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FABRICATION AND PHYSICAL TESTING OF GRAPHITE COMPOSITE PANELS UTILIZING WOVEN GRAPHITE FABRIC WITH CURRENT AND ADVANCED STATE-OF-THE-ART RESIN SYSTEMS

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Hitco Defense Products Division
Gardena, California

June 1979

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Under Contract NAS 2-9977

HITCO
Defense Products Division
Gardena, California 90249

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16. Abstract

Graphite Composite panels were fabricated using woven fabrics with current and advanced state-of-the-art resin systems. Three weaves were evaluated; a balanced plain weave, a balanced 8-harness satin weave, and a semi-unidirectional crowfoot satin weave. The current state-of-the-art resin system selected was Fiberite's 934 Epoxy; the advanced resin systems evaluated were Phenolic, Phenolic/Novolac, Benzyl and Bismaleimide. The panels were fabricated for testing on NASA/Ames Research Center's Composites Modification Program. Room temperature mechanical tests only were performed by Hitco; the results are contained in this report. The major portion of the panels fabricated were shipped to NASA/Ames for their testing.

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FABRICATION AND PHYSICAL TESTING OF GRAPHITE COMPOSITE PANELS UTILIZING WOVEN GRAPHITE FABRIC WITH CURRENT AND ADVANCED STATE-OF-THE-ART RESIN SYSTEMS

Samuel C. S. Lee

Hitco

1.0 INTRODUCTION

This report finalizes the results of the National Aeronautics and Space Administration's Ames Research Center Contract NAS 2-9977 with Hitco for fabrication and physical testing of woven graphite composite panels using current and advanced resin systems, in support of NASA's Composites Modification Program. Currently the aircraft industry uses graphite/epoxy laminates in a number of structural applications, the typical resin system consisting of a high temperature epoxy such as Ciba-Geigy's MY-720 with an aromatic amine hardener such as Diamino Diphenyl Sulfone. The program endeavors to find alternate resin systems with improved high temperature mechanical and flammability properties.

2.0 PANEL FABRICATION

Panels were fabricated under two tasks as follows:

2.1 Task 1 - Fabric Selection

The objective of this task was to select a particular style of fabric for use on the program. Three candidate weaves were selected, all supplied by the Fiberite Corporation impregnated with 934 resin, their standard high temperature epoxy. These weaves were:

Style	Type Weave	Fabric Weight g/m^2 (oz/yd^2)	Warp to Fill Strength Ratio
133	8-harness satin	373 (11)	1:1
134	Plain	186 (5.5)	1:1
177	Crowfoot satin	214 (6.3)	6:1

The prepregs were laminated into 610 x 610 x 3.2 mm (24 x 24 x 1/8 in) panels in an autoclave under 690 kPa (100 psi) pressure using a surface bleed system designed to yield a cured fiber fraction of approximately 65%. The fiber orientation was parallel warp. Each cured panel was cut into four 305 mm (12 in) squares. One square was retained by Hitco for room temperature mechanical testing; the other three were shipped to NASA/Ames. The particulars of the prepreg materials are shown in Table I, while the cure cycles used are shown in Table II.

2.2 Task 2 - Fabrication of Panels Using Advanced Resin Systems

The objective of Task 2 was to fabricate panels using advanced resin systems selected by NASA/Ames. Four such systems were used: three phenol based systems and a bismaleimide. The 934 epoxy was repeated as well to serve as a baseline. The selected advanced resin systems were Xylok 210, Code M-751, MXG 6070 and WFR 1200. A description of each follows:

Xylok 210 is a product of Albright and Wilson Limited of England, and is marketed in the USA by Ciba Geigy. It is a hexamine curing phenolic novolac type resin possessing good long term performance to 230°C (446°F). The manufacture of this resin has been discontinued at present, and its future availability is questionable. The resin used on this contract was supplied by NASA/Ames in varnish form.

The NASA Code M-751 resin is a product of Technochemie GmbH of Dossenheim, West Germany. It is a conventional bismaleimide resin similar to the commercially available Rhodia Kerimid 601, but with improved room temperature storage stability. The resin is supplied in powder form; a solution is obtained by dissolving the powder in N-Methyl Pyrrolidone. The resin used on this contract was supplied by NASA/Ames.

MXG 6070 is a proprietary product of Fiberite's West Coast Division. It is a conventional phenolic resin compounded for non-flammability and low smoke emission and was designed for use in advanced aircraft interiors.

WFR 1200 is a single stage phenol formaldehyde resin supplied in an aqueous solution by the Weyerhauser Company. It is produced by a different process than conventional phenolics, and has been referred to as a "benzyl" resin. The resin used on this contract was supplied by the Weyerhauser Company.

The prepregs used in Task 2 were coated by the Fiberite Corporation using their HMF 133 fabric as the reinforcement. All were coated in the Winona, Minnesota plant with the exception of the MXG 6070, which was prepared by the Orange, California plant. Table I is a summary of the prepreg specifics, while Table II is a compilation of the cures used. 7432 cm^2 (8 ft^2) of 3.2 mm (1/8 in) thick paneling was fabricated with each prepreg. Of this quantity, 4645 cm^2 (5 ft^2) was shipped to NASA/Ames in the form of 305 mm (12 in) squares, and the remainder retained by Hitco for testing.

Panel No. 9, the last panel in Task 2, was originally scheduled to be fabricated with yet another advanced resin system, however, since the two resins under consideration were not available in time to be incorporated into the program, it was decided to use the 934 epoxy for that panel as well. All 7432 cm^2 (8 ft^2) of Panel No. 9 was shipped to NASA/Ames.

3.0 TESTING

Hitco performed only the room temperature mechanical tests on the panels fabricated on this program. High temperature mechanical, flammability and fiber release testing was done by NASA/Ames. The specific properties evaluated by Hitco were:

1. Flexural Strength and Modulus at 23°C (73°F), Warp and Fill
2. Tensile Strength and Modulus at 23°C (73°F), Warp and Fill
3. Compressive Strength and Modulus at 23°C (73°F), Warp and Fill
4. Short Beam Shear Strength at 23°C (73°F), Warp and Fill

The cutting plan, specimen sizes and test methods used on both Task 1 and 2 panels were identical, and are shown in Figure 1. The test methods selected are typical of those used in the aerospace industry.

Fiber volumes were calculated from measured specific gravities and are approximate only. More accurate values could not be obtained because of the lack of a standard method of measuring the resin contents of the cured panels. The usual method employed is acid digestion, however, it was discovered that some of the resins are resistant to the nitric acid used. Burndown has proven to be unreliable because of the varying heat resistances of the different resin systems, and the fact that the graphite fiber itself oxidizes at the high temperatures required. In calculating the fiber volumes, an assumed voids content of 0.5% was used.

4.0 RESULTS AND DISCUSSION

4.1 Task 1 Test Results

A summary of the Task 1 panel testing is presented as Table III, while the individual test results are shown as Tables IV, V and VI. As can be seen in the tables, the cured fiber volumes were all higher than the target 65%, but since they ranged from 66-70%, the mechanical properties of the panels could be compared to each other without artificially normalizing the values. The results are substantially as expected, although with the supposedly "balanced" 133 and 134 weaves, the fill and warp properties in some cases were noticeably out of balance. This is probably caused by distortion of the yarns in one direction or the other during the impregnation and "B" staging of the fabric as witnessed by the unevenness of the tracer yarns, especially in the fill direction.

The 133 8-harness satin weave was selected as the fabric style for use on Task 2. This particular weave displays balanced properties and is favored for structures with some degree of curvature or complexity because of its superior drape as compared to plain weave fabrics.

4.2 Task 2 Test Results

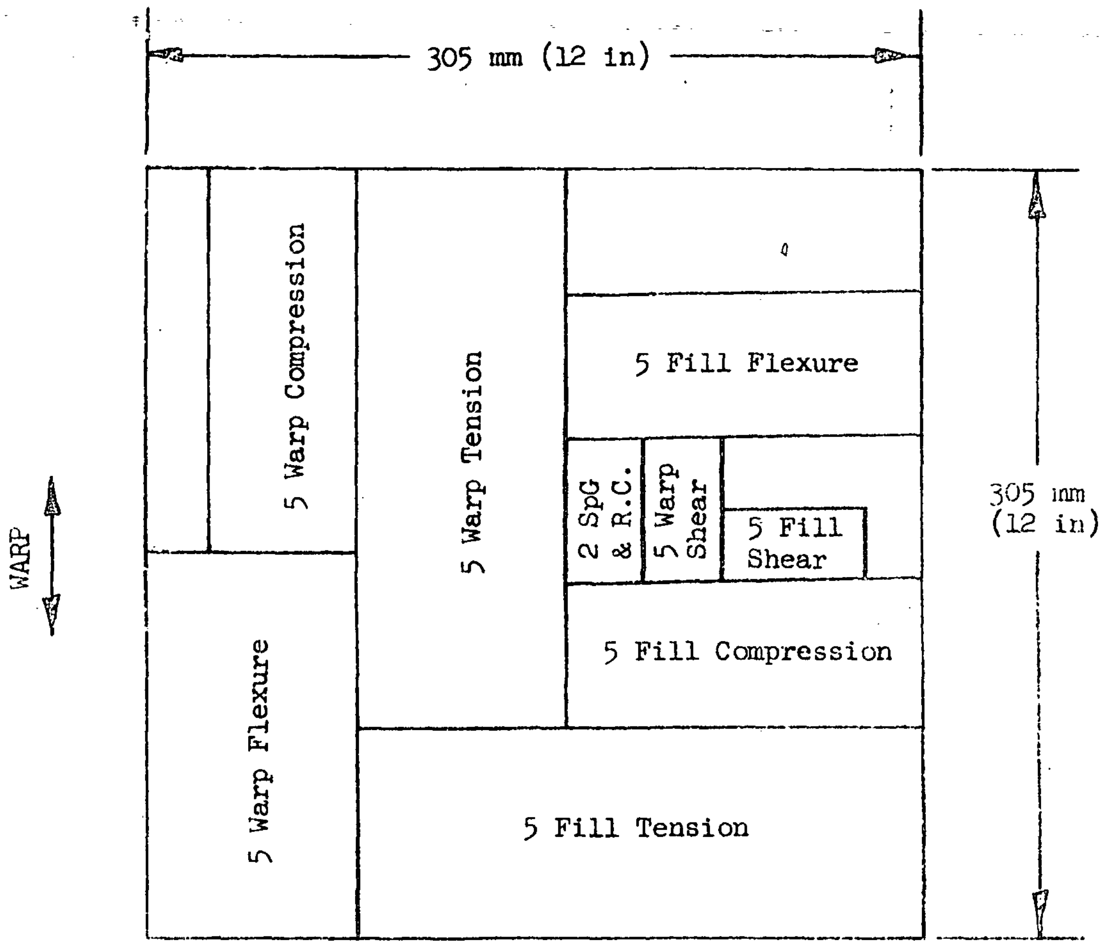
The results of the Task 2 mechanical tests are summarized in Table VII, while Table VIII is a comparison of a typical current epoxy resin system, Fiberite 934, with the advanced resin systems, with all results expressed as a percentage of the epoxy control. The individual test results are presented as Tables IX through XIII. Panel No. 9, which was a repeat of Panel No. 4, was not tested.

A survey of the results show that the moduli values, with the exception of the MXG 6070, agree quite well with the epoxy control, as might be expected since this property is primarily controlled by the fiber volume. The quality of the bond is actually revealed by the strength values, especially the shear strength. Here it can be seen that the bismaleimide is the equal of the epoxy control, and is followed in descending order by the benzyl, the phenolic/novolac and finally the phenolic. It should be pointed out that the above results are for room temperature testing only. We have obtained higher flexural strengths for the phenolic/novolac and benzyl systems on small study panels, however, the shear values obtained for such panels followed the trend noted in Table VIII.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Hitco's participation in the Composites Modification Program was limited to fabrication of test panels and determination of room temperature mechanical properties, therefore it would be presumptuous for us to draw any conclusions or make any recommendations as to replacing current epoxies with any of the advanced resin systems evaluated. From our limited perspective, it would seem that the best advanced system studied on this contract was the NASA Code M-751 bismaleimide, which was the equal of the epoxy in room temperature properties, and judging from its chemistry, should have improved high temperature and flammability properties without the use of additives. From a fabrication standpoint, the M-751 was relatively easy to process, much like the epoxy, but required a long postcure.

Figure 1. Cutting Plan, Specimen Sizes and Test Methods



Type Test	Specimen Dimensions	Test Method
Tension	12.7 x 203 mm (.50 x 8.0 in)	ASTM D-3039 (76 mm gage length)
Compression	6.4 x 140 mm (.25 x 5.5 in)	ASTM D-3410 (Celanese Fixture)
Flexure	12.7 x 140 mm (.50 x 5.5 in)	ASTM D-790 (32:1 span)
Short Beam Shear	6.4 x 19 mm (.25 x .75 in)	ASTM D-2344 (4:1 span)
Specific Gravity	25 x 25 mm (1.0 x 1.0 in)	ASTM D-792

TABLE I. PREPREG MATERIALS

PANEL NO.	RESIN SYSTEM	STYLE WEAVE	LOT NO.	ROLL NO.	RESIN SOLIDS CONTENT	VOLATILES CONTENT	PERCENT FLOW
TASK 1							
PANEL #1	934 EPOXY	133	B8-115	1B-2	37.0	0.9	NOT MEASURED
PANEL #2	934 EPOXY	134	B8-153	2B-2	41.4	1.3	NOT MEASURED
PANEL #3	934 EPOXY	177	B8-177	1	37.8	1.2	NOT MEASURED
TASK 2							
PANEL #4	934 EPOXY	133	B9-060 B9-078	2C-2 4	43.0 39.9	1.7 0.9	NOT MEASURED NOT MEASURED
PANEL #5	XYLOK 210 PHENOLIC/NOVOLAC	133	B9-079	1-6	39.0	10.1	21.3
PANEL #6	CODE M-751 BISMALEIMIDE	133	B9-081	1-6	38.0	16.5	21.6
PANEL #7	MXG 6070 PHENOLIC	133	2147	1	51.0	8.3	33.2
PANEL #8	WFR 1200 BENZYL	133	B9-080	1-6	39.4	12.6	22.4
PANEL #9	934 EPOXY	133	B9-106	5A-1	39.4	0.8	NOT MEASURED

NOTE: ALL FABRICS COATED BY FIBERITE/WINONA EXCEPT FOR THE MXG 6070, WHICH WAS COATED BY FIBERITE/ORANGE

TABLE II. STANDARD CURE CYCLES

RESIN SYSTEM	PREPREG STAGING CYCLE (IN OVEN)	CURE CYCLE (IN AUTOCLAVE): TIME AT TEMPERATURE	CURE CYCLE (IN AUTOCLAVE): PRESSURE KPa (psi)	CURE CYCLE (IN AUTOCLAVE): VACUUM mm (in) HG	POSTCURE CYCLE (UNRESTRAINED IN OVEN)
934 EPOXY	NONE	30 MIN @ 23°C (73°F)	0 (0)	737 (29)	NONE
		15 MIN @ 120°C (248°F)	" "	" "	
		45 MIN @ 120°C (248°F)	690 (100)	" "	
		4½ HRS @ 180°C (356°F)	" "	" "	
XYLOK 210 PHENOLIC/ NOVOLAC	NONE	1 HR @ 82°C (180°F)	1380 (200)	737 (29)	6 HRS @ 175°C (347°F)
		1 HR @ 121°C (250°F)	" "	" "	4 HRS TO 200°C (392°F)
		4 HRS @ 177°C (350°F)	" "	" "	13 HRS TO 250°C (482°F)
		4 HRS @ 202°C (395°F)	" "	" "	SLOW COOL DOWN
CODE M-751 BISMALEIMIDE	15 MIN @ 135°C (275°F)	30 MIN @ 121°C (250°F)	0 (0)	737 (29)	2 HRS @ 154°C (310°F)
		4 HRS @ 177°C (350°F)	690 (100)	" "	2 HRS @ 182°C (360°F)
					15 HRS @ 210°C (410°F)
					SLOW COOL DOWN
MXG 6070 PHENOLIC	NONE	HEAT TO 93°C (200°F)	0 (0)	737 (29)	NONE
		1 HR @ 93°C (200°F)	690 (100)	0 (0)	
		4 HRS @ 150°C (302°F)	" "	" "	
WFR 1200 BENZYL	10 MIN @ 129°C (265°F)	20 MIN @ 54°C (130°F)	172 (25)	737 (29)	4 HRS @ 121°C (250°F)
		20 MIN @ 79°C (175°F)	" "	" "	SLOW COOL DOWN
		40 MIN @ 104°C (220°F)	345 (50)	" "	
		4 HRS @ 129°C (265°F)	" "	" "	

TABLE III. TASK 1 TEST SUMMARY

PANEL NO.	STYLE WEAVE	CALC. FIBER VOLUME %	TEST DIRECT.	FLEXURE		TENSION		COMPRESSION		BEAM SHEAR STRENGTH MPa (Ksi)
				STRENGTH MPa (Ksi)	MODULUS GPa (Msi)	STRENGTH MPa (Ksi)	MODULUS GPa (Msi)	STRENGTH MPa (Ksi)	MODULUS GPa (Msi)	
1	133	70.7	WARP	784 (114)	72.9 (10.6)	590 (85.6)	74.1 (10.7)	563 (81.6)	72.8 (10.6)	76.5 (11.1)
			FILL	897 (130)	69.9 (10.1)	606 (87.9)	70.6 (10.2)	626 (90.8)	70.9 (10.3)	76.3 (11.1)
2	134	66.0	WARP	730 (106)	65.2 (9.5)	614 (89.0)	66.8 (9.7)	491 (71.2)	69.8 (10.1)	77.7 (11.3)
			FILL	725 (105)	62.3 (9.0)	591 (85.7)	61.1 (8.9)	700 (102)	64.0 (9.3)	70.5 (10.2)
3	177	68.8	WARP	1115 (162)	112.7 (16.3)	1249 (181)	104.2 (15.1)	893 (130)	112.8 (16.4)	99.9 (14.5)
			FILL	284 (41)	23.9 (3.5)	164 (24)	24.9 (3.6)	362 (53)	27.2 (3.9)	38.6 (5.6)

Table IV. Mechanical Test Results

NASA/Ames Graphite Fabric Studies Using Current and Advanced State-of-the-Art Resins

Panel Number 1 (8-harness satin weave) Size 305 mm x 305 mm (12 in x 12 in)

Material 10 plies HMF 133/34 Orientation Parallel Warp

Calculated Fiber Volume 70.7% Cured Specific Gravity 1.596

Test Property	Spec. No.	Tested in the Warp Direction		Tested in the Fill Direction	
		Strength MPa (Psi x 10^3)	Modulus GPa (Psi x 10^6)	Strength MPa (Psi x 10^3)	Modulus GPa (Psi x 10^6)
Flexure	1	867 (126)	74.9 (10.9)	905 (131)	69.9 (10.1)
	2	793 (115)	73.4 (10.6)	941 (136)	70.4 (10.2)
	3	678 (98)	72.1 (10.5)	900 (131)	71.1 (10.3)
	4	839 (122)	72.1 (10.5)	928 (135)	70.1 (10.2)
	5	744 (108)	72.1 (10.5)	811 (118)	68.2 (9.9)
	Average	784 (114)	72.9 (10.6)	897 (130)	69.9 (10.1)
	Std Dev	76 (11)	1.2 (0.2)	51 (7)	1.1 (0.2)
Tension	1	601 (87.1)	72.4 (10.5)	626 (90.8)	69.0 (10.0)
	2	592 (85.8)	72.4 (10.5)	613 (88.9)	72.4 (10.5)
	3	601 (87.1)	76.5 (11.1)	603 (87.4)	71.0 (10.3)
	4	597 (86.6)	73.8 (10.7)	584 (84.7)	69.6 (10.1)
	5	561 (81.3)	75.2 (10.9)	605 (87.8)	71.0 (10.3)
	Average	590 (85.6)	74.1 (10.7)	606 (87.9)	70.6 (10.2)
	Std Dev	17 (2.5)	1.8 (0.3)	15 (2.2)	1.3 (0.2)
Compression	1	605 (87.7)	71.0 (10.3)	628 (91.1)	69.6 (10.1)
	2	536 (77.8)	67.6 (9.8)	618 (89.6)	72.4 (10.5)
	3	534 (77.4)	71.0 (10.3)	619 (89.8)	71.7 (10.4)
	4	516 (74.9)	75.2 (10.9)	604 (87.6)	71.7 (10.4)
	5	622 (90.2)	79.3 (11.5)	661 (95.9)	69.0 (10.0)
	Average	563 (81.6)	72.8 (10.6)	626 (90.8)	70.9 (10.3)
	Std Dev	47 (6.8)	4.5 (0.7)	21 (3.0)	1.5 (0.2)
Short Beam Shear	1	74.5 (10.8)		71.7 (10.4)	
	2	75.8 (11.0)		75.8 (11.0)	
	3	80.7 (11.7)		75.2 (10.9)	
	4	72.4 (10.5)		78.6 (11.4)	
	5	79.3 (11.5)		80.0 (11.6)	
	Average	76.5 (11.1)		76.3 (11.1)	
	Std Dev	3.4 (0.5)		3.2 (0.5)	

Table V. Mechanical Test Results

NASA/Ames Graphite Fabric Studies Using Current and Advanced State-of-the-Art Resins

Panel Number 2 (plain weave) — Size 305 mm x 305 mm (12 in x 12 in)

Material 18 plies HMF 134/34 — Orientation Parallel Warp

Calculated Fiber Volume 66.0% — Cured Specific Gravity 1.576

Test Property	Spec. No.	Tested in the Warp Direction		Tested in the Fill Direction	
		Strength MPa (Psi x 10^3)	Modulus GPa (Psi x 10^6)	Strength MPa (Psi x 10^3)	Modulus GPa (Psi x 10^6)
Flexure	1	738 (107)	65.4 (9.5)	745 (108)	62.3 (9.0)
	2	793 (115)	65.9 (9.6)	739 (107)	62.5 (9.1)
	3	610 (88)	64.5 (9.4)	699 (101)	63.2 (9.2)
	4	774 (112)	64.4 (9.3)	714 (104)	62.1 (9.0)
	5	737 (107)	65.9 (9.6)	729 (106)	61.8 (9.0)
	Average	730 (106)	65.2 (9.5)	725 (105)	62.3 (9.0)
	Std Dev	72 (10)	0.8 (0.1)	19 (3)	0.6 (0.1)
Tension	1	618 (89.6)	69.9 (10.1)	635 (92.1)	61.4 (8.9)
	2	631 (91.5)	66.9 (9.7)	627 (90.9)	61.4 (8.9)
	3	644 (93.4)	66.2 (9.6)	548 (79.5)	60.7 (8.8)
	4	632 (91.7)	63.4 (9.2)	508 (73.7)	61.4 (8.9)
	5	543 (78.7)	67.6 (9.8)	638 (92.6)	60.7 (8.8)
	Average	614 (89.0)	66.8 (9.7)	591 (85.7)	61.1 (8.9)
	Std Dev	41 (5.9)	2.4 (0.3)	60 (8.7)	0.4 (0.1)
Compression	1	527 (76.5)	67.6 (9.8)	604 (87.6)	64.1 (9.3)
	2	466 (67.6)	69.6 (10.1)	656 (95.2)	64.1 (9.3)
	3	454 (65.9)	68.3 (9.9)	749 (108.6)	64.1 (9.3)
	4	516 (74.9)	73.8 (10.7)	724 (105.0)	62.7 (9.1)
	5	492 (71.4)	69.6 (10.1)	767 (111.2)	64.8 (9.4)
	Average	491 (71.2)	69.8 (10.1)	700 (101.5)	64.0 (9.3)
	Std Dev	31 (4.5)	2.4 (0.3)	68 (9.9)	0.8 (0.1)
Short Beam Shear	1	80.7 (11.7)		64.8 (9.4)	
	2	81.4 (11.8)		83.4 (12.1)	
	3	73.8 (10.7)		62.1 (9.0)	
	4	77.9 (11.3)		76.5 (11.1)	
	5	74.5 (10.8)		65.5 (9.5)	
	Average	77.7 (11.3)		70.5 (10.2)	
	Std Dev	3.5 (0.5)		9.1 (1.3)	

Table VI. Mechanical Test Results

NASA/Ames Graphite Fabric Studies Using Current and Advanced State-of-the-Art Resins

Panel Number 3 (crowfoot satin weave) Size 305 mm x 305 mm (12 in x 12 in)

Material 16 plies HMF 177/34 Orientation Parallel Warp

Calculated Fiber Volume 68.8% Cured Specific Gravity 1.588

Test Property	Spec. No.	Tested in the Warp Direction		Tested in the Fill Direction	
		Strength MPa (Psi x 10^3)	Modulus GPa (Psi x 10^6)	Strength MPa (Psi x 10^3)	Modulus GPa (Psi x 10^6)
Flexure	1	1021 (148)	112.9 (16.4)	288 (42)	23.0 (3.3)
	2	1258 (182)	111.3 (16.1)	289 (42)	23.8 (3.5)
	3	1073 (156)	112.0 (16.2)	283 (41)	24.4 (3.5)
	4	1021 (148)	112.9 (16.4)	285 (41)	24.3 (3.5)
	5	1203 (175)	114.2 (16.6)	273 (40)	23.8 (3.5)
	Average	1115 (162)	112.7 (16.3)	284 (41)	23.9 (3.5)
	Std Dev	110 (16)	1.1 (0.2)	6 (1)	0.6 (0.1)
Tension	1	1234 (179)	102.7 (14.9)	167 (24)	25.5 (3.7)
	2	1236 (179)	104.1 (15.1)	159 (23)	24.8 (3.6)
	3	1281 (186)	105.5 (15.3)	163 (24)	24.8 (3.6)
	4	1257 (182)	103.4 (15.0)	170 (25)	24.8 (3.6)
	5	1239 (180)	105.5 (15.3)	162 (24)	24.8 (3.6)
	Average	1249 (181)	104.2 (15.1)	164 (24)	24.9 (3.6)
	Std Dev	20 (3)	1.3 (0.2)	4 (1)	0.3 (0.0)
Compression	1	859 (125)	110.3 (16.0)	371 (54)	26.9 (3.9)
	2	896 (130)	109.6 (15.9)	330 (48)	26.9 (3.9)
	3	895 (130)	111.0 (16.1)	436 (63)	27.6 (4.0)
	4	923 (134)	114.5 (16.6)	359 (52)	26.9 (3.9)
	5	894 (130)	118.6 (17.2)	316 (46)	27.6 (4.0)
	Average	893 (130)	112.8 (16.4)	362 (53)	27.2 (3.9)
	Std Dev	23 (3)	3.8 (0.6)	47 (7)	0.4 (0.1)
Short Beam Shear	1	100.7 (14.6)		42.4 (6.1)	
	2	99.3 (14.4)		36.4 (5.3)	
	3	105.5 (15.3)		38.7 (5.6)	
	4	95.2 (13.8)		37.4 (5.4)	
	5	98.6 (14.3)		38.2 (5.5)	
	Average	99.9 (14.5)		38.6 (5.6)	
	Std Dev	3.7 (0.5)		2.3 (0.3)	

TABLE VII. TASK 2 TEST SUMMARY

PANEL NO.	RESIN SYSTEM	CALC. FIBER VOL. %	TEST DIRECT.	FLEXURE		TENSION		COMPRESSION		BEAM SHEAR STRENGTH MPa (Ksi)
				STRENGTH MPa (Ksi)	MODULUS GPa (Msi)	STRENGTH MPa (Ksi)	MODULUS GPa (Msi)	STRENGTH MPa (Ksi)	MODULUS GPa (Msi)	
4	934 EPOXY	69.3	WARP	775 (112)	63.4 (9.20)	658 (95.3)	79.7 (11.6)	533 (77.2)	75.3 (10.9)	72.1 (10.5)
			FILL	874 (127)	66.7 (9.68)	676 (98.1)	76.2 (11.1)	532 (77.2)	70.6 (10.2)	70.9 (10.3)
5	XYLOK 210	66.6	WARP	680 (98.6)	67.8 (9.83)	562 (81.5)	78.2 (11.4)	479 (69.5)	76.3 (11.1)	54.8 (7.94)
			FILL	771 (112)	64.9 (9.41)	590 (85.5)	73.2 (10.6)	551 (79.9)	71.8 (10.4)	50.4 (7.31)
6	CODE M-751 BISMALEIMIDE	66.9	WARP	859 (125)	66.2 (9.60)	618 (89.6)	75.5 (10.9)	567 (82.2)	72.4 (10.5)	71.1 (10.3)
			FILL	811 (118)	63.4 (9.19)	647 (93.9)	73.1 (10.6)	585 (84.9)	66.7 (9.7)	71.9 (10.4)
7	MXG 6070 PHENOLIC	66.1	WARP	540 (78.3)	64.2 (9.32)	582 (84.4)	75.1 (10.9)	377 (54.7)	77.0 (11.2)	38.6 (5.60)
			FILL	515 (74.7)	59.8 (8.67)	434 (62.9)	62.0 (8.98)	335 (48.6)	68.8 (10.0)	35.9 (5.20)
8	WFR 1200 BENZYL	66.5	WARP	761 (111)	63.6 (9.23)	533 (77.4)	74.7 (10.9)	529 (76.7)	72.9 (10.6)	61.3 (8.89)
			FILL	852 (123)	60.7 (8.80)	581 (84.3)	70.7 (10.3)	536 (77.7)	71.6 (10.4)	63.3 (9.18)

TABLE VIII

COMPARISON OF ADVANCED RESIN SYTEMS TO EPOXY CONTROL

PANEL NO.	RESIN SYSTEM	PERCENT OF CONTROL						
		STRENGTH				MODULUS		
		FLEXURE	TENSION	COMPRESS	SHEAR	FLEXURE	TENSION	COMPRESS
4	934 EPOXY (CONTROL)	100	100	100	100	100	100	100
5	XYLOK 210	88	86	97	74	102	97	102
6	CODE M-751 BISMALEIMIDE	101	95	108	100	100	95	95
7	MXG 6070 PHENOLIC	64	76	67	52	95	88	100
8	WFR 1200 BENZYL	98	84	100	87	96	93	99

NOTE: THE AVERAGE OF THE WARP AND FILL VALUES FOR EACH MATERIAL WAS USED IN CALCULATING THE PERCENTAGES IN THIS TABLE.

Table IX. Mechanical Test Results

NASA/Ames Graphite Fabric Studies Using Current and Advanced State-of-the-Art Resins

Panel Number 4 (Graphite/Epoxy) Size 305 mm x 305 mm (12 in x 12 in)

Material 10 plies HMF 133/34 Orientation Parallel warp

Calculated Fiber Volume 69.3% Cured Specific Gravity 1.590

Test Property	Spec. No.	Tested in the Warp Direction		Tested in the Fill Direction	
		Strength MPa (Psi x 10^3)	Modulus GPa (Psi x 10^6)	Strength MPa (Psi x 10^3)	Modulus GPa (Psi x 10^6)
Flexure	1	724 (105)	62.9 (9.12)	910 (132)	66.9 (9.70)
	2	781 (113)	64.7 (9.39)	856 (124)	65.8 (9.55)
	3	832 (121)	63.7 (9.24)	820 (119)	67.3 (9.76)
	4	776 (112)	63.2 (9.17)	862 (125)	66.2 (9.60)
	5	763 (111)	62.7 (9.10)	922 (134)	67.4 (9.78)
	Average	775 (112)	63.4 (9.20)	874 (127)	66.7 (9.68)
	Std Dev	39 (6)	0.8 (0.12)	42 (6)	0.7 (0.10)
Tension	1	634 (91.9)	80.7 (11.7)	685 (99.4)	75.1 (10.9)
	2	697 (101.0)	79.7 (11.6)	654 (94.8)	76.3 (11.1)
	3	697 (101.0)	80.4 (11.7)	705 (102.2)	76.2 (11.0)
	4	630 (91.4)	79.6 (11.5)	680 (98.6)	75.7 (11.0)
	5	630 (91.3)	78.2 (11.3)	658 (95.4)	77.8 (11.3)
	Average	658 (95.3)	79.7 (11.6)	676 (98.1)	76.2 (11.1)
	Std Dev	36 (5.2)	1.0 (0.2)	21 (3.0)	1.0 (0.2)
Compression	1	508 (73.6)	81.4 (11.8)	555 (80.5)	66.9 (9.7)
	2	539 (78.1)	74.5 (10.8)	549 (79.7)	68.9 (10.0)
	3	526 (76.3)	74.3 (10.8)	541 (78.4)	69.0 (10.0)
	4	517 (75.0)	74.7 (10.8)	515 (74.7)	77.9 (11.3)
	5	573 (83.1)	71.7 (10.4)	500 (72.5)	70.3 (10.2)
	Average	533 (77.2)	75.3 (10.9)	532 (77.2)	70.6 (10.2)
	Std Dev	25 (3.7)	3.6 (0.5)	24 (3.4)	4.3 (0.6)
Short Beam Shear	1	65.8 (9.5)		70.5 (10.2)	
	2	76.5 (11.1)		68.2 (9.9)	
	3	69.5 (10.1)		69.9 (10.1)	
	4	74.5 (10.8)		71.9 (10.4)	
	5	73.9 (10.7)		74.4 (10.8)	
	Average	72.1 (10.5)		70.9 (10.3)	
	Std Dev	4.3 (0.6)		2.3 (0.3)	

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Table X. Mechanical Test Results

NASA/Ames Graphite Fabric Studies Using Current and Advanced State-of-the-Art Resins

Panel Number 5 (Graphite/Xylok 210) Size 305 mm x 305 mm (12 in x 12 in)

Material 10 plies HMF 133/Xylok 210 Orientation Parallel warp

Calculated Fiber Volume 66.6% Cured Specific Gravity 1.555

Test Property	Spec. No.	Tested in the Warp Direction		Tested in the Fill Direction	
		Strength MPa (Psi x 10^3)	Modulus GPa (Psi x 10^6)	Strength MPa (Psi x 10^3)	Modulus GPa (Psi x 10^6)
Flexure	1	676 (98.1)	67.1 (9.73)	714 (103.6)	64.2 (9.31)
	2	712 (103.2)	67.0 (9.71)	827 (120.0)	64.0 (9.28)
	3	634 (91.9)	69.3 (10.05)	742 (107.6)	66.5 (9.64)
	4	686 (99.5)	68.1 (9.87)	835 (121.1)	65.7 (9.53)
	5	692 (100.4)	67.4 (9.77)	739 (107.2)	64.0 (9.29)
	Average	680 (98.6)	67.8 (9.83)	771 (111.9)	64.9 (9.41)
	Std Dev	29 (4.2)	0.9 (0.14)	56 (8.0)	1.2 (0.16)
Tension	1	566 (82.1)	77.7 (11.3)	577 (83.6)	72.9 (10.6)
	2	574 (83.2)	76.3 (11.1)	584 (84.6)	73.1 (10.6)
	3	558 (80.9)	78.5 (11.4)	585 (84.9)	72.4 (10.5)
	4	571 (82.9)	80.0 (11.6)	594 (86.2)	73.0 (10.6)
	5	539 (78.2)	78.4 (11.4)	608 (88.1)	74.7 (10.8)
	Average	562 (81.5)	78.2 (11.4)	590 (85.5)	73.2 (10.6)
	Std Dev	14 (2.0)	1.3 (0.2)	12 (1.7)	0.9 (0.1)
Compression	1	502 (72.8)	75.2 (10.9)	563 (81.6)	73.8 (10.7)
	2	454 (65.9)	73.8 (10.7)	582 (84.4)	73.7 (10.7)
	3	486 (70.4)	79.3 (11.5)	517 (74.9)	71.7 (10.4)
	4	505 (73.2)	76.6 (11.1)	539 (78.2)	66.9 (9.7)
	5	449 (65.1)	76.4 (11.1)	553 (80.2)	73.1 (10.6)
	Average	479 (69.5)	76.3 (11.1)	551 (79.9)	71.8 (10.4)
	Std Dev	26 (3.8)	2.0 (0.3)	25 (3.6)	2.9 (0.4)
Short Beam Shear	1	56.7 (8.22)		49.5 (7.18)	
	2	54.0 (7.83)		51.3 (7.44)	
	3	54.9 (7.96)		51.0 (7.40)	
	4	52.9 (7.67)		49.5 (7.18)	
	5	55.3 (8.02)		50.8 (7.37)	
	Average	54.8 (7.94)		50.4 (7.31)	
	Std Dev	1.4 (0.20)		0.9 (0.12)	

Table XI. Mechanical Test Results

NASA/Ames Graphite Fabric Studies Using Current and Advanced State-of-the-Art Resins

Panel Number 6 (Graphite/Bismaleimide) Size 305 mm x 305 mm (12 in x 12 in)

Material 10 plies HMF 133/M-751 Orientation Parallel warp

Calculated Fiber Volume 66.9% Cured Specific Gravity 1.583

Test Property	Spec. No.	Tested in the Warp Direction: Strength MPa (Psi x 10^3)	Tested in the Warp Direction: Modulus GPa (Psi x 10^6)	Tested in the Fill Direction: Strength MPa (Psi x 10^3)	Tested in the Fill Direction: Modulus GPa (Psi x 10^6)
Flexure	1	807 (117)	66.4 (9.63)	791 (115)	61.7 (8.95)
	2	875 (127)	66.3 (9.61)	794 (115)	63.5 (9.20)
	3	882 (128)	66.4 (9.63)	848 (123)	63.5 (9.22)
	4	846 (123)	66.0 (9.57)	805 (117)	64.1 (9.29)
	5	883 (128)	65.9 (9.56)	817 (119)	64.1 (9.30)
	Average	859 (125)	66.2 (9.60)	811 (118)	63.4 (9.19)
	Std Dev	33 (5)	0.2 (0.03)	23 (3)	1.0 (0.14)
Tension	1	631 (91.5)	77.5 (11.2)	655 (95.0)	71.8 (10.4)
	2	601 (87.2)	76.4 (11.1)	649 (94.1)	73.3 (10.6)
	3	576 (83.5)	74.1 (10.7)	624 (90.5)	73.5 (10.7)
	4	633 (91.8)	74.7 (10.8)	649 (94.2)	72.9 (10.6)
	5	649 (94.1)	75.0 (10.9)	659 (95.6)	74.0 (10.7)
	Average	618 (89.6)	75.5 (10.9)	647 (93.9)	73.1 (10.6)
	Std Dev	29 (4.2)	1.4 (0.2)	14 (2.0)	0.8 (0.1)
Compression	1	539 (78.1)	75.2 (10.9)	604 (87.6)	71.0 (10.3)
	2	573 (83.0)	74.5 (10.8)	629 (91.2)	64.1 (9.3)
	3	558 (81.0)	65.5 (9.5)	609 (88.3)	68.3 (9.9)
	4	531 (77.0)	71.7 (10.4)	541 (78.5)	66.2 (9.6)
	5	632 (91.7)	75.1 (10.9)	543 (78.8)	64.1 (9.3)
	Average	567 (82.2)	72.4 (10.5)	585 (84.9)	66.7 (9.7)
	Std Dev	40 (5.8)	4.1 (0.6)	41 (5.8)	3.0 (0.4)
Short Beam Shear	1	71.9 (10.4)		70.1 (10.2)	
	2	72.0 (10.4)		73.7 (10.7)	
	3	70.0 (10.2)		72.7 (10.5)	
	4	71.8 (10.4)		68.1 (9.9)	
	5	69.9 (10.1)		74.7 (10.8)	
	Average	71.1 (10.3)		71.9 (10.4)	
	Std Dev	1.1 (0.1)		2.7 (0.4)	

Table XII. Mechanical Test Results

NASA/Ames Graphite Fabric Studies Using Current and Advanced State-of-the-Art Resins

Panel Number 7 (Graphite/Phenolic) Size 305 mm x 305 mm (12 in x 12 in)

Material 10 plies HMF 133/MXG 6070 Orientation Parallel warp

Calculated Fiber Volume 66.1% Cured Specific Gravity 1.566

Test Property	Spec. No.	Tested in the Warp Direction		Tested in the Fill Direction	
		Strength MPa (Psi x 10^3)	Modulus GPa (Psi x 10^6)	Strength MPa (Psi x 10^3)	Modulus GPa (Psi x 10^6)
Flexure	1	499 (72.3)	63.8 (9.26)	541 (78.4)	59.6 (8.65)
	2	534 (77.5)	64.6 (9.37)	538 (78.0)	60.3 (8.74)
	3	536 (77.8)	65.7 (9.53)	528 (76.5)	60.3 (8.74)
	4	552 (80.1)	63.6 (9.23)	478 (69.4)	59.5 (8.63)
	5	579 (84.0)	63.4 (9.20)	489 (71.0)	59.4 (8.61)
	Average	540 (78.3)	64.2 (9.32)	515 (74.7)	59.8 (8.67)
	Std Dev	29 (4.3)	0.9 (0.13)	29 (4.2)	0.4 (0.06)
Tension	1	619 (89.8)	73.7 (10.7)	447 (64.9)	64.5 (9.35)
	2	588 (85.3)	78.5 (11.4)	420 (60.9)	61.5 (8.91)
	3	575 (83.4)	74.1 (10.8)	441 (63.9)	60.6 (8.80)
	4	546 (79.2)	75.4 (10.9)	422 (61.2)	59.9 (8.69)
	5	581 (84.2)	73.6 (10.7)	439 (63.7)	63.3 (9.17)
	Average	582 (84.4)	75.1 (10.9)	434 (62.9)	62.0 (8.98)
	Std Dev	26 (3.8)	2.1 (0.3)	12 (1.8)	1.9 (0.27)
Compression	1	376 (54.5)	77.9 (11.3)	331 (48.1)	69.6 (10.1)
	2	374 (54.3)	82.1 (11.9)	368 (53.4)	65.5 (9.5)
	3	373 (54.2)	68.3 (9.9)	315 (45.7)	71.7 (10.4)
	4	388 (56.3)	82.0 (11.9)	321 (46.5)	70.3 (10.2)
	5	373 (54.2)	74.5 (10.8)	339 (49.1)	66.9 (9.7)
	Average	377 (54.7)	77.0 (11.2)	335 (48.6)	68.8 (10.0)
	Std Dev	6 (0.9)	5.8 (0.8)	21 (3.0)	2.5 (0.4)
Short Beam Shear	1	37.9 (5.50)		35.0 (5.08)	
	2	39.0 (5.66)		36.3 (5.27)	
	3	37.6 (5.46)		37.3 (5.41)	
	4	38.7 (5.61)		35.3 (5.12)	
	5	39.9 (5.79)		35.4 (5.13)	
	Average	38.6 (5.60)		35.9 (5.20)	
	Std Dev	0.9 (0.13)		1.0 (0.14)	

Table XIII. Mechanical Test Results

NASA/Ames Graphite Fabric Studies Using Current and Advanced State-of-the-Art Resins

Panel Number 8 (Graphite/Benzyl) Size 305 mm x 305 mm (12 in x 12 in)

Material 10 plies HMF 133/WFR 1200 Orientation Parallel warp

Calculated Fiber Volume 66.5% Cured Specific Gravity 1.582

Test Property	Spec. No.	Tested in the Warp Direction		Tested in the Fill Direction	
		Strength MPa (Psi x 10^3)	Modulus GPa (Psi x 10^6)	Strength MPa (Psi x 10^3)	Modulus GPa (Psi x 10^6)
Flexure	1	811 (118)	63.7 (9.24)	830 (120)	60.4 (8.76)
	2	756 (110)	66.8 (9.69)	842 (122)	59.5 (8.64)
	3	776 (113)	62.9 (9.13)	899 (130)	61.8 (8.96)
	4	781 (113)	61.5 (8.92)	843 (122)	61.9 (8.97)
	5	682 (99)	63.2 (9.17)	847 (123)	59.9 (8.69)
	Average	761 (111)	63.6 (9.23)	852 (123)	60.7 (8.80)
	Std Dev	48 (7)	2.0 (0.28)	27 (4)	1.1 (0.15)
Tension	1	516 (74.9)	77.4 (11.2)	580 (84.1)	70.9 (10.3)
	2	525 (76.1)	74.1 (10.8)	588 (85.3)	70.2 (10.2)
	3	467 (67.7)	74.8 (10.9)	557 (80.8)	70.5 (10.2)
	4	582 (84.4)	72.9 (10.6)	632 (91.6)	71.4 (10.4)
	5	577 (83.7)	74.1 (10.8)	548 (79.5)	70.4 (10.2)
	Average	533 (77.4)	74.7 (10.9)	581 (84.3)	70.7 (10.3)
	Std Dev	48 (6.9)	1.7 (0.2)	33 (4.7)	0.5 (0.1)
Compression	1	524 (76.0)	73.1 (10.6)	497 (72.1)	69.6 (10.1)
	2	528 (76.6)	70.3 (10.2)	571 (82.8)	71.7 (10.4)
	3	522 (75.7)	73.0 (10.6)	574 (83.3)	71.5 (10.4)
	4	543 (78.8)	71.0 (10.3)	519 (75.3)	73.1 (10.6)
	5	528 (76.6)	77.2 (11.2)	517 (75.0)	71.9 (10.4)
	Average	529 (76.7)	72.9 (10.6)	536 (77.7)	71.6 (10.4)
	Std Dev	8 (1.2)	2.7 (0.4)	35 (5.0)	1.3 (0.2)
Short Beam Shear	1	57.3 (8.32)		61.4 (8.91)	
	2	65.5 (9.50)		66.4 (9.63)	
	3	57.3 (8.31)		65.5 (9.50)	
	4	64.7 (9.38)		64.7 (9.38)	
	5	61.5 (8.93)		58.5 (8.49)	
	Average	61.3 (8.89)		63.3 (9.18)	
	Std Dev	3.9 (0.56)		3.3 (0.47)	