY

Panel Number	006		007		008	
Temperature	73°F (23°C)	280°F(133°C)	73°F (23°C)	280°F(138°C)	73°F (23°C)	280°F(138°C)
Tensile (Dog-bone specimen)						
Ultimate stress; average Ksi(MPa)	44.8(309)	33.1(228)	44.8(309)	32.0(220)	45.6(314)	31.9(220)
Standard deviation Ksi(MPa)	2.8 (19)	2.2 (15)	2.9 (20)	0.8 (6)	3.6 (25)	2.4 (16)
Initial modulus; average Msi(GPa)	3.72(25.7)	2.93(20.2)	3.72(25.7)	2.81(19.4)	3.56(24.5)	2.64(18.2)
Standard deviation Msi(GPa)	0.22 (1.6)	0.23 (1.6)	0.15 (1.1)	0.25 (1.7)	0.40 (2.8)	0.80 (0.6)
Secondary modulus; average Msi(GPa)	2.66(18.3)	2.59(17.8)	2.76(19.0)	2.48(17.1)	2.75(18.9)	———
Standard deviation Msi(GPa)	0.03 (0.5)	0.15 (1.0)	0.13 (0.9)	0.10 (0.6)	0.12 (0.8)	———
Tensile (straight-sided specimen)						
Ultimate stress; average Ksi(MPa)	46.8(323)	36.4(251)	45.9(316)	32.3(223)	45.1(311)	30.8(212)
Standard deviation Ksi(MPa)	3.7 (25)	2.1 (14)	3.7 (26)	2.1 (14)	3.5 (24)	1.2 (8)
Initial modulus: average Msi(GPa)	3.53(24.3)	2.98(20.5)	3.93(27.1)	2.74(18.9)	3.50(24.1)	2.86(19.7)
Standard deviation Msi(GPa)	0.43 (3.0)	0.20 (1.4)	0.32 (2.2)	0.33 (2.3)	0.49 (3.4)	0.09 (0.6)
Secondary modulus; average Msi(GPa)	2.99(20.6)	2.55(17.6)	2.96(20.4)	———	2.83(19.5)	2.43(16.7)
Standard deviation Msi(GPa)	0.36 (2.5)	0.18 (1.2)	0.05 (0.3)	———	0.08 (0.6)	0.12 (0.8)
Flexural						
Ultimate stress; average Ksi(MPa)	67.3(464)	———	67.6(466)	———	67.5(465)	———
Standard deviation Ksi(MPa)	2.5 (17)	———	4.3 (30)	———	2.2 (15)	———
Initial modulus; average Msi(GPa)	3.54(24.4)	2.74(18.9)	3.51 (24)	2.52(17.4)	3.62 (25)	2.60(17.9)
Standard deviation MSi(GPa)	0.10 (0.7)	0.10 (0.7)	0.10 (0.7)	0.20 (1.4)	0.17 (1.2)	0.15 (1.0)
Apparent Interlaminar Shear						
Ultimate stress; average Ksi(MPa)	8.21(56.6)	2.89(19.9)	7.64(52.7)	2.15(14.8)	7.99(55.1)	2.20(15.2)
Standard deviation; Ksi(MPa)	0.10 (0.7)	0.08 (0.6)	0.35 (2.4)	0.12 (0.8)	0.33 (.23)	0.20 (1.4)

TABLE B7

SINGLE-LAP-SHEAR TEST RESULTS OF FILM ADHESIVES
FOR FIBERGLASS TO FIBERGLASS BOND

Panel No.	Adhesive	Specimen No.	Temperature °F	Temperature °C	Maximum Shear Stress PSI	Maximum Shear Stress (MPa)
B101	FM96	1	280	(138)	1040	(7.17)(a)
		2	280	(138)	1190	(8.20)(a)
		3	76	(24)	1735	(11.96)
		4	72	(22)	1480	(10.20)
B102	FM96U	1	280	(138)	660	(4.55)
		2	280	(138)	1000	(6.89)
		3	72	(22)	1260	(8.69)
		4	72	(22)	1445	(9.96)
B103	AF143	1	280	(138)	1140	(7.86)
		2	280	(138)	1150	(7.93)
		3	72	(22)	1545	(10.65)
		4	72	(22)	1525	(10.51)
B104	HT424	1	280	(138)	485	(3.34)
		2	280	(138)	470	(3.24)
		3	72	(22)	1120	(7.72)
		4	73	(23)	1090	(7.52)

(a) Interlaminar shear failure in composite. All other specimens failed at composite/adhesive bond.

TABLE B8

SINGLE-LAP-SHEAR TEST RESULTS OF FOAM ADHESIVES
FOR FIBERGLASS TO FIBERGLASS BOND

Panel #	Adhesive	Spec. #	Temperature °F	(°C)	Maximum Shear Stress PSI	(MPa)	Type of Failure (a)
B301	3M-3015	1	76	(24)	385	(2.65)	95% adhesive
		3	76	(24)	460	(3.17)	95% adhesive
		2	280	(138)	375	(2.58)	80% adhesive
		4	280	(138)	390	(2.69)	70% adhesive
B302	FM41	1	71	(22)	310	(2.14)	90% cohesive
		3	71	(22)	315	(2.17)	90% cohesive
		2	280	(138)	170	(1.17)	95% cohesive
		4	280	(138)	175	(1.21)	100 cohesive
B303	HT424	1	71	(22)	225	(1.55)	90% cohesive
		3	71	(22)	225	(1.55)	90% cohesive
		2	280	(138)	210	(1.45)	80% adhesive
		4	280	(138)	190	(1.31)	90% cohesive
B304	Hysol 3050	1	71	(22)	505	(3.48)	50% cohesive
		3	71	(22)	435	(3.00)	80% cohesive
		2	280	(138)	335	(2.31)	95% cohesive
		4	280	(138)	275	(1.90)	100% cohesive
B305	HT424	1	71	(22)	195	(1.34)	70% cohesive
		3	71	(22)	235	(1.62)	50% cohesive
		2	280	(138)	225	(1.55)	50% cohesive
		4	280	(138)	235	(1.62)	90% cohesive

(a) adhesive - lack of adherence to composite material
cohesive - failure in the adhesive

TABLE B9

SINGLE-LAP-SHEAR TEST RESULTS FOR FIBERGLASS TO METAL BOND

Panel #	Adhesive/ Metal Prep.	Specimen Number	Temperature °F	(°C)	Maximum Shear Stress PSI	(MPa)	Type of Failure
B201	FM96/Acid etch & no prime	1	76	(24)	1765	(12.17)	95% adhesive failure at steel/adhesive bond
		3	76	(24)	1530	(10.55)	100% adhesive failure at steel/adhesive bond
		2	280	(138)	1275	(8.79)	100% interlaminar shear failure in composite
		4	280	(138)	1315	(9.07)	100% interlaminar shear failure in composite
B202	FM96/no acid etch & no prime	1	74	(23)	1290	(8.89)	100% adhesive failure at steel/adhesive bond
		3	74	(23)	1090	(7.52)	100% adhesive failure at steel/adhesive bond
		2	280	(138)	1520	(10.48)	100% interlaminar shear failure in composite
		4	280	(138)	1400	(9.65)	100% interlaminar shear failure in composite
B203	FM96/Acid etch & spray prime	1	74	(23)	1725	(11.89)	50% adhesive failure at composite/adhesive bond
		3	74	(23)	1350	(9.31)	100% adhesive failure at steel/adhesive bond
		2	280	(138)	1275	(8.79)	100% interlaminar shear failure in composite
		4	280	(138)	1285	(8.86)	100% interlaminar shear failure in composite
B204	FM96/no acid etch & no spray prime	1	74	(23)	1290	(8.89)	95% adhesive failure at steel/adhesive bond
		3	74	(23)	1180	(8.14)	100% adhesive failure at steel/adhesive bond
		2	280	(138)	1485	(10.34)	80% adhesive failure at steel/adhesive bond + 50% interlaminar shear in composite
		4	280	(138)	1595	(11.00)	90% adhesive failure at steel/adhesive bond + 10% interlaminar shear in composite
B205	HT424/Acid etch & spray prime	1	74	(23)	1660	(11.44)	90% adhesive failure at composite/adhesive bond + 50% interlaminar shear in composite
		3	74	(23)	1630	(11.24)	70% adhesive failure at composite/adhesive bond + 20% interlaminar shear in composite
		2	280	(138)	525	(3.62)	100% adhesive failure at steel/adhesive bond + 100% interlaminar shear in composite
		4	280	(138)	440	(3.03)	100% interlaminar shear failure in composite
B206	AF143/Acid etch & spray prime	1	74	(23)	1710	(11.79)	20% adhesive failure at steel/adhesive bond + 80% cohesive failure in adhesive
		3	74	(23)	1755	(12.19)	50% adhesive failure at steel/adhesive bond + 50% cohesive failure in adhesive
		2	280	(138)	1740	(12.00)	100% interlaminar shear failure in composite
		4	280	(138)	1550	(10.69)	100% interlaminar shear failure in composite
B207	FM96U/no acid & dip prime	1	74	(23)	1695	(11.69)	80% adhesive failure at steel/adhesive bond
		3	74	(23)	1450	(10.00)	50% adhesive failure at steel/adhesive bond + 50% adhesive failure at composite/adhesive bond
		2	280	(138)	1105	(7.62)	90% adhesive failure at steel/adhesive bond
		4	280	(138)	1180	(8.14)	80% adhesive failure at steel/adhesive bond
B208	No adhesive /acid etch & spray prime	1	74	(23)	1120	(7.72)	100% failure at steel/composite bond
		3	74	(23)	955	(6.58)	100% failure at steel/composite bond
		2	280	(138)	(9)	———	100% failure at steel/composite bond
		4	280	(138)	640	(4.41)	100% failure at steel/composite bond

(9) Operator error

TABLE B10

THREE POINT FLEXURE TEST RESULTS FOR FIBERGLASS TO ALUMINUM HONEYCOMB BONDED PANEL

Area of Panel	Adhesive	Specimen Number	Temperature ^{o}F	(^{o}C)	Maximum Core Shear Stress (Midspan) Developed at Failure PSI	(MPa)	Type of Failure
1	FM41	1F1	72	(22)	595	(4.10)	Adhesive shear failure at composite/adhesive bond on compression side of beam
1	FM41	1F2	280	(138)	340	(2.34)	Compression failure in composite face on compression side of beam at center load point
2	3M-3015	2F1	72	(22)	330	(2.28)	Adhesive shear failure (as in specimen 1F1)
2	3M-3015	2F2	280	(138)	340	(2.34)	Compression failure (as in specimen 1F2)
3	Ht424 (2 layers)	3F1	72	(22)	495	(3.41)	Initial failure was interlaminar shear in composite on compression side next to load point
3	Ht424 (2 layers)	3F2 (1)	280	(138)	80	(0.55)	Interlaminar shear failure in composite (1 ply from adhesive) on tensile side of beam
4	Ht424 (1 layer)	4F1	65	(18)	440	(3.03)	Initial failure was interlaminar shear (as in specimen 3F1)
4	Ht424 (1 layer)	4F2 (1)	280	(138)	95	(0.66)	Interlaminar shear failure (as in specimen 3F2)
5	Hysol 3050	5F1	66	(19)	465	(3.21)	Adhesive shear failure at core/adhesive bond on compression side of beam
5	Hysol 3050	5F2 (1)	280	(138)	395	(2.72)	Adhesive shear failure (as in specimen 1F1)
6	FM96U	6F1	67	(19)	555	(3.83)	Compression failure (as in specimen 1F2)
6	FM96U	6F2 (1)	280	(138)	355	(2.45)	Compression failure (as in specimen 1F2)

(1) A 1/8" X 1" metal pad was placed under the center load point in an attempt to prevent compression failure in the composite face at 280^{o}F.

TABLE B11

EDGEWISE COMPRESSION TEST RESULTS FOR FIBERGLASS TO ALUMINUM HONEYCOMB BONDED PANEL

Area of Panel	Adhesive	Specimen #	Temperature °F	(°C)	Maximum Facing Stress KSI	(MPa)	Compression modulus in Facings MSI	(GPa)	Type of Failure
1	FM41	1C1	72	(22)	47.1	(325)	4.5	(31.0)	Crushing at end of facing
1	FM41	1C2	280	(138)	20.2	(139)	3.2	(22.1)	Corner crack in one end of facing
2	3M-3015	2C1	72	(22)	41.2	(284)	4.2	(29.0)	Crushing at end of facing
2	3M-3015	2C2	280	(138)	19.6	(135)	3.1	(21.4)	Crushing at end of facing
3	Ht 424	3C1	72	(22)	36.3	(250)	3.9	(26.9)	Compression failure in one facing
3	(2 layers)	3C2	280	(138)	9.9	(68)	2.8	(19.3)	Adhesive shear failure in one corner
4	Ht 424 (1 layer)	4C1	73	(23)	34.5	(238)	3.9	(26.9)	Adhesive shear failure along one end of facing
4	Ht 424 (1 layer)	4C2	280	(138)	8.9	(61)	2.6	(17.9)	Compression failure on one facing
5	Hysol 3050	5C1	73	(23)	36.0	(248)	4.1	(28.3)	Crushing at end of facing
5	Hysol 3050	5C2	280	(138)	16.3	(112)	3.0	(20.7)	Crushing at end of facing
6	FM96U	6C1	72	(22)	40.7	(281)	4.0	(27.6)	Crushing at end of facing
6	FM96U	6C2	280	(138)	18.8	(130)	3.0	(20.7)	Crushing at end of facing

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