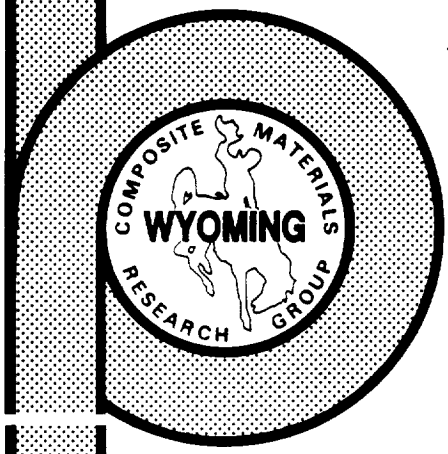
TENSILE, COMPRESSION, OPEN-HOLE COMPRESSION AND DOUBLE CANTILEVER BEAM FRACTURE TOUGHNESS TESTING OF MULTIPLE NASA LANGLEY RESEARCH CENTER COMPOSITE MATERIALS



FINAL REPORT

RESEARCH GRANT NAG-1-1294

JULY 1999

Submitted To:

Dr. Norman J. Johnston, Mail Stop 226
Polymeric Materials Branch
NASA Langley Research Center
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COMPOSITE MATERIALS RESEARCH GROUP
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The attached data summarizes the work performed by the Composite Materials Research Group at the University of Wyoming funded by the NASA LaRC Research Grant NAG-1-1294. The work consisted primarily of tension, compression, open-hole compression and double cantilever beam fracture toughness testing performed an a variety of NASA LaRC composite materials. Tests were performed at various environmental conditions and pre-conditioning requirements. The primary purpose of this work was to support the LaRC material development efforts. The data summaries are arranged in chronological order from oldest to newest.

Report UW-CMRG-R-94-103

TENSILE, OPEN-HOLE COMPRESSION AND DOUBLE CANTILEVER BEAM FRACTURE TOUGHNESS TESTING OF SEVERAL IM7/LARC™ COMPOSITE MATERIALS

FINAL REPORT

MAY 1994

Submitted To:

Dr. Tan Hou, Mail Stop 226
Polymeric Materials Branch
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Submitted By:

Scott L. Coguill
Jeff A. Kessler
Donald F. Adams

TENSILE, OPEN-HOLE COMPRESSION AND DOUBLE CANITLEVER BEAM FRACTURE TOUGHNESS TESTING OF SEVERAL IM7/LARC™ COMPOSITE MATERIALS

SECTION

Section 1.
Tensile Testing

1.1 Introduction

Elevated temperature tensile tests were performed by the Composite Materials Research Group (CMRG) on two different unidirectional composite materials provided by NASA-Langley Research Center. The composite materials consisted of Hercules IM-7 carbon fiber and either LARC™-IAX20B (4%) or LARC™-IA matrix resin formulations. Precut, untabbed specimens were supplied from two panel sources. Specimens GD-1693- 6 through 10 were originally cut from an IM7/LARC™-IAX20B panel. Specimens GD-1643-1 through 4 were originally cut from an IM7/LARC™-IA (4%) panel.

1.2 Procedure

As received, Specimens GD1693-6 through -10 were 9.0 inches long by 0.5 inch wide. The specimens were tabbed with 2.25 inch long G-10 glass-fabric/epoxy tapered tabs. The tabs were tapered to an angel of 7° and bonded to the specimens with Techkits A-12 epoxy adhesive. A uniaxial strain gage was bonded with high temperature adhesive to Specimen 1693-6. Biaxial strain gages were applied to the other four specimens. These five specimens were tested in an Instron 1321 test frame that was equipped with wedge grips and a U-joint for self alignment.

The specimens were placed in the wedge grips and then a clam-shell style zone heater, with a five inch long heated section, was placed around the gage section. A thermocouple was taped to the specimen inside the heated region. Once the temperature

on the thermocouple reached 177°C, the tests were performed. There were no slipping problems with the grips for these specimens.

Specimens GD-1643-1 through -4 were tabbed with 2.5 inch AS4/3501-6 $[(0/90)_4/\bar{0}]_s$ material with a 30° taper. Tabs were bonded with HTA24 adhesive (350°F cure.) The graphite/epoxy tabs were chosen as an alternative high temperature tabbing option. The specimens were only six inches long, which left a 1 inch gage section after tabbing. Biaxial gages were applied to each specimen.

Testing was performed in an Instron 1321 universal test frame, initially equipped with a temperature chamber. Severe gripping difficulties were initially encountered. The first three specimens were gripped with mechanical action wedge grips and the entire assembly was surrounded by the temperature chamber. The specimens were loaded into the preheated chamber and testing started when the temperature returned to 177°C. The temperature was stable to ±0.5°C. The difficulty occurred when the carbon/epoxy tabs slipped in the grips. The surface ply of the tabs was oriented in the longitudinal direction. The pointed teeth of the grip face tended to cut grooves in the tab surfaces, causing the tabs to slip out of the grips at low loads. A non-zero orientation of the tabbing materials may have prevented some of the slipping.

When the grips did not slip and load accumulated, a second problem occurred. At loads in excess of 50% of the expected failure load, the outer plies of the tabbing sheared off the tab itself. Even with these problems, the first three specimens were eventually tested to failure with wedge grips inside a temperature chamber by repeated retests. This

technique would not work for the fourth specimen. After trying many modifications of the test technique, a successful method was found. The specimens were gripped with hydraulic grips and the test temperature was attained by a short zone heater that only affected the gage section. The test temperature was stable to ±1.0°C. By keeping the tabs near room temperature and by applying a large initial clamping force, the gripping was adequate to achieve specimen failure.

1.3 Results

The results of the tensile testing of specimens GD-1693-6 through -10 are listed in Table 1. The results of the tensile testing of specimens GD-1643-1 through -4 are listed in Table 2. These latter results show a definite trend of increasing strength. The documentation received with the specimens recorded the cutting plan for the panel from which the specimens were taken. This plan showed Specimen #1 being closest to the original panel edge and Specimen #4 being furthest from this same edge. This correlates with the increasing specimen strength from Specimens 1 to 4. The variation in gripping methods may have had an effect on the strength values, but the clear pattern of the data indicated it to be more of a panel problem.

Plots of the stress versus strain data recorded for each test specimen are also included in Appendix A.

TABLE 1
AXIAL TENSILE TEST RESULTS
NASA-LANGLEY IM7/LARC-IAX20B, GD 1693
TESTED AT 177° C

SPECIMEN NO.	TENSILE STRENGTH (ksi)	MODULUS (Msi)	STRAINS AT FAILURE LONG/TRAN (percent)	POISSON'S RATIO
6	303	25.4		*
7	281	21.3	1.44/0.47	0.37
8	302	22.5	1.30/0.40	0.35
9	256	22.1	0.95/0.37	0.36
10	288	17.8	1.74/0.33	0.47
AVERAGE	286	21.8	1.36/0.39	0.39
STD. DEV.	19	2.7	0.3/0.05	0.06
CV%	7	12	22/13	15

TABLE 2
AXIAL TENSILE TEST RESULTS
NASA-LANGLEY IM7/LARC-IA (4%), GD-1643
TESTED AT 177°C

SPECIMEN NO.	TENSILE STRENGTH (ksi)	MODULUS (Msi)	STRAINS AT FAILURE LONG/TRAN (percent)	POISSON'S RATIO
1	310	23.5	*	0.37
2	318	21.6	1.45/0.44	0.38
3	359	25.1	1.36/0.51	0.41
4	377	23.3	*	0.35
AVERAGE	341	23.4	1.41/0.48	0.39
STD.DEV.	28	2.7	0.05/0.04	0.06
CV%	8	5.1	3.5/8.3	15.4

* Strain measurements not available at failure.

Section 2
Open-Hole Compression

2.1 Introduction

Open-Hole Compression (OHC) tests at room temperature and 177°C were performed on NASA Langley Research Center (LaRC) supplied specimens. The specimen preparation and testing were per the guidelines of the Boeing specification BSS 7260. Premade specimens were supplied to the CMRG by LaRC to be instrumented and tested. Tables 3 and 4 list the specimens and material types supplied.

2.2 Procedure

Dimensional requirements for the specimens were 12.0 inches long by 1.50 inches wide. A 0.25 inch diameter hole was drilled in the center of each specimen. Each specimen was instrumented with a biaxial strain gage. The specimens were each bolted into the test fixture and a compressive load was applied until the specimen failed. All specimens were tested using an Instron 1334 universal test frame. For the 177°C testing, the test fixture was enclosed in an environmental chamber. Specimens were allowed to heat up and stabilize at the test temperature before load was applied. Two channels of strain data, longitudinal and transverse, were recorded throughout each test.

2.3 Results

The results of the OHC testing are listed in Tables 3 and 4. Some modifications to the test method were made to accommodate the specimens as they were received. Specimens GD-1623-1 and -2 and GD-1624-1 and -2 were fabricated 2.0 inches too short by LaRC. They supplied additional material from panels GD-1610 and GD-1616, which was cut and ground into 1.0 inch by 1.50 inch spacers. Despite the need for spacers, all

TABEL 3
OPEN-HOLE COMPRESSION TEST RESULTS FOR IM7/LaRC-IA COMPOSITE MATERIALS AT ROOM TEMPERATURE AND 177°C

MATERIAL	LAMINATE NO.	TEST TEMPERATURE. (°C)	SPECIMEN NO.	OPEN- HOLE COMPRESSION STRENGTH (ksi)	STRAIN AT FAILURE LONG/TRANS (percent)	MODULUS (Msi)	POISSON'S RATIO
IM7/LaRC-IA (4%)	GD-1651	RT	1	47.3	0.57/0.12	8.51	0.33
			2	44.3	0.34/0.11	7.02	0.16
			AVERAGE	**45.8**	**0.46/0.12**	**7.77**	**0.25**
		177	3	33.3	0.39/0.11	7.26	0.31
			4	32.6	*	*	*
			AVERAGE	**33.0**			
IM7/LaRC-IAX10A	GD-1658	RT	1	43.5	0.60/0.13	8.67	0.24
			2	48.7	0.65/0.14	8.20	0.18
			AVERAGE	**46.1**	**0.63/0.14**	**8.44**	**0.21**
		177	3	36.1	0.39/0.11	7.60	0.31
			4	32.5	0.45/0.10	6.85	0.23
			AVERAGE	**34.3**	**0.42/0.11**	**7.23**	**0.27**
IM7/LaRC-IAX20B	GD-1691	RT	1	43.4	0.56/0.10	7.91	0.18
			2	45.2	0.50/0.14	9.19	0.29
			3	43.2	*	5.79	0.12
			AVERAGE	**43.9**	**0.53/0.12**	**7.63**	**0.20**
IM7/LaRC-IAX20B	GD-1698	177	1	33.1	0.47/0.07	7.78	0.18
			2	31.9	*	*	*
			AVERAGE	**32.5**			

* Data unavailable due to gage failure during testing.

TABLE 4
OPEN HOLE COMPRESSION TEST RESULTS FOR IM7/LaRC-RP46
COMPOSITE MATERIAL
TESTED AT ROOM TEMPERATURE AND 177°C

MATERIAL	LAMINATE NO.	TEST TEMP. (°C)	SPECIMEN NO.	OPEN HOLE COMPRESSION STRENGTH (ksi)	STRAIN @ FAILURE (percent)	MODULUS (Msi)
IM7/LaRC-RP46	GD-1623	RT	1	40.9	6.1	7.5
	GD-1624		1	38.3	4.6	7.0
			AVERAGE	**39.6**	**5.4**	**7.3**
	GD-1623	177	2	34.5	4.9	7.1
	GD-1624		2	33.2	4.5	7.0
				33.9	**4.7**	**7.1**

four of the short specimens achieved acceptable failures. Specimens 1651-1 and 1651-2 were received warped; however they also exhibited acceptable failures. The remainder of the specimens failed in an acceptable manner. It should be noted that Specimens GD-1651-4 and GD-1658-4 had nonstandard widths of 1.1 inches. Specimens 1651-4 and GD-1698-2 exhibited strain gage problems; therefore no modulus or Poison's ratio data were obtained for these two specimens. Specimen GD-1691-3 experienced premature failure of the unidirectional gage, preventing the measurement of the failure strain. Finally, Specimen GD-1698-3 was accidentally broken during preparation and consequently not tested.

Section 3
Double Cantilever Beam

3.1 Introduction

Double-cantilever beam fracture toughness tests were performed by the Composite Materials Research Group on specimens of two different unidirectional composite materials provided by NASA Langley Research Center. Test Specimens GD-1630-1 through -4 consisted of Hercules IM-7 carbon fiber and LARC-RP46 resin. Test specimens GD-1697-2 through -4 consisted of Hercules IM-7 carbon fiber and LARC-IAX20B resin. Three replicate specimens were tested for each material. Multiple crack extensions were performed on each replicate.

3.2 Specimen Configuration and Test Method

As received from NASA, the test specimens were nominally 1 inch wide, 6 inches long and between 0.125 inch and 0.145 inch thick. A 1.0 inch long Kapton insert at the midplane of one end of the specimen (placed during laminate fabrication) facilitated crack initiation and extension. It was noted that the specimens provided were smaller than the nominal 1.5 inch wide, 9.0 inch long configuration specified in References [1-3]. No preconditioning was performed on the specimens prior to testing.

In general, the methodology presented in Reference [1] was used for the present work. Crack opening loads were introduced to the specimens via piano hinges attached to the specimen faces at the insert end of each specimen. The hinges were bolted to the specimen using the technique presented in Reference [2]. The test methods used were an exact duplicate of those used in earlier work for NASA (Reference [4]).

For the majority of the tests, the cracks were extended manually approximately one-half inch from the end of the Kapton insert prior to testing. The initial crack length prior to testing was therefore nominally 0.5 inches, to reduce the load on the hinge adhesive.

The testing was performed in an Instron 1125 universal electromechanical testing machine with conventional mechanical wedge-action grips. A universal joint was used in the load train. A crosshead speed of 2mm/minute was used for the majority of the tests, although some were conducted at 5mm/minute. The crosshead speed had no discernible effect upon the results.

To conduct a test, the free half of each hinge was placed in the grips and the chart recorder was nulled. The crosshead was then moved at a fairly high crosshead rate (20mm/minute) until just prior to crack extension, at which point the crosshead rate was reduced to 2mm/minute and the loading was continued until the crack had extended about 0.5 inch. The crack length was measured with dial calipers and the specimen was then unloaded. This process was repeated several times; most specimens were subjected to 5 crack extensions. The crack length was measured on each side of the specimen from an imaginary line between the two hinge pivots to the crack front, and the crack lengths from each side were averaged for use in the calculations. As mentioned above, the procedures from References [1] and [4] were followed. The methods presented in References [2] and [3] are similar, except that the specimen is not unloaded at the end of each crack propagation. Also, in Reference [3] the free end of the specimen is supported.

Load versus crosshead displacement curves were recorded on the Instron chart during each test and are appended to this report. The beam deflections were measured

with the crosshead displacement unit integral to the testing machine, rather than at the specimen. Although it is preferred to directly measure the displacement of the specimen halves at the hinge pivot, time constraints precluded this option. The wedge grips were preloaded and the load train was kept as simple and short as possible to minimize extraneous displacements.

Just as in Reference [4], two different data reduction techniques were used to calculate the critical strain energy release rate G_{IC} for each material; 1) Energy-area integration method or 2) Modified compliance calibration method (MCC). The results of both methods of calculation appear on the data worksheets. Only the energy-area integration results are reported in the data summary tables.

3.3 Test Results

The individual worksheets for energy determination are included in Appendix B. Table 5 shows the individual and average energy levels for each specimen.

TABLE 5
DOUBLE CANTILEVER BEAM INTERLAMINARFRACTURE TOUGHNESS TEST RESULTS FOR IM7 CARBON FIBER/RP46 RESIN UNIDIRECTIONALCOMPOSITE LAMINATE GD-1630

SPECIMEN NO.	G_{IC} (kJ/m$^{2)}$ Crack Extension Number Individual Values						SPECIMEN AVERAGE	SPECIMEN STD. DEV.
	1	2	3	4	5	6		
1	0.897	1.101	1.064	1.082	1.008	0.941	1.015	0.082
2	1.475	1.034	1.152	1.288	1.318	1.130	1.233	0.159
3	0.951	0.745	0.809	0.745	0.726	0.654	0.772	0.101
4	1.750	0.784	0.857	1.107	0.805	0.820	1.021	0.377
						Overall	1.010	0.224

TABLE 6
DOUBLE CANTILEVER BEAM INTERLAMINARFRACTURE TOUGHNESS TEST RESULTS FOR IM7 CARBON FIBER/LARC-IAX20B RESIN UNIDIRECTIONALCOMPOSITE LAMINATE GD-1697

SPECIMEN NO.	G_{IC} (kJ/m$^{2)}$ Crack Extension Number Individual Values					SPECIMEN AVERAGE	SPECIMEN STD.DEV.
	1	2	3	4	5		
1	2.422	1.557	1.911	1.800	1.749	1.888	0.325
2	4.297	2.327	1.975	1.988	2.018	2.521	1.003
3	2.014	1.903	1.830	1.800	1.805	1.870	0.090
					Overall	2.093	0.647

APPENDIX A

INDIVIDUAL STRESS-STRAIN PLOTS FOR TENSILE AND OPEN-HOLE COMPRESSION TESTS

APPENDIX B

INDIVIDUAL LOAD-DISPLACEMENT CURVES FOR DOUBLE CANTILEVE BEAM TESTS

Notes on interpreting load-displacement curves:

1. Plots are percent of full scale load (in Newtons) vs. crosshead displacement in millimeters x proportional constant. The full scale load in Newtons is equal to the indicated displacement divided by the proportional constant. Note: Each small block on the plots is 1 percent full scale load by 2mm (not 1 mm.)

2. Example: A curve peak at 32 minor blocks on the load axis and 47 minor blocks on displacement axis. The chart indicates that the full scale load was 500N and the proportional rate was 10:1. The curve peak load is therefore: 0.32 x 500N = 160N, and the curve peak displacement is: (47/2)/10 = 2.35mm.

3. The width of the chart paper is the load axis. The length of the chart paper is the displacement axis. Some charts have been reduced in size and are so noted.

APPENDIX C

INDIVIDUAL SPECIMEN WORKSHEETS FOR DOUBLE CANTILEVER BEAM TESTS

Notes on interpreting worksheets:

1. Upper section of each worksheet is specimen name and dimensions.

2. Second section of each worksheet is various conversion constants and initial crack lengths.

3. Third section of each worksheet is area-energy calculation data and results, as well as specimen compliance data and calculations, (from chart deflection and load data).

4. Fourth section of each worksheet (lower left) is modified compliance calibration data and calculation area.

5. See annotated worksheet on the next page for additional information.

TENSILE AND COMPRESSIVE TESTING OF IM7/LARC™(4%) AND IM7/LARC™(5.5%) AT 177°C

June 1994

submitted to:

Tan Hou
NASA Langley
Hampton Virginia

submitted by:

Scott L. Coguill
Donald F. Adams

COMPOSITE MATERIALS RESEARCH GROUP
DEPARTMENT of MECHANICAL ENGINEERING
University of Wyoming **Laramie, Wyoming 82071**

The strength results for panel JJS-1800 show the opposite trend. The edge specimens supported the most load. This also could be a result of fiber wash from the molding operation, but, no fiber alignment irregularities were obvious from the panel inspection. It is also apparent that this material has a potential strength in excess of 400 ksi at 177°C, but irregularities in panel fabrication or testing tend to lower the average strengths. Overall, the JJS1800 panel had high average strength and modulus values.

If you have any questions concerning this phase of the testing, please do not hesitate to call me.

Best Regards,

Scott L. Coguill
Staff Engineer

COMPOSITE MATERIALS RESEARCH GROUP
University of Wyoming

Box 3295
Laramie, Wyoming 82071
(307) 766-2371, 766-2221

June 13, 1994

NASA Langley Research Center
Mail Stop 226
Hampton VA 23665-5225

Dear Tan:

Enclosed please find the results of the elevated temperature compressive tests we performed on the IM7/LARC™ 8515 (4%) (panel JJS-1771) and IM7/LARC™-8515 (5.5%) (panel JJS-1793). composite samples you sent to us. From each panel, we prepared as many standard 0.5 by 5.5 inch tabbed IITRI specimens as the material would allow. This resulted in two 0.5 and one 0.25 inch wide specimens from panel JJS1771 and four 0.5 and one 0.4 inch wide from panel JJS1793. Each panel was tabbed with 1/16 inch thick non-tapered G-11 woven fiberglass/epoxy laminate. A high temperature film adhesive, 3M AF-191, was used to bond the tabs. Each specimen was instrumented with a pair of back-to-back uniaxial strain gages.

Initially, the specimens were to be tested in the IITRI fixture enclosed in a temperature chamber. The first specimen tested was the narrow specimen from panel JJS 1793. The tabbing adhesive failed before the specimen could fail. All subsequent testing was performed using a very small zone heater that only heated the gage section of each test specimen. A dummy Gr/Ep specimen with internal and external thermocouples was used to calibrate the temperature conditioning system. Once a reliable technique was established, it was used for all the compression testing. Each specimen was heated to and held at 177°C for 20 minutes.

The resulting strength values showed considerable scatter, especially for panel JJS1793. The very high strength value (253 ksi) for specimen #1 may have been due to under heating of the specimen. We experimented with thermocouple placement on the

dummy specimen and determined that thermocouple placement is critical for the conditioning technique utilized. If the tip of the thermocouple was moved slightly off the specimen, the actual specimen temperature may have been as low as 275° F. Our experimentation further verified that this technique is reliable if properly implemented.

I am returning the broken specimens along with this report. If you have any questions concerning this phase of the testing or the tensile testing, please do not hesitate to call me.

Best Regards,

Scott L. Coguill
Staff Engineer

TABLE 1
AXIAL TENSILE TEST RESULTS
NASA-LANGLEY IM7/LARC™ 8515(5.5%), JJS-1800
TESTED AT 177° C

SPECIMEN NO.	TENSILE STRENGTH (ksi)	MODULUS (Msi)	STRAINS AT FAILURE LONG/TRAN (percent)	POISSON'S RATIO
NT1800-1	419	30.3	1.30/>0.17	0.20
NT1800-2	352	25.3	1.37/0.46	0.34
NT1800-3	328	23.1	1.51/>0.30	0.35
NT1800-4	352	25.9	1.34/0.41	0.33
NT1800-5	376	28.6	1.37/0.35	0.30
AVERAGE	365	26.6	1.38/>0.34	0.30
STD. DEV.	31	3	0.07/>0.1	0.05
CV%	8	11	5/29	17

TABLE 2
AXIAL TENSILE TEST
NASA-LANGLEY IM7/LARC™ 8515(4%), JJS-1788
TESTED AT 177° C

SPECIMEN NO.	TENSILE STRENGTH (ksi)	MODULUS (Msi)	STRAINS AT FAILURE LONG/TRAN (percent)	POISSON'S RATIO
NT1788-1	329	26.1	1.23/0.44	0.38
NT1788-2	324	22.4	1.42/0.44	0.33
NT1788-3	352	24.4	1.42/0.55	0.39
NT1788-4	346	23.2	1.49/0.41	0.31
NT1788-5	338	24.5	1.39/0.44	0.34
AVERAGE	338	24.1	1.39/0.46	0.35
STD. DEV.	10	1	0.09/0.05	0.03
CV%	3	5	6/11	9

TABLE 3
IITRI COMPRESSION TEST
NASA-LANGLEY IM7/LARC™ 8515(5.5%), JJS-1793
TESTED AT 177° C

SPECIMEN NO.	ULTIMATE STRENGTH (ksi)	AVERAGE AXIAL STRAINS AT FAILURE (Percent)	AVERAGE COMPRESSIVE MODULUS (Msi)
NC1793-1	253	1.16	25.5
NC1793-2	160	0.77	22.2
NC1793-3	208	1.10	21.7
NC173-4	164	0.76	22.9
AVERAGE	196	0.95	23.1
STD.DEV.	38	0.2	1.5
CV %	19	21	6

TABLE 4
IITRI COMPRESSION TEST RESULTS
NASA-LANGLEY IM7/LARC™ 8515(4%), JJS-1771
TESTED AT 177° C

SPECIMEN NO.	ULTIMATE STRENGTH (ksi)	AVERAGE AXIAL STRAINS AT FAILURE (Percent)	AVERAGE COMPRESSIVE MODULUS (Msi)
NC1771-1	154	0.72	23.2
NC1771-2	136	0.62	22.9
NC1771-3	204*		
AVERAGE	165	0.67	23.1
STD.DEV.	29	0.05	0.2
CV %	18	7	0.9

* No strain gage.

REPORT NO. UW-CMRG-R-94-105

COMPRESSIVE TESTING OF IM7/PETI COMPOSITE MATERIALS AT ROOM AND ELEVATED TEMPERATURES

JULY 1994

submitted to:

Tan Hou
NASA-LangleyResearch Center
Hampton, Virginia

submitted by:

Scott L. Coguill
Jeff A. Kessler
Donald F. Adams

PREFACE

This final technical report presents the results of a series of compression test requests submitted by Steve Wilkinson of NASA-Langley. All work was performed by the Composite Materials Research Group (CMRG) within the Department of Mechanical Engineering at the University of Wyoming. This work was part of NASA-Langley Research Grant NAG-1-1294. Co-principal investigators were Messrs. Scott L. Coguill and Jeff A. Kessler, Staff Engineers.

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INTRODUCTION

A variety of IM7/PETI composite laminates were provided to the CMRG by NASA-Langley. A complete listing is presented in Table 1. Compression tests at room temperature, 150°C and 177°C were performed on specimens fabricated from the aforementioned laminates.

TABLE 1
NASA-LANGLEY SUPPLIED MATERIALS

PANEL NUMBER	MATERIAL
JJS 1499	AS4/LaRC™IA (4%)
JJS 1491	IM7/VPI-PETI-1
JS 1498	IM7/LaRC™-PETI-1
JS 1510	IM7/LaRC™-PETI-1
JJS 1509	IM7/LaRC™-PETI-1
JJS 1586	IM7/VPI-PETI-2
JS 1593	IM7/LaRC™-PETI-2
JJS 1605	IM7/LaRC™-PETI-2
JJS 1614	IM7/LaRC™-PETI-3

SUMMARY OF RESULTS

Table 2 presents the compressive strength and modulus data obtained in this study. All testing was per the guidelines of ASTM Standard D3410 using the IITRI fixture. Elevated temperature test conditions were achieved using a small zone heater.

TABLE 2
LONGITUDINAL COMPRESSIVE TEST RESULTS

PANEL NO.	MATERIAL	TEST TEMPERATURE	SPECIMEN NUMBER	ULTIMATE STRESS (ksi)	LONGITUDINAL MODULUS[1] (Msi)	FAILURE STRAIN[1] (percent)
JJS1499	AS4/LaRC IA (4%)	RT	1	129	15.8	0.89
			2	121	16.3	0.93
			3	122	18.2	0.77
			4	123	14.2	0.78
			5	116	17.2	0.58
			AVERAGE	122	16.5	0.79
			STD. DEV.	5	1.3	0.14
JJS1491	IM7/VPI-PETI-1	RT	1	167	22.9	0.76
			2	185	24.4	0.78
			3	186	22.9	0.81
			4	185	24.0	0.81
			5	187	21.8	0.81
			AVERAGE	182	23.2	0.79
			STD.DEV.	8	1.0	0.02
JJS1491	IM7/VPI-PETI-1	177°C	1	172	22.3	0.96
			2	108	21.5	0.50
			3	161	21.7	0.84
			AVERAGE	147	21.8	0.77
			STD.DEV.	34	0.4	0.2

TABLE 2 (Continued)
LONGITUDINAL COMPRESSIVE TEST RESULTS

PANEL NO.	MATERIAL	TEST TEMPERATURE	SPECIMEN NUMBER	ULTIMATE STRESS (ksi)	LONGITUDINAL MODULUS[1] (Msi)	FAILURE STRAIN[1] (percent)
JJS1498	IM7/LaRC™-PETI-1	RT	1	156	18.7	0.88
			2	203	24.3	0.90
			3	208	23.9	0.93
			4	177	21.2	0.84
			5	201	22.8	0.93
			AVERAGE	189	22.2	0.90
			STD.DEV.	22	2.3	0.04
JJS1510	IM7/LaRC™-PETI-1	RT	1	180	20.6	0.93
			2	214	22.4	0.96
			AVERAGE	197	21.5	0.94
			STD.DEV.	24	1.3	0.02
		177°C	1	173	26.1	0.71
			2	168	24.4	0.71
			AVERAGE	170	25.2	0.71
			STD.DEV.	4	1.2	0
JJS1509	IM7/LaRC™-PETI-1	150°C	1	178	30.1	0.65
			2	185	25.5	0.88
			AVERAGE	182	27.8	0.77
			STD.DEV.	5	3.3	0.12

TABLE 2 (Continued)
LONGITUDINAL COMPRESSIVE TEST RESULTS

PANEL NO.	MATERIAL	TEST TEMP	SPECIMEN NUMBER	ULTIMATE STRESS (ksi)	LONGITUDINAL MODULUS[1] (Msi)	FAILURE STRAIN[1] (percent)
JJS 1586	IM7/VPI-PETI-2	RT	1	146	15.7	0.99
			2	159	17.6	0.59
			3	160	17.6	0.94
			4	169	18.8	0.92
			AVERAGE	158	17.4	0.86
			STD.DEV.	9	1.3	0.16
		177°	1	148	18.7	0.84
			2	134	18.7	0.64
			3	126	21.1	0.65
			4	131	17.9	0.75
			AVERAGE	135	19.1	0.72
			STD.DEV.	9	1.4	0.08
JJS 1593	IM7/LaRC™-PETI-2	RT	1	174	20.4	0.94
			2	160	23.8	1.6
			3	165	19.9	1.6
			4	188	24.3	1.0
			5	161	19.1	1.7
			AVERAGE	170	21.5	1.4
			STD.DEV.	12	2.4	0.33

TABLE 2 (Continued)
LONGITUDINAL COMPRESSIVE TEST RESULTS

PANEL NO.	MATERIAL	TEST TEMP	SPECIMEN NUMBER	ULTIMATE STRESS (ksi)	LONGITUDINAL MODULUS[1] (Msi)	FAILURE STRAIN[1] (percent)
JJS 1605	IM7/LaRC™-PETI-2	150°C	1	198	20.5	0.99
			2	201	21.7	1.00
			3	185	20.9	0.91
			4	148	21.2	0.69
			AVERAGE	183	21.1	0.90
			STD.DEV.	24	0.5	0.1
		177°C	1[2]	42	16.2	0.27
			2	153	21.7	0.74
			3	182	19.5	1.00
			4	194	24.3	0.90
			AVERAGE	143	20.4	0.73
			STD.DEV.	69	3.4	0.3
JJS 1614	IM7/LaRC™-PETI-3	RT	1	141	20.1	0.71
			2	153	26.3	0.83
			3	150	19.9	0.56
			4	172	20.1	0.56
			5	170	21.6	0.52
			AVERAGE	157	21.6	0.64
			STD.DEV.	13	2.7	0.12

TABLE 2 (Continued)
LONGITUDINAL COMPRESSIVE TEST RESULTS

PANEL NO.	MATERIAL	TEST TEMP	SPECIMEN NUMBER	ULTIMATE STRESS (ksi)	LONGITUDINAL MODULUS[1] (Msi)	FAILURE STRAIN[1] (percent)
JJS1614	IM7/LaRC™-PETI-3	177°C	1[2]	38		
			2[2]	26		
			3[2]	19		
			4[2]	47	20.1	0.24
			AVERAGE	32	20.1	0.24
			STD.DEV.	12		

[1] Strain and modulus are an average from two gages where applicable.
[2] Test temperature may have been as high as 185°C due to temperature controller error.

SPECIMEN PREPARATION AND TEST METHOD

The majority of panels supplied by NASA-Langley required tabbing and cutting prior to testing. Most specimens were tabbed with 1/16 inch thick, tapered glass/epoxy G-10 or G-11 laminate. The gage section end of each tab was tapered 15 degrees. The tabs on all of the JJS 1586, 1605 and 1614 specimens at 177°C were non-tapered (90°). The tabs on JJS 1510 at 177°C were cross-plied Gr/ Ep. All tabs were 2.5 inches long. A variety of epoxy tabbing adhesives were used including Techkits A-12, AF-191.M and HT424. This array of adhesives only had marginal success at maintaining a bond at the elevated temperatures. When the tabbed section of the specimen was at elevated temperatures, only the HT424 held. Unfortunately, the tab itself failed in these instances. To resolve this problem, all elevated temperature tests were performed using a small local zone heater that only heated the gage section.

The specimen dimensions were 5.5 inches long by 0.250 inches wide with a 0.5 inch gage section. Cutting operations were performed with a 0.040 wide water-cooled aluminum -oxide abrasive wheel.

The zone heater operation was verified using a dummy Gr/Ep specimen containing a thermocouple imbedded in the gage section and an external thermocouple on the surface of the specimen. The instrumented dummy specimen was placed in the test fixture and heated until the internal specimen temperature was stabilized at the desired test temperature. The temperature controller parameters and external thermocouple placement details were then recorded for use on subsequent test specimens. During

elevated temperature tests, the specimens were held at temperature for 15 minutes prior to load application.

Each specimen tested was instrumented with back-to-back foil element strain gages for the measurement of axial strain. The gages used were Micromeasurements EA-13-125AD-120. The back-to-back gages were used to detect bending.

The specimens were loaded to failure using an IITRI compression fixture in an Instron Model 1334 100 kip servo-hydraulic test frame. The IITRI fixture was used with either serrated or flame-sprayed grip faces. Only the JJS 1568, 1605 and 1614 at 177°C specimens were tested using the flame sprayed grip faces. All specimens were tested at a displacement rate of 1mm/min.

Load, displacement and strain data were recorded throughout each test on a personal computer. Modulus values were defined as the slope of a linear fit over the data range of 1000 to 6000 με on the stress versus strain plot. The average of the back-to-back gages was used for the modulus determinations.

RESULTS AND DISCUSSION

Considerable difficulty was encountered when initially attempting to test at 150°C and 177°C. Initially,the entire test fixture was enclosed in an environmental chamber mounted in the test frame. The chamber was heated to the test temperature and load application began. No specimens were failed in this manner since either the tabbing adhesive or the tabbing material failed at low loads. A variety of tab adhesives and tab materials were tried with little success. It was decided that the only way to fail these

APPENDIX A

COMPRESSIVE STRESS VERSUS STRAIN PLOTS

UW-CMRG-R-95-108

TENSILE, COMPRESSION, COMPRESSION-AFTER-IMPACT, OPEN-HOLE COMPRESSION AND DOUBLE CANTILEVER BEAM TESTING OF IM7/LARC™ MATERIALS

Interim Report

May 1995

submitted to:

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Grant No. NAG-1-1294

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PREFACE

This interim report presents the results of work conducted during the time period from January 1, 1995 through May 15, 1995 under NASA Langley Research Center Grant No. NAG-1-1294. Dr. Tan Hou is serving as Project Monitor. All work was performed by the Composite Materials Research Group (CMRG) within the Department of Mechanical Engineering at the University of Wyoming, under the direction of Professor Donald F. Adams. The Principal Investigators for this project were Mr. Scott L. Coguill, CMRG Staff Engineer, and Ms. Ronda J. Coguill, CMRG Laboratory Manager.

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SECTION 1

DOUBLE CANTILEVER BEAM TESTING

1.1 Introduction

Double cantilever beam fracture toughness tests were performed on IM7/LARC™- 8515 (5.5%), IM7/ LARC™-PETI-5 and IM7/LARC™-SCI(4%) materials. Three replicate specimens were tested for each material. Multiple crack extensions were performed on each replicate. Table 1 gives a listing of the panels and number of samples tested. The energy release rate (G_{IC}) was determined for each specimen.

Table 1

Double Cantilever Beam
Test Panel Identification

Composite	Panel Identification
IM7/LARC™-8515 (5.5%)	JJS-1825
IM7/LARC™-PETI-5	JJS-1826
IM7/LARC™-PETI-5	JJS-1843
IM7/LARC™-SCI(4%)	JJS-1930
IM7/LARC™-SCI(4%)	JJS-1933

1.2 Test Method

The panels that were sent to the CMRG had poor consolidation along the edges. In order to avoid these regions and still get three test specimens per panel, each specimen was cut to a nominal width of 0.8 inches rather than the standard 1.0 inch. A one inch long Kapton insert had been placed in the mid-plane across the width of the panel during laminate fabrication. This insert facilitated crack initiation and extension.

In general, the methodology presented in Reference [1] was used for the present work. Crack opening loads were introduced in the specimens via piano hinges attached

to the specimen faces at the insert end of each specimens. The hinges were bolted to the specimens using the technique presented in Reference [1].

Specimen Number 1 from panel JJS-1843 was the first specimen tested. The specimen was not precracked, per the recommendation of Ref. [3]. This proved to be unwise since the load to initiate the first crack was greater than the hinge arrangement could support. Due to the triangular bolt pattern in the hinges, the specimen split longitudinally at approximately one-third (in line with an edge bolt) across its width. Thereafter, the crack front only propagated through approximately two-thirds (in-line with the middle and edge bolt) of the specimen width. All subsequent test specimens were precracked in order to avoid this situation. With the exception of Specimen JJS-1843-1, the cracks were extended manually approximately one-half inch beyond the end of the Kapton insert prior to testing. Since the hinge pivot was one inch from the end of the speicmen, the initial crack length prior to testing was therefore nominally 0.5 inches. This crack extension reduced the load on the hinges. The tests were conducted at room temperature in an MTS universal test frame, with conventional mechanical wedge-action grips. A universal joint was used in the load train as well. Testing speed was 2mm/min. Figure 1 shows a photo of the test set-up.

The test methods used were identical to those used in earlier work for NASA-Langley [2]. To conduct a test, the free half of each hinge was placed in the wedge grips The ends of the specimen were opened by the constant rate displacement of the test frame hydraulic ram. Ram movement continued until the crack had propagated approximately 0.5 inch. The crack length was measured with dial calipers and the specimen was then

unloaded. This process was repeated several times; most specimens were subjected to 5 crack extensions. The crack length was measured on each side of the specimen from an imaginary line between the two hinge pivots to the crack front. The crack lengths from each side were averaged for use in the calculations.

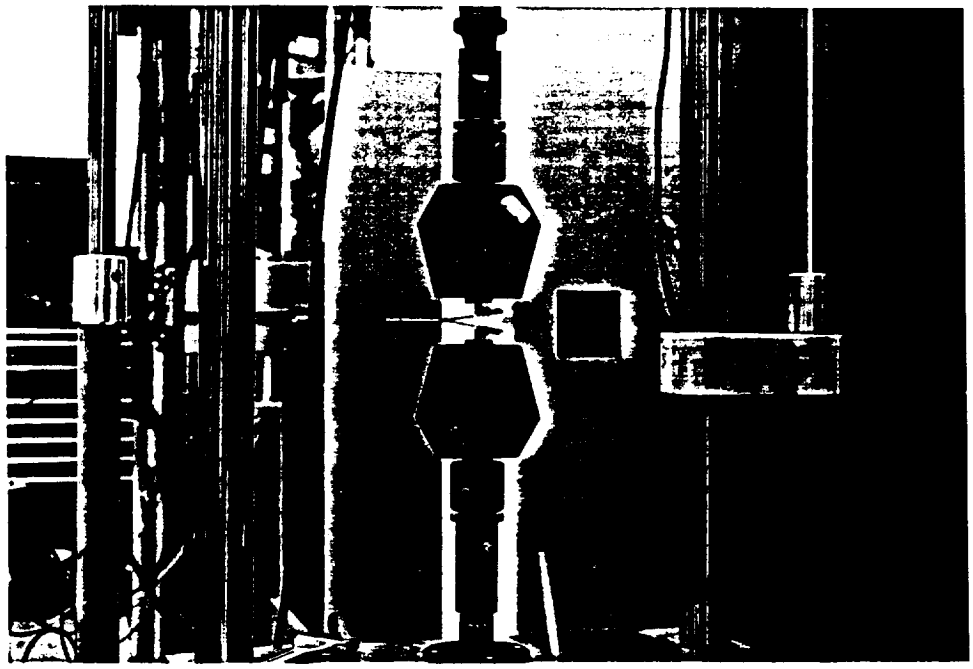

Figure 1. Double Cantilever Beam Test Set-Up

Load as well as hydraulic ram displacement data were digitally recorded by a computer throughout each test. Crack opening measurements were made via the LVDT internal to the hydraulic ram. Load versus ram displacement curves were created from each crack extension data file.

The Energy-Area integration method was used to determine the critical strain energy release rate (G_{IC}) for each material using the following formula [3]:

$$G_{IC} = \frac{\Delta Ai}{w(a_i - a_{i-1})}$$

where:

ΔA_i = included area of crack extension i as obtained from the Load vs. Ram displacement plot.

$(a_i - a_{i-1})$ = crack extension

w = specimen width

Samples of the type of plot produced are in Appendix A. Each plot represents five crack extensions.

1.3 Results and Discussion

The individual worksheets for energy determination and load versus ram displacement plots are included in Appendix A. Tables 2-6 show the individual and average energy levels for each specimen. It should be noted that panel JJS-1825 displayed significant fiber bridging.

The failed specimens were returned to NASA-Langley for future observations.

Table 2
Double Cantilever Beam Interlaminar Fracture Toughness Test Results
For IM7/LARC™-8515 (5.5%) Material Panel JJS-1825

Specimen No.	G_{IC} (kJ/m^2) Crack Extension Individual Values 1	2	3	4	5	Specimen Average	Specimen Std.Dev.
1	1.276	1.162	1.208	1.218	1.132	1.200	0.055
2	1.412	1.138	1.192	0.960	1.031	1.147	0.174
3	2.002	1.285	1.159	1.171	1.103	1.344	0.374
					Overall	1.230	0.238

Table 3
Double Cantilever Beam Interlaminar Fracture Toughness Test Results
For IM7/LARC™-PETI-5 Material Panel JJS-1826

Specimen No.	G_{IC} (kJ/m^2) Crack Extension Individual Values 1	2	3	4	5	Specimen Average	Specimen Std.Dev.
1	0.676	0.688	0.677	0.750	0.638	0.686	0.041
2	0.707	0.696	0.659	0.719	0.639	0.684	0.034
3	0.934	0.952	1.047	0.958	1.094	0.997	0.070
					Overall	0.789	0.159

Table 4
Double Cantilever Beam Interlaminar Fracture Toughness Test Results
For IM7/LARC™-PETI-5 Material Panel JJS-1843

Specimen No.	G_{IC} (kJ/m^2) Crack Extension Individual Values 1	2	3	4	5	Specimen Average	Specimen Std.Dev.
1	2.724*	1.338	1.223	1.258	0.971	1.503	0.696
2	0.575	0.601	0.639	0.655	0.576	0.609	0.036
3	0.323	0.699	0.643	0.718	0.631	0.603	0.161
					Overall	0.606*	0.110*

* Specimen No. 1, Extension 1 not included in overall statistics

Table 5
Double Cantilever Beam Interlaminar Fracture Toughness Test Results
For IM7/Larc™-SCI (4%) Material Panel JJS-1930

Specimen No.	G_{IC} (kJ/m^2) Crack Extension Individual Values 1	2	3	4	5	Specimen Average	Specimen Std.Dev.
1	1.281	1.172	1.390	1.412	1.510	1.353	0.130
2	0.928	0.996	0.966	1.072	1.123	1.017	0.079
3	1.263	1.274	1.119	1.387	1.541	1.317	0.157
					Overall	1.229	0.195

Table 6

Double Cantilever Beam Interlaminar Fracture Toughness Test Results
For IM7/LARC™-SCI (4%) MaterialPanel JJS-1933

Specimen No.	G_{IC} (kJ/m^2) Crack Extension Individual Values					Specimen Average	Specimen Std.Dev.
	1	2	3	4	5		
1	1.741	1.599	1.471	1.511	1.394	1.543	0.133
2	1.161	1.186	1.094	1.090	1.205	1.147	0.053
3	0.964	0.906	0.887	0.851	0.988	0.919	0.056
					Overall	1.203	0.279

SECTION 2

COMPRESSION TESTING

2.1 Introduction

Compression tests using the IITRI fixture were performed on IM7/ LARC™-PETI-IX (JJS-2036) at room temperature and 177°C, and IM7/ LARC™-PETI-5 (JJS-1842), and IM7/LARC™-SCI(4%) (JJS-1927) at 177°C only. Six replicates from each NASA-supplied panel were tested. Compressive strength and modulus were determined for each test specimen.

2.2 Test Method

The tests were performed per ASTM D3410, Procedure B, using the IITRI compression fixture [4]. Six tabbed specimens measuring 0.25 inches wide by 5.5 inches long with a nominal thickness of 0.25inches were prepared from each panel. Square-ended G-11 tabbing material (1/16 inch thick), and elevated temperature glass fabric epoxy composite laminate, was adhered with 3M AF191 film adhesive, leaving a 0.500 inch long gage section. Strain gages (Measurements Group EA-06-125AC-350) were adhered to the mid-section of both sides of each specimen using M-Bond 610 high temperature adhesive. Back-to-back gages were used to assure that buckling was not occurring during the testing.

The IITRI fixture was equipped with tungsten-carbide flame-sprayed wedges. All tests were performed in an Instron Model 1334 universal test frame. Elevated temperatures were achieved using a coiled wire zone heater. The heating coil controls were calibrated using a thermocouple imbedded in a dummy graphite/epoxy specimen

with a second externally attached thermocouple. The results of this calibration were the basis of the controller settings for all subsequent tests.

The specimens were loaded to failure at a rate of 0.05 inches per minute. Stress and strain data were digitally recorded using a personal computer. The modulus was calculated using the slope of a linear line fit of data between 1000με and 3000με on the stress versus strain plot.

2.3 Results and Discussion

Tables 7 through 10 show the compressive strengths and moduli of the tested specimens. Appendix B contains the stress versus strain plots for these tests. A typical failure mode for this test can be seen in Figure 2. The stress versus strain plots reveal three types of failure behavior; bending, buckling or compression. Page B-6 shows typical (for this project) bending behavior, Page B-3 depicts typical buckling behavior at failure and Page B-8 illustrated the normal compressive failure most predominate with this project. It should be noted that failure strengths were not highly influenced by failure mode.

Panels JJS-1842 and JJS 1927 were only tested at 177°C per the instructions of the Nasa-Langley monitor. Specimen No. #1 of Panel JJS-1842 was actually tested in an environmental chamber. The tab adhesive failed prematurely preventing specimen failure. All subsequent high temperature tests utilized a small zone heater that concentrated the heat around the gage section while keeping the tabs at a lower temperature.

No failure data were available for Specimen No. 6 of Panel JJS-1842. This specimen did in fact fail in the gage section shortly after the fixture halves made contact with the zone heater. However, the load interference produced by their contact made it impossible to determine at what stress level the specimen failed.

Table 7

IITRI Compression Test Results
At Room Temperature
IM7/LARC™-PETI-IX
Panel JJS-2036, $[0]_{18}$

Specimen Number	Compressive Strength (Ksi)	Compressive Modulus (Msi)*
3	217	22.8
4	254	23.2
5	225	23.2
AVERAGE	232	23.1
STD.DEV.	19.5	0.23
CV (%)	8	10

* Average modulus from back to back strain gages.

Table 8

IITRI Compression Test Results
At 177°C
IM7/LARC™-PETI-IX
Panel JJS-2036, $[0]_{18}$

Specimen Number	Compressive Strength (Ksi)	Compressive Modulus (Msi)*
6	206	22.7
7	207	20.8
8	260	22.6
AVERAGE	224	22.0
STD.DEV.	31	1.1
CV (%)	14	5

* Average modulus from back to back strain gages.

Table 9

IITRI Compression Test Results
At 177°C
IM7/LARC™-PETI-5
Panel JJS-1842$[0]_{18}$

Specimen Number	Compressive Strength (Ksi)	Compressive Modulus (Msi)*
1	+	20.3
2	177	19.8
3	193	21.0
4	180	19.8
5	145	18.8
6	#	20.0
7	182	21.8
AVERAGE	175	20.2
STD.DEV.	18.1	1.0
CV (%)	10	5

* Average modulus from back to back strain gages.
\+ Premature tab failure, therefore no stress at failure
\# Failure stress unavailable.

Table 10

IITRI Compression Test Results
At 177°C
IM7/LARC™-PETI-5
Panel JJS-1927 $[0]_{21}$

Specimen Number	Compressive Strength (Ksi)	Compressive Modulus (Msi)*
3	202	24.8
4	156	23.2
5	167	22.2
6	170	21.8
7	159	23.8
8	181	24.6
AVERAGE	172	23.4
STD.DEV.	16.8	1.2
CV (%)	10	5

* Average modulus from back to back strain gages

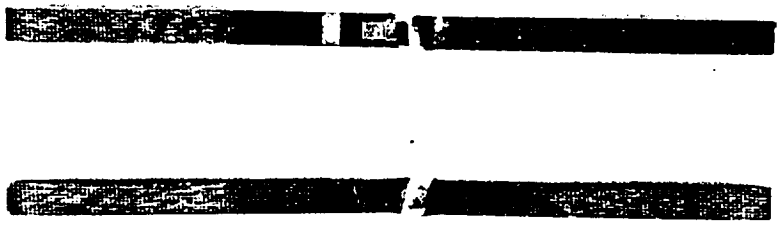

Figure 2 Typical Failures of IITRI Compression Specimens
Specimens Nos. 4 and 8 from Panel JJS-1927

SECTION 3

COMPRESSION-AFTER-IMPACT TESTING

3.1 Introduction

One panel (JJS-1870) of IM7/LARC™-PETI-5 material was sent to the CMRG for Compression-After-Impact testing. NASA-Langley had impacted the panel at 1500 inch-pounds/inch of thickness and also strain gaged it prior to sending it to the CMRG. Compressive strength and modulus after impact were determined for this panel.

3.2 Test Method

The panel was tested in compression using a standard 4" x 6" Compression-After-Impact fixture [5]. SACMA Recommended Test Method 2-88 was followed for this test [5]. The testing was conducted in an Instron Model 1334 universal test frame. Data from the four strain gages (Measurements Group CEA-06-187UW-350) were collected by a personal computer and used to determine the material modulus. The modulus was calculated using the slope of a linear line fit of data between 1000με and 3000με on the stress versus strain plot. The testing was conducted at a rate of 0.05 inches per minute to failure.

3.3 Results and Discussion

Table 11 shows the compressive strength as well as the moduli calculated from each strain gage. Appendix C contains the stress versus strain plot. The test specimen as received was 5 13/16 inches long; however, the test method [5] calls for a 6 inch long specimen. The test fixture was adjusted to accommodate the shorter specimen. As is apparent from the plot in Appendix C, the specimen loaded very uniformly. The lateral

jump in strain depicted in the stress versus strain plot resulted when an audible pop occurred during the test.

Table 11

Compression After Impact
IM7/LARCc™-PETI-5
Panel JJS-1870 $[45/0/-45/90]_{4s}$

COMPRESSIVE STRENGTH (ksi)	MODULUS 1 (Msi)	MODULUS 2 (Msi)	MODULUS 3 (Msi)	MODULUS 4 (Msi)	AVERAGE MODULUS (Msi)
47.4	7.1	7.1	7.5	7.1	7.2

SECTION 4
TENSION TESTING

4.1 Introduction

The IM7/LARC™-PETI-5 and IM7/LARC™-SCI(4%) materials were tested in tension at 177°C. Five specimens were fabricated from each of the two panels supplied by NASA-Langley. Tensile strength, modulus and Poisson's ratio were determined for each test specimen.

4.2 Test Method

The specimens were tested per ASTM D3039 [6]. Two-inch long 1/16 inch thick G-11 glass-fabric/epoxy tapered tabs were used. The tabs were tapered to an angle of 7° and bonded to the specimens with TechKits A-12 adhesive. To obtain the required five test replicates from each of the narrow panels supplied, specimens were cut 0.4 inches wide. The specimens were 9 inches long and thus had a 5 inch gage section. A biaxial strain gage (Measurements Group EA-06-062TT-350) was adhered at the midlength of one face of each specimen using M-Bond 610 high temperature adhesive. The tests were conducted in an Instron Model 1321 universal test frame equipped with mechanical wedge grips and a U-joint for self alignment.

Elevated temperatures were achieved with a 5 inch long clam shell zone heater. A thermocouple was taped to the specimen inside the heated zone. As soon as the temperature of the thermocouple reached 177°C, the tensile test was begun. The specimens were loaded at a rate of 0.05 inches per minute to failure.

Table 13

Tension Testing Results
ASTM D3039
Panel JJS 1920 $[0]_8$
at 177°C

Specimen Number	Tensile Strength (Ksi)	Tensile Modulus (Msi)	Poisson's Ratio
1	362.3	29.3	0.31
2	409.5	29.2	0.34
3	336.6	21.3	0.25
4	335.2	27.3	0.39
5	324.2	29.3	0.29
AVERAGE	353.6	27.3	0.32
STD. DEV.	34.2	3.4	0.05
CV (%)	10	12	16

Figure 3. Typical Failures of Tensile Specimens
Panel JJS-1920, Specimens No. 1 and 2

SECTION 5.

OPEN-HOLE COMPRESSION TESTING

5.1 Introduction

NASA-Langley supplied twenty panels of IM7/LARC™-PETI-5 and one panel of IM7/LARC™-SCI material, panel JJS-1998. All panels had the same 24-ply lay-up, viz., $[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$, but were cured at different conditions by NASA. The panels were shipped to the CMRG for Open-Hole Compression testing at room temperature and at 177°C. Table 14 lists the various panels, curing conditions, and test temperatures.

5.2 Test Method

Three one inch wide by 3 inch long specimens, nominally 0.125 inch thick, were cut from each panel, being sure to stay away from the poorly consolidated areas noted on the panels. Using a water-cooled carbide bit, a 1/4" hole was drilled in the midsection of each specimen. The ends of each specimen were ground flat and parallel to insure accurate loading. Testing was per Northrop Specification NAI-1504 [7].

The room temperature tests were conducted immediately after the specimens were prepared, using the Northrop-style test fixture [7]. A total of 60±10 inch-pounds of torque was applied to each Allen head bolt on the fixture. The four bolts on the fixture coverplates were each torqued to 10 inch-pounds. The fixture was then end-loaded at a rate of 0.05 inches per minute to failure. Load was applied through a spherical seat platen. Figure 4 shows the unassembled fixture. The weight of the spherical seat platen (8 pounds) was considered insignificant to the test results.

Table 14

Open-Hole Compression Test
Panel Identification

PANEL NAME	MOLDING CYCLE			TEST TEMPERATURE (°C)
	B-stage Step	Consolidation Step	Pressure (psi)	
JJS-2051	250°C/0.5 hr	371°C/1.0hr	200	RT
JJS-2054	250°C/0.5 hr	371°C/1.0hr	200	177
JJS-2048	300°C.0.5hr	371°C/1.0hr	200	RT
JJS-2056	300°C.0.5hr	371°C/1.0hr	200	177
JJS-2046	300°C.1.0hr	371°C/1.0hr	200	RT
JJS-2055	300°C.1.0hr	371°C/1.0hr	200	177
JJS-2019	250°C/1.0hr	350°C/1.0hr	200	RT
JJS-2057	250°C/1.0hr	350°C/1.0hr	200	177
JJS-2012	250°C/1.0hr	360°C/1.0hr	185	RT
JJS-2026	250°C/1.0hr	360°C/1.0hr	185	177
JJS-2058	250°C/1.0hr	350°C/1.0hr	185	RT
JJS-2063	250°C/1.0hr	350°C/1.0hr	185	177
JJS-2011	250°C/1.0hr	371°C/1.0hr	175	RT
JJS-2100	250°C/1.0hr	371°C/1.0hr	175	177
JJS-2060	250°C/1.0hr	355°C/1.0hr	175	RT
JJS-2064	250°C/1.0hr	355°C/1.0hr	175	177
JJS-2061	250°C/1.0hr	371°C/1.0hr	160	RT
JJS-2065	250°C/1.0hr	371°C/1.0hr	160	177
JJS-2101	*	*	*	RT
JJS-2104	*	*	*	177
JJS-1998+	*	*	*	RT

* No information was supplied by NASA.

\+ IM7/LARC™ -SCI

Figure 4. Unassembled Open-Hole Compression Fixture

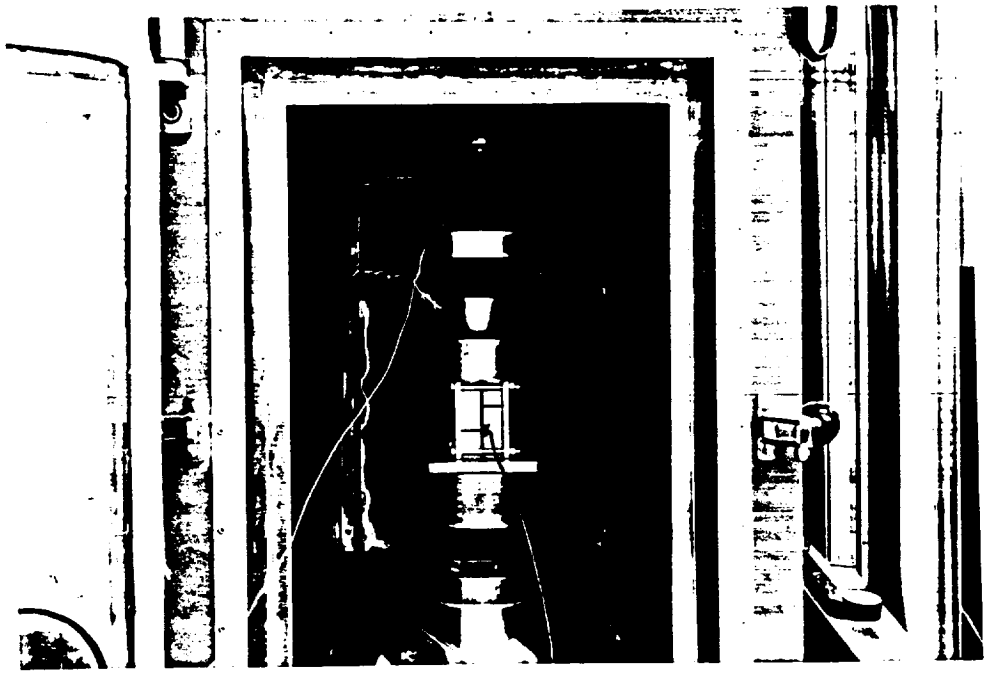

Figure 5. Elevated Temperature Open-Hole Compression Test Set-up

As per NAI-1504 [7], the high temperature specimens were preconditioned at 98% relative humidity at 160°F until they attained a weight gain of approximately 0.7%. Some materials reached this goal within 20 days. After 42 days, all specimens were tested, regardless of their weight gain percentage. The high temperature tests were conducted in a Bemco environmental chamber within an Instron Model 1334 universal test frame. Figure 5 shows the Open-Hole-Compression test set-up in the Bemco environmental chamber, which is in place in the test frame. The temperature ramp specified in NAI-1504 [7] was closely followed. A thermocouple was mounted on the specimen. The time to reach testing temperature did not exceed the recommended 12 minutes. The specimen was then held at temperature for 60 ±15 seconds before being end-loaded to failure at a rate of 0.05 inches per minute. As quickly as possible, the specimen was removed from the fixture and weighed to establish the weight loss due to the high temperature exposure during testing.

5.3 Results and Discussion

Tables 15 and 16 show the various materials and their compressive strengths. The unconsolidated areas marked on the panels as received had no apparent effect on the open-hole strength value. Panel JJS-2063 had the most inconsistent moisture weight gain. This panel was marked at both ends as having large unconsolidated areas. It is logical to assume that this panel condition was likely responsible for the wide swing from moisture gain to loss for Specimen No.3 of Panel JJS-2063. Figures 6A and 6B depict typical failure modes for both the room temperature and elevated temperature tests.

Table 15
Northrop Open-Hole Compression Test Results
IM7/LARC™-PETI-5
$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_S$
Room Temperature

Panel Number	Specimen Number	Compressive Strength (ksi)
JJS-2051	1	55.9
	2	59.8
	AVERAGE	57.8
JJS-2048	1	54.5
	2	55.5
	AVERAGE	55.0
JJS-2046	1	46.6
	2	45.0
	AVERAGE	45.8
JJS-2019	1	46.7
	2	47.2
	AVERAGE	47.0
JJS-2012	1	55.9
	2	53.3
	AVERAGE	54.6
JJS-2058	1	45.8
	2	42.3
	3	43.9
	AVERAGE	44.0
	STD. DEV.	1.8
	CV (%)	4
JJS-2011	1	54.1
	2	56.1
	AVERAGE	55.1
JJS-2060	1	41.1
	2	40.7
	3	45.5
	AVERAGE	42.4
	STD.DEV.	2.7
	CV (%)	6

TABLE 15 (Cont.)

Open-Hole Compression Test Results
IM7/LARC™-PETI-5
$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_S$
Room Temperature

Panel Number	Specimen Number	Compressive Strength (Ksi)
JJS-2061	1	56.7
	2	55.8
	3	56.4
	AVERAGE	56.3
	STD.DEV.	0.5
	CV (%)	0.9
JJS-2101	1	45.0
	2	42.2
	3	44.6
	AVERAGE	43.9
	STD. DEV.	1.5
	CV (%)	3

TABLE 16
Open-Hole Compression Test Results
IM7/LARC™-SCI
$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_S$
Room Temperature

Panel Number	Specimen Number	Compressive Strength (ksi)
JJS-1998	1	54.1
	2	56.1
	AVERAGE	55.1

Table 17

Open-Hole Compression Test Results
IM7/LARC™-PETI-5
$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$
177°C

Panel Number	Specimen Number	Compressive Strength (ksi)	Weight Gain At Test (Percent)	Weight Gain After Test (percent)	Length Of Preconditioning* (days)
JJS-2054	1	42.3	0.68	0.58	28
	2	37.1	0.74	0.63	28
	AVERAGE	39.7			
JJS-2056	1	41.9	0.65	0.56	35
	2	46.6	0.65	0.57	35
	AVERAGE	44.3			
JJS-2055	1	42.3	0.71	0.60	28
	2	42.0	0.70	0.59	28
	AVERAGE	42.1			
JJS-2057	1	26.7	0.56	0.47	42
	2	26.3	0.55	0.47	42
	3	24.6	0.57	0.49	42
	AVERAGE	25.9			
	STD.DEV.	1.1			
	CV (%)	4			
JJS-2026	1	44.4	0.69	0.46	28
	2	41.4	0.66	0.48	35
	AVERAGE	42.9			
JJS-2063	1	30.1	0.52	0.40	42
	2	31.6	0.58	0.40	42
	3	25.1	0.72	0.34	28
	AVERAGE	28.9			
	STD.DEV.	3.4			
	CV (%)	12			
JJS-2064	1	26.0	0.69	0.49	28
	2	26.9	0.66	0.57	35
	3	26.7	0.74	0.58	28
	AVERAGE	26.5			
	STD.DEV.	0.5			
	CV (%)	2			

* 160°F, 98% RH.

TABLE 17 (cont.)

Open-Hole Compression Test Results
IM7/LARC™-PETI-5
$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$
177°C

Panel Number	Specimen Number	Compressive Strength (ksi)	Weight Gain At Test (percent)	Weight Gain After Test (percent)	Length Of Preconditioning* (days)
JJS-2100	1	26.2	0.70	0.59	42
	2	31.0	0.74	0.65	42
	3	28.9	0.72	0.62	42
	AVERAGE	28.7			
	STD.DEV.	2.4			
	CV (%)	8			
JJS-2064	1	26.0	0.69	0.49	28
	2	26.9	0.66	0.57	35
	3	26.7	0.74	0.58	28
	AVERAGE	26.5			
	STD.DEV.	0.5			
	CV %	2			
JJS-2065	1	43.5	0.68	0.58	28
	2	48.3	0.71	0.61	28
	3	52.7	0.69	0.60	28
	AVERAGE	48.2			
	STD.DEV.	4.6			
	CV (%)	9			
JJS-2104	1	32.4	0.74	0.67	42
	2	32.1	0.74	0.66	42
	3	30.6	0.72	0.61	42
	AVERAGE	31.7			
	STD.DEV.	1.0			
	CV (%)	3			

*160°F, 98% RH.

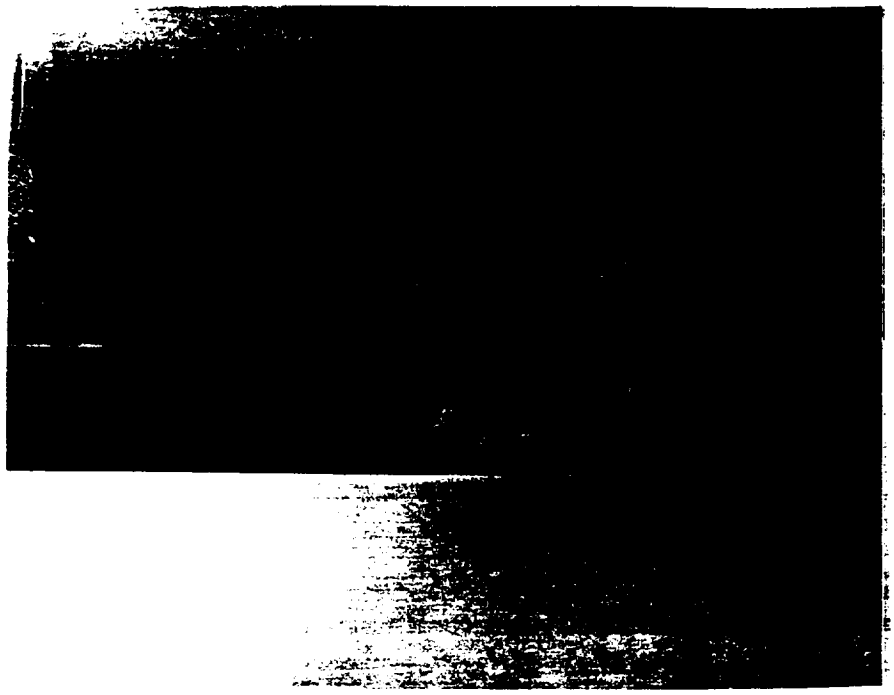

Figure 6-A. Typical Open-Hole Compression Test Failure
As Observed on Specimen Surface
Panel JJS 2054

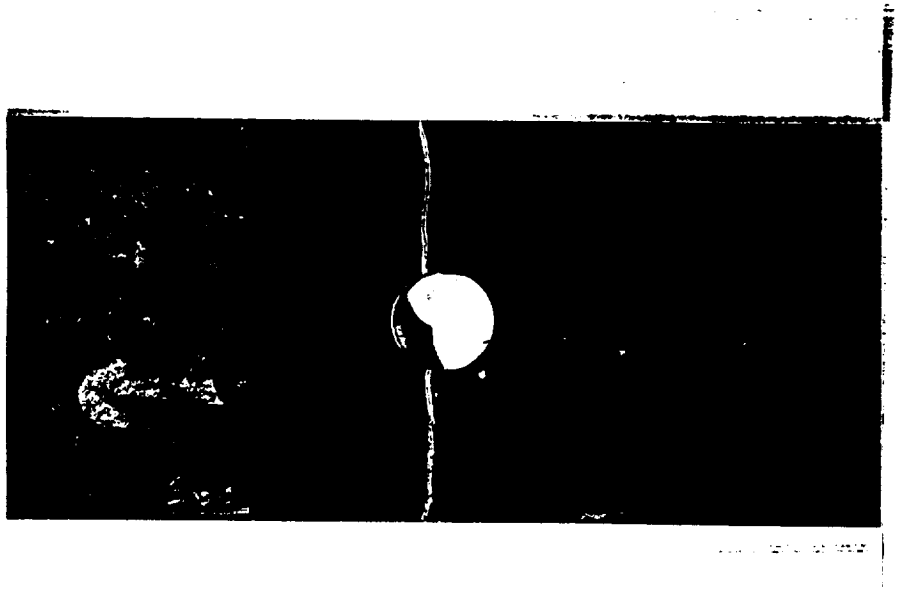

Figure 6-B. Typical Open-Hole Compression Test Failure
As Observed on Specimen Edge
Panel JJS-2054

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2. S.L. Coguill, J.A. Kessler, D.F. Adams, "Tensile, Open-Hole Compression and Double Cantilever Beam Fracture Toughness Testing of Several IM7/LARC™ Composite Materials", Report No. UW-CMRG-R-94-103, Department of Mechanical Engineering, University of Wyoming, Laramie, Wyoming, May 1994.

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7. "Preimpregnated Carbon/BMI Materials for 375°F Service," Northrop Aircraft Division Materials Specification NAI-1504, Northrop Corporation, Hawthorne, California, May 1988.

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FAX: (804) 864-8312

Remarks:

Scott:

I will ship 14 - 3.5"x3.5" OHC panels to you tomorrow, 7/12/95.

Panel IDs, lay-up orientation, required test temperatures and number of specimen required from each panel are summarized in the attached table. Please use the previously specified conditions to pre-treat specimens for the 177°C (wet) measurements.

OHC specimen is 3" x 1" with 0° in 3" dimension. Please line up your blade first along 90° edge of the panel when you set up the saw for cutting. As you can see, one edge (along 0°) was trimmed for inspecting the panel lay-up orientation. This essentially disqualify that edge of the panel to be used as reference to align the saw blade.

In some cases, 2 specimens are requested for a panel due to damages caused by sampling. You will prepare those 2 specimens outside the damaged area.

We would like to have the RT values first, and elevated temperature properties as soon as you can deliver later. If you have any questions, please call me. As you know, we can not afford another mistake any more.

Best regards.

Measurements of OHC strength

All panels are IM7/LARC™-PETI-5, 3" x 3" - [±45/90/0/0/±45/0/0/±45/0]s

(I) Study of the effect of B-staging condition

Panel ID	Molding Cycle			OHC Measurement		
	B-stage step	Consolidation step	Pressure (psi)	Test T (°C)	No. specimen	
JJS-2173	300°C/1.0 hr	371°C/1.0 hr	200	RT	3	✓
JJS-2227	Ramp 4°C/min	371°C/1.0 hr	200 Psi appl.	RT	2	✓
JJS-2229	RT-371°C	371°C/1.0 hr	at 300°C	177 (wet)	3	✓

(II) Study of the window of optimal consolidation conditions

JJS-2222	250°C/1.0 hr	355°C/1.0 hr	175	RT	2	✓
JJS-2224	250°C/1.0 hr	355°C/1.0 hr	175	177 (wet)	2	✓
JJS-2143	250°C/1.0 hr	355°C/1.0 hr	200	RT	3	✓
JJS-2217	250°C/1.0 hr	355°C/1.0 hr	200	177 (wet)	2	✓

(III) Study of post cure

	Molding Condition		Post Cure	OHC measurement		
	B-stage	Consolidation	Condition	Test T (°C)	No specimen	
JJS-2188	250°C/1 hr	371°C/3hr/200Psi	---	RT	3	✓
JJS-2204	250°C/1 hr	371°C/3hr/200Psi	---	177 (wet)	2	✓
JJS-2209	250°C/1 hr	371°C/3hr/175Psi	---	RT	2	✓
JJS-2230	250°C/1 hr	371°C/3hr/175Psi	---	177 (wet)	3	✓
JJS-2211	250°C/1 hr	355°C/1hr/200Psi	371°C/2 hrs	RT	2	✓
JJS-2212	250°C/1 hr	355°C/1hr/200Psi	371°C/2 hrs	177 (wet)	2	✓

JJS-2207	250°C/1 hr	355°C/1hr/200Psi	---	177 (wet)	2	✓

Open Hole Compression Test Results
IM7/LARC-PETI-5
$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$
Room Temperature

PANEL NUMBER	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)
JJS-2173	1	48.4
	2	50.7
	3	52.3
	AVERAGE	50.5
	STD.DEV.	2.0
	CV%	4
JJS-2227	1	53.7
	2	57.0
	AVERAGE	55.4
	STD.DEV.	2.3
	CV%	4
JJS-2222	1	56.0
	2	52.2
	AVERAGE	54.1
	STD.DEV.	2.7
	CV%	5
JJS-2143	1	52.9
	2	53.7
	3	52.1
	AVERAGE	52.9
	STD.DEV.	0.8
	CV%	1
JJS-2188	1	47.8
	2	50.0
	3	51.1
	AVERAGE	49.6
	STD.DEV.	1.7
	CV%	3

Open Hole Compression Test Results
IM7/LARC-PETI-5
$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$
Room Temperature

PANEL NUMBER	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)
JJS-2209	1	52.5
	2	55.9
	AVERAGE	54.2
	STD.DEV.	1.7
	CV%	3
JJS-2211	1	53.3
	2	53.0
	AVERAGE	53.1
	STD.DEV.	0.2
	CV%	0.4

Open Hole Compression Test Results
IM7/LARC-PETI-5
$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$
177°C*

PANEL NUMBER	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)	WEIGHT GAIN AT TEST (percent)	WEIGHT GAIN AFTER TEST (percent)
JJS-2229	1	41.6	0.61	0.52
	2	38.1	0.59	0.54
	3	39.0	0.59	0.53
	AVERAGE	**39.6**		
	STD.DEV.	1.8		
	CV%	4.5		
JJS-2224	1	33.1	0.68	0.51
	2	36.8	0.49	0.43
	3	28.7	0..68	0.30
	AVERAGE	**32.9**		
	STD.DEV.	4.1		
	CV%	12.5		
JJS-2217	1	36.4	0.56	0.51
	2	37.7	0.60	0.52
	AVERAGE	**37.1**		
	STD.DEV.	0.9		
	CV%	2.4		
JJS-2204	1	37.8	0.70	0.57
	2	39.3	0.67	0.59
	AVERAGE	**38.6**		
	STD.DEV.	1.1		
	CV%	2.8		

*Preconditioned 51 days at 71°C and 98%RH

Open Hole Compression Test Results
IM7/LARC-PETI-5
$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$
177°C*

PANEL NUMBER	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)	WEIGHT GAIN AT TEST (percent)	WEIGHT GAIN AFTER TEST (percent)
JJS-2230	1	32.7	0.64	0.57
	2	35.5	0.61	0.53
	3	36.8	0.63	0.54
	AVERAGE	**35.0**		
	STD.DEV.	2.1		
	CV%	6.0		
JJS-2212	1	37.0	0.56	0.51
	2	38.1	0.60	0.52
	AVERAGE	**37.6**		
	STD.DEV.	0.8		
	CV%	2.1		
JJS-2207	1	35.2	0.56	0.50
	2	35.2	0.57	0.52
	AVERAGE	**35.2**		
	STD.DEV.	0.0		
	CV%	0.0		

*Preconditioned 51 days at 71°C and 98%RH

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Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping 7 - 3.5"x3.5" OHC panels to you. This lot is designated as OHC measurement (III).

Panel IDs, lay-up orientation, required test temperatures and number of specimen required from each panel are summarized in the attached table. Please use the previously specified conditions to pre-treat specimens for the 177°C (wet) measurements.

OHC specimen is 3" x 1" with 0° in 3" dimension. Please check the fiber orientation in the specimen after cutting.

We would like to have the RT values first, and elevated temperature properties as soon as you can deliver later. If you have any questions, please call me.

Best regards.

Measurements of OHC strength (III)

All panels are IM7/LARC™-PETI-5, 3" x 3" - $[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_S$

(I) Study of the shelf life

Panel ID	Molding Cycle			OHC Measurement		
	B-stage step	Consolidation step	Pressure (psi)	Test T (°C)	No. speci.	Stre., Ksi
JJS-2276	250°C/1.0 hr	371°C/1.0 hr	200	RT	3	
JJS-2277	250°C/1.0 hr	371°C/1.0 hr	200	177 (wet)	3	

(II) Study of the window of optimal consolidation conditions

JJS-2278	250°C/1.0 hr	371°C/1.0 hr	100	RT	3	
JJS-2284	250°C/1.0 hr	350°C/1.0 hr	150	RT	3	
JJS-2281	250°C/1.0 hr	350°C/1.0 hr	175	RT	3	
JJS-2182	250°C/1.0 hr	350°C/1.0 hr	200	RT	3	
JJS-2283	250°C/1.0 hr	340°C/1.0 hr	200	RT	3	

Open Hole Compression Test Results
IM7/LARC-PETI-5
$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$
177°C*

PANEL NUMBER	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)	WEIGHT GAIN AT TEST (percent)	WEIGHT GAIN AFTER TEST (percent)
JJS-2277	1	41.2	0.41	0.35
	2	45.9	0.37	0.35
	3	42.3	0.37	0.29
	AVERAGE	**43.1**		
	STD.DEV.	2.4		
	CV%	6		

*Preconditioned 14 days at 71°C and 98%RH

Open Hole Compression Test Results
IM7/LARC-PETI-5 $[\pm 45/90/(0/\pm 45)_2/0]_s$
Room Temperature

PANEL NUMBER	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)
JJS-2281	1	57.4
	2	56.5
	3	58.6
	AVERAGE	**57.5**
	STD.DEV.	**1.1**
	CV%	**2**
JJS-2282	1	58.5
	2	58.3
	3	58.3
	AVERAGE	**58.4**
	STD.DEV.	**0.1**
	CV%	**0.2**
JJS-2283	1	41.7
	2	45.5
	3	46.9
	AVERAGE	**44.7**
	STD.DEV.	**2.7**
	CV%	**6**
JJS-2276	1	59.8
	2	56.7
	3	55.4
	AVERAGE	**57.3**
	STD.DEV.	**2.3**
	CV%	**4**
JJS-2278	1	64.3
	2	60.0
	3	61.0
	AVERAGE	**61.8**
	STD.DEV.	**2.2**
	CV%	**4**
JJS-2284	1	60.8
	2	51.6
	3	44.8
	AVERAGE	**52.4**
	STD.DEV.	**8.0**
	CV%	**15**

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Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

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FAX: (804) 864-8312

Remarks:

Scott:

I am shipping 2 - 3.5"x3.5" OHC panels to you. This lot is designated as OHC measurement (IV).

Panel ID	Prepreg history	Molding cycle	OHC test T (°C)	No. spec. needed
JJS2244	30 days storage	371°C/200 Psi	RT	3
JJS245	30 days storage	371°C/200 Psi	177 (wet)	3

Laminate lay-up: $[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$.

OHC specimen is 3" x 1" with 0° in 3" dimension. Please check the fiber orientation in the specimen after cutting.

Please use the previously specified conditions to pre-treat specimens for the 177°C (wet) measurements. Moisture treatment for 14 days max.

We would like to have the RT values first, and elevated temperature properties as soon as you can deliver later. If you have any questions, please call me.

Best regards.

Open Hole Compression Test Results

IM7/LARC-PETI-5

$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$

RT

PANEL NUMBER	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)
JJS-2244	1	66.5
	2	64.5
	3	65.5
	AVERAGE	**65.5**
	STD.DEV.	1.0
	CV%	2

Open Hole Compression Test Results

IM7/LARC-PETI-5

$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$

177°C*

PANEL NUMBER	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)	WEIGHT GAIN AT TEST (percent)	WEIGHT GAIN AFTER TEST (percent)
JJS-2245	1	45.1	0.37	0.28
	2	47.6	0.35	0.29
	3	46.2	0.37	0.31
	AVERAGE	**46.3**		
	STD.DEV.	1.3		
	CV%	3		

*Preconditioned 14 days at 71°C and 98%RH

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144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping 5 - 3.5"x3.5" OHC panels to you. This lot is designated as OHC measurement (V).

Panel ID	Molding cycle			OHC Measurements	
	B-stage	Consolidation	Pressure	Test T (°C)	No. Spec. Needed
JJS-2344	250°C/1 hr	371°C/1 hr	100	177	3
JJS-2345	250°C/1 hr	350°C/1 hr	150	177	3
JJS-2347	250°C/1 hr	350°C/1 hr	175	177	3
JJS-2349	250°C/1 hr	350°C/1 hr	200	177	3
JJS-2350	250°C/1 hr	340°C/1 hr	200	177	3

Laminate lay-up: $[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_S$.

OHC specimen is 3" x 1" with 0° in 3" dimension. Please check the fiber orientation in the specimen after cutting.

All tests shall be performed at 177°C (wet) condition. Please use the previously specified conditions to pre-treat specimens for the 177°C (wet) measurements. Moisture treatment for 14 days max.

We would like to have the RT values first, and elevated temperature properties as soon as you can deliver later. If you have any questions, please call me.

Best regards.

Open Hole Compression Test Results
IM7/LARC-PETI-5 (OHC V)
$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$
177°C*

PANEL NUMBER	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)	WEIGHT GAIN AT TEST (percent)	WEIGHT GAIN AFTER TEST (percent)
JJS-2349	1	38.6	0.32	0.26
	2	35.1	0.31	0.24
	3	35.8	0.28	0.11
	AVERAGE	**36.5**		
	STD.DEV.	1.8		
	CV%	5		

*Preconditioned 14 days at 71°C and 98%RH

Open Hole Compression Test Results
IM7/LARC-PETI-5 (OHC V)
$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$
177°C*

PANEL NUMBER	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)	WEIGHT GAIN AT TEST (percent)	WEIGHT GAIN AFTER TEST (percent)
JJS-2350	1	32.9	0.22	
	2	33.0	0.25	
	3	29.8	0.12	
	AVERAGE	**31.9**		
	STD.DEV.	1.8		
	CV%	6		

*Preconditioned 14 days at 71°C and 98%RH

Open Hole Compression Test Results

IM7/LARC-PETI-5 (OHC V)

$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$

177°C*

PANEL NUMBER	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)	WEIGHT GAIN AT TEST (percent)	WEIGHT GAIN AFTER TEST (percent)
JJS-2347	1	32.7	0.36	0.24
	2	33.3	0.36	0.28
	3	36.8	0.35	0.29
	AVERAGE	**34.3**		
	STD.DEV.	2.2		
	CV%	6		

*Preconditioned 14 days at 71°C and 98%RH

Open Hole Compression Test Results
IM7/LARC-PETI-5 (OHC V)
$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$
177°C*

PANEL NUMBER	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)	WEIGHT GAIN AT TEST (percent)	WEIGHT GAIN AFTER TEST (percent)
JJS-2344	1	44.5	0.48	0.41
	2	43.2	0.50	0.47
	3	42.4	0.48	0.41
	AVERAGE	**43.4**		
	STD.DEV.	1.0		
	CV%	2		

*Preconditioned 14 days at 71°C and 98%RH

Open Hole Compression Test Results
IM7/LARC-PETI-5 (OHC V)
$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$
177°C*

PANEL NUMBER	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)	WEIGHT GAIN AT TEST (percent)	WEIGHT GAIN AFTER TEST (percent)
JJS-2345	1	37.1	0.37	0.28
	2	35.1	0.35	0.29
	3	33.6	0.43	0.23
	AVERAGE	**35.3**		
	STD.DEV.	1.7		
	CV%	5		

*Preconditioned 14 days at 71°C and 98%RH

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 11/21/95

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping 2 - 3.5"x3.5" - $[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_S$ OHC panels to you. This lot is designated as LARC™-8515 (I).

LARC™-8515 (I)

Panel ID	Molding cycle			OHC Measurements	
	B-stage	Consolidation	Pressure	Test T (°C)	No. Spec. Needed
JJS-2365	225°C/1 hr	380°C/1 hr	200	RT	3
JJS-2366	225°C/1 hr	380°C/1 hr	200	177 wet	3

OHC specimen is 3" x 1" with 0° in 3" dimension. Please check the fiber orientation in the specimen after cutting.

Please use the previously specified conditions to pre-treat specimens for the 177°C (wet) measurements. Moisture treatment for 14 days max.

We would like to have the RT values first, and elevated temperature properties as soon as you can deliver later. If you have any questions, please call me.

Best regards.

Open Hole Compression Test Results
LARC™-8515 (I)
$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$
RT

PANEL NUMBER	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)
JJS-2365	1	55.4
	2	60.3
	3	50.6
	AVERAGE	**55.4**
	STD.DEV.	4.8
	CV%	9

Open Hole Compression Test Results
LARC™-8515 (I)
$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$
177°C*

PANEL NUMBER	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)	WEIGHT GAIN AT TEST (percent)	WEIGHT GAIN AFTER TEST (percent)
JJS-2366	1	39.7	0.46	0.38
	2	39.9	0.47	0.41
	3	39.9	0.45	0.39
	AVERAGE	**39.8**		
	STD.DEV.	0.1		
	CV%	0.3		

*Preconditioned 14 days at 71°C and 98%RH

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 12/15/95

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping 4 - 1"x6" - $[0]_{24}$ fracture toughness specimens to you.
This lot is designated as LARC™-8515 (II).

LARC™-8515 (II)

Panel ID	Molding cycle			G_{IC} Measurements	
	B-stage	Consolidation	Pressure	Test T (°C)	No. Spec. Needed
JJS-2382	225°C/1 hr	380°C/1 hr	200	RT	4

There is a 1" x 0.0005" kapton film inserted in the mid-plan in each specimen.
If you have any questions, please call me.

Best regards.

Double Cantilever Beam Interlaminar Fracture Toughness Test Restuls
LARC™-8515 (5%)(II), Panel JJS-2382

	G_{IC} (kJ/m^2)						
	Crack Extension Individual Values						
Specimen No.	1	2	3	4	5	Specimen Average	Specimen Std.Dev.
1	2.275	1.431	1.386	1.075	1.416	1.515	0.449
2	1.899	1.080	1.209	1.114	1.099	1.280	0.349
3	1.360	1.536	1.381	1.645	1.505	1.485	0.117
4	1.284	1.405	1.543	1.990	1.470	1.538	0.270
					Overall	1.455	0.312

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 1/19/96

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping following composite specimens for testing at RT and 177°C:
This lot is designated as LARC™-8515 (III).

LARC™-8515 (III)

Panel ID	Mechanical test	Specimen No. at testing condition	
		RT	177°C
JJS-2360	IITRI strength & modulus	4	4
JJS-2363, 2364	0° tensile strength & modulus	4	4

IITRI testings at 177°C may be done by zone heating.
If you have any questions, please call me.

Best regards.

0° Tensile Test Results
LARC 8515 (III), JJS-2364
Room Temperature

Specimen Number	Strength (ksi)	Strain @ Failure* (percent)	Poisson's Ratio	Modulus (Msi)
1	335.0	1.4	0.32	23.4
2	363.3	1.4	0.32	23.2
3	388.9	1.5	0.34	23.2
4	343.3	1.6	0.36	20.9
AVERAGE	**357.6**	**1.5**	**0.34**	**22.7**
STD.DEV.	**24**	**0.1**	**0.02**	**1.2**
CV(%)	**7**	**6**	**6**	**5**

* All strain vaules are averages of back-to-back strain gage data.

0° Tensile Test Results
LARC 8515 (III), JJS-2363
177°C

Specimen Number	Strength (ksi)	Strain @ Failure* (percent)	Poisson's Ratio	Modulus (Msi)
1	315.5	1.4	0.34	22.1
2	321.5	1.4	0.31	22.6
3	267.5	1.2	0.34	23.3
4	273.0	1.3	0.38	24.3
AVERAGE	**294.4**	**1.3**	**0.34**	**23.1**
STD.DEV.	**28**	**0.1**	**0.03**	**1.0**
CV(%)	**10**	**8**	**9**	**4**

* All strain vaules are averages of back-to-back strain gage data.

IITRI Compression Test Results
LARC 8515 (III), JJS-2360
Room Temperature

Specimen Number	Strength (ksi)	Strain @ Failure* (percent)	Poisson's Ratio	Modulus (Msi)
1	172.0	0.96	0.34	19.4
2	218.3	1.30	0.36	20.4
3	146.0	0.79	0.38	19.6
4	217.9	1.42	0.40	19.4
AVERAGE	**188.6**	**1.12**	**0.37**	**19.7**
STD.DEV.	**35.7**	**0.29**	**0.02**	**0.5**
CV(%)	**19**	**26**	**5**	**2**

* All strain vaules are averages of back-to-back strain gage data.

IITRI Compression Test Results
LARC 8515 (III), JJS-2360
177°C

Specimen Number	Strength (ksi)	Strain @ Failure* (percent)	Poisson's Ratio	Modulus (Msi)
5	111.5	0.54	0.35	21.4
6	151.0	0.74	0.31	23.0
7	178.5	0.99	0.36	19.6
8	181.0	0.75	0.38	23.0
AVERAGE	**155.5**	**0.76**	**0.35**	**21.8**
STD.DEV.	**32.3**	**0.18**	**0.03**	**1.6**
CV(%)	**21**	**24**	**8**	**7**

* All strain vaules are averages of back-to-back strain gage data.

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 3/13/96

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping six OHC specimens for you to test. The composite is Modified IM7/LARC™-PETI5. This lot is designated as Modified PETI5 (031396).

The specimen specifications and test requirements for each set of specimens are tabulated below:

Modified PETI5 (031396)

Specimen	Property required	Test condition
JJS-2449-1	OHC strength	RT
JJS-2449-2	OHC strength	RT
JJS-2449-3	OHC strength	350°F wet
JJS-2450-1	OHC strength	RT
JJS-2450-2	OHC strength	350°F wet
JJS-2450-3	OHC strength	350°F wet

Previously used humidity treatment procedure is required for preparing 350°F wet test specimens. This is a priority task and we appreciate your attentions. If you have any questions, please call.

Best regards.

Open Hole Compression Test Results

Modified IM7/LARC™-PETI-5 (031396)
$[\pm 45/90/(0/\pm 45)_2/0]_s$
Room Temperature

Panel Number	Replicate Number	Compressive Strength (psi)
JJS-2449	1	61.5
JJS-2449	2	62.7
JJS-2450	1	61.7
	Average	**62.0**
	Std.Dev.	**0.6**
	CV%	**1**

Modified IM7/LARC™-PETI-5 (031396)
$[\pm 45/90/(0/\pm 45)_2/0]_s$
177°C

Panel Number	Replicate Number	Compressive Strength (psi)
JJS-2449	3	51.4
JJS-2450	2	49.8
JJS-2450	3	46.6
	Average	**49.3**
	Std.Dev.	**2.4**
	CV%	**5**

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 3/11/96

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping OHC and in-plane shear specimens for you to test. The composite is IM7/LARC™-8515 (4.5% offset). This lot is designated as LARC™-8515 (031096).

These specimens have been treated by five different solvents: MEK, Toluene, Hydraulic fluid, Jet fuel and Hot water, respectively. Including the control specimens, there are total six sets of OHC and in-plane shear specimens. The specimen specifications and test requirements for each set of specimens are tabulated below:

LARC™-8515 (031096)

Test	Specimen lay-up & size	No. specimen treated by each solvent	Property required	Test condition
in-plane shear	$[\pm 45]_{2s}$ - 0.5" x 9"	5	G_{12} at RT (BSS-7320)	RT
OHC	$[45/0/-45/90]_{3s}$ - 3" x 1"	3	OHC strength (Northrop)	350°F dry

If you have any questions, please call.

Best regards.

Open Hole Compression Test Results
Solvent Treated IM7/LARC™-8515 (4.5% offset), Lot No. 031096
Room Temperature

CONDITIONING SOLVENT	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)
Control	2	33.0
	7	35.1
	55	32.6
	Average	**33.6**
	Std. Dev.	**1.3**
	CV (%)	**4**
Jet Fuel	12	35.0
	33	40.2
	1010	33.5
	Average	**36.2**
	Std. Dev.	**3.5**
	CV (%)	**10**
Hot Water	8	34.6
	22	36.4
	66	35.5
	Average	**35.5**
	Std. Dev.	**0.9**
	CV (%)	**2**
Toluene	3	34.6
	9	37.5
	44	38.2
	Average	**36.8**
	Std. Dev.	**1.9**
	CV (%)	**5**

COMPOSITE MATERIALS RESEARCH GROUP
4/25/96

Open Hole Compression Test Results
Solvent Treated IM7/LARC™-8515 (4.5% offset), Lot No. 031096
Room Temperature

CONDITIONING SOLVENT	REPLICATE NUMBER	COMPRESSIVE STRENGTH (psi)
Hydraulic Fluid	6	34.3
	10	34.3
	77	37.0
	Average	**35.2**
	Std. Dev.	**1.6**
	CV (%)	**4**
MEK	1	35.2
	4	35.2
	99	33.2
	Average	**34.5**
	Std. Dev.	**1.1**
	CV (%)	**3**

±45 In-Plane Shear Modulus

Solvent Treated IM7/LARC™-8515 (4.5% offset), Lot No. 031096

CONDITIONING SOLVENTS	SAMPLE NO.	SHEAR MODULUS G_{12} (Msi)
Control	A4	0.74
	A10	0.79
	A15	0.75
	B6	0.76
	B17	0.80
	Average	**0.77**
	Std. Dev.	**0.02**
	CV (%)	**3**
Hydraulic Fluid	A6	0.91
	A17	0.68
	B2	0.68
	B8	1.01
	B13	0.95
	Average	**0.85**
	Std. Dev.	**0.15**
	CV (%)	**18**
Hot Water	A12	0.84
	A19	0.74
	B4	0.88
	B10	0.83
	B15	0.83
	Average	**0.82**
	Std. Dev.	**0.05**
	CV (%)	**6**
Jet Fuel	A7	0.78
	A18	0.74
	B3	0.84
	B9	0.81
	B14	0.86
	Average	**0.81**
	Std. Dev.	**0.05**
	CV (%)	**6**

±45 In-Plane Shear Modulus

Solvent Treated IM7/LARC™-8515 (4.5% offset), Lot No. 031096

CONDITIONING SOLVENTS	SAMPLE NO.	SHEAR MODULUS G_{12} (MSI)
Toluene	A2	0.59
	A8	0.80
	A13	0.91
	B12	0.84
	B19	0.75
	Average	**0.78**
	Std. Dev.	**0.12**
	CV (%)	**15**
MEK	A3	0.81
	A9	0.88
	A14	0.80
	B7	0.89
	B18	0.72
	Average	**0.82**
	Std. Dev.	**0.07**
	CV (%)	**8**

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 3/14/96

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping following composite specimens for testing at RT and 177°C:
This lot is designated as Modified PETI5-031496

Modified PETI5-031496

Panel ID	Mechanical test	No. specimen testing condition	
		RT	177°C
JJS-2455	IITRI strength & modulus	5	4
JJS-2442	0° tensile strength & modulus	0	5

IITRI testinhs at 177°C may be done by zone heating.
If you have any questions, please call me.
This is a priority job. We would appreciate your immediate attention. We also would like to receive RT values as soon as you obtain them.

Best regards.

IITRI Compression Test Results
Modified IM7/LARC™-PETI5 (031496), JJS-2455
Room Temperature

Specimen Number	Strength (ksi)	Strain @ Failure* (percent)	Modulus# (Msi)
1	193	1.09	19.8
2	224	1.29	20.6
3	184	1.06	19.3
4	174	1.05	18.7
5	181	1.04	19.8
Average	**191**	**1.11**	**19.6**
Std. Dev.	**20**	**0.10**	**0.7**
%CV	**10**	**9**	**4**

* All strain values are averages of back-to-back strain gage data.
# Modulus determined over the strain range of 1000 to 3000με.

IITRI Compression Test Results
Modified IM7/LARC™-PETI5 (031496), JJS-2455
177°C

Specimen Number	Strength (ksi)	Strain @ Failure* (percent)	Modulus# (Msi)
1	177.8	0.86	22.4
2	187.0	0.96	20.8
3	169.0	0.84	20.2
4	167.2	0.77	20.8
Average	**175.2**	**0.86**	**21.0**
Std. Dev.	**9.1**	**0.08**	**0.9**
%CV	**5**	**9**	**4**

* All strain values are averages of back-to-back strain gage data.
# Modulus determined over the strain range of 1000 to 3000με.

0° Tensile Test Results
Modified PETI5-031496, JJS-2442
177°C

Specimen Number	Strength (ksi)	Strain @ Failure* (percent)	Poisson's Ratio	Modulus (Msi)
1	300.9	1.29	0.34	22.4
2	315.4	1.35	0.36	22.2
3	318.5	1.42	0.30	21.9
4	340.1	1.42	0.36	23.9
5	331.1	1.33	0.33	23.4
AVERAGE	**321.2**	**1.36**	**0.34**	**22.8**
STD.DEV.	**15.1**	**0.06**	**0.02**	**0.8**
CV(%)	**5**	**4**	**6**	**3**

* All strain vaules are averages of back-to-back strain gage data.

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 3/20/96

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping following composite specimens for testing at RT:

Modified PETI5-032096

Panel ID	Mechanical test	No. specimen testing condition
		RT
JJS-2444	0° tensile strength & modulus	5

LARC-IAX3-032096

Panel ID	Mechanical test	No. specimen testing condition
		RT
JJS-2453	IITRI strength & modulus	6

If you have any questions, please call me.

Lot **Modified PETI5-032096** is a priority job. We would appreciate your immediate attention.

Best regards.

0° Tensile Test Results
Modified PETI5-032096, JJS-2444
Room Temperature

Specimen Number	Strength (ksi)	Strain @ Failure* (percent)	Poisson's Ratio	Modulus (Msi)
1	341.8	1.35	0.34	23.1
2	304.0	1.24	0.28	22.4
3	357.3	1.43	0.32	22.8
4	334.3	1.33	0.23	22.8
5	304.6	1.33	0.33	21.2
AVERAGE	**328.5**	**1.34**	**0.30**	**22.5**
STD.DEV.	**23.4**	**0.07**	**0.04**	**0.7**
CV(%)	**7**	**5**	**13**	**3**

* All strain vaules are averages of back-to-back strain gage data.

IITRI Compression Test Results
LARC-IAX3-032096 JJS-2453
Room Temperature

Specimen Number	Strength (ksi)	Strain @ Failure* (percent)	Modulus# (Msi)
1	185.1	0.91	21.7
2	161.3	0.75	22.4
3	138.5	0.75	21.2
4	121.7	0.59	20.8
5	143.9	0.70	21.3
Average	**150.1**	**0.74**	**21.5**
Std. Dev.	**24.1**	**0.11**	**0.6**
%CV	**16**	**15**	**3**

* All strain values are averages of back-to-back strain gage data.
# Modulus determined over the strain range of 1000 to 3000με.

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 5/13/96

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071
TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666
TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping 15 OHC specimens for you to test. The composites are Modified IM7/LARC™-PETI5 and IAX3. Lot designations are shown below.

Specimen	Property required	Test condition	Note
Modified PETI5 (051396)			
JJS-2493-1	OHC strength	RT	TM-155 + TM-157
JJS-2493-2	OHC strength	350°F wet	TM-155 + TM-157
JJS-2498-1	OHC strength	350°F wet	TM-155 + TM-157
JJS-2511-1	OHC strength	RT	TM-155 + TM-157
JJS-2511-2	OHC strength	350°F wet	TM-155 + TM-157
JJS-2503-1	OHC strength	RT	TM-155 low resin
JJS-2503-2	OHC strength	350°F wet	TM-155 low resin
JJS-2508-1	OHC strength	RT	TM-155 low resin
JJS-2508-2	OHC strength	350°F wet	TM-155 low resin
IAX3 (051396)			
JJS-2475-1	OHC strength	RT	5% GBL
JJS-2475-2	OHC strength	RT	5% GBL
JJS-2475-3	OHC strength	350°F wet	5% GBL
JJS-2477-1	OHC strength	RT	5% GBL
JJS-2477-2	OHC strength	350°F wet	5% GBL
JJS-2477-3	OHC strength	350°F wet	5% GBL

Previously used humidity treatment procedure is required for preparing 350°F wet test specimens. Please check orientation of each specimen, drill a 1/4" hole and perform the test. This is a priority task and we appreciate your immediate attentions. If you have any questions, please call.

Open Hole Compression Test Results

Modified IM7/LARC™-PETI-5 (051396)-
$[\pm 45/90/(0/\pm 45)_2/0]_s$
Room Temperature

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
JJS-2493-1	0.135	60.3
JJS-2511-1	0.145	58.5
JJS-2508-1	0.151	60.4

IAX3 (051396)
$[\pm 45/90/(0/\pm 45)_2/0]_s$
Room Temperature

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
JJS-2475-1	0.125	60.6
JJS-2475-2	0.125	57.6
JJS-2477-1	0.125	57.1

Open Hole Compression Test Results

Modified IAX3 (051396)

$[\pm 45/90/(0/\pm 45)_2/0]_s$

177°C

Preconditioned at 71°C, 98% RH for 14 days

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
JJS-2475-3	0.125	36.3
JJS-2477-2	0.125	33.9
JJS-2477-3	0.126	26.8

Open Hole Compression Test Results

Modified PETI-5 (051396)

$[\pm 45/90/(0/\pm 45)_2/0]_s$

177°C

Preconditioned at 71°C, 98% RH for 14 days

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
JJS-2493-2	0.135	39.8
JJS-2498-1	0.137	37.6
JJS-2511-2	0.147	41.0
JJS-2508-2	0.151	40.0

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 6/7/96

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping 12 OHC specimens for you to test. Lot designations are shown below.

PETI5-A1-2 PA (060796)			
Specimen	Property required	Test condition	Note
JJS-2519-1	OHC strength	RT	TM-168
JJS-2519-2	OHC strength	RT	TM-168
JJS-2521-1	OHC strength	RT	TM-168
JJS-2521-2	OHC strength	350°F wet	TM-168
JJS-2521-3	OHC strength	350°F wet	TM-168
JJS-2519-3	OHC strength	350°F wet	TM-168
PETI5-A1-2 PAA (060796)			
JJS-2554-1	OHC strength	RT	TM-172
JJS-2554-2	OHC strength	RT	TM-172
JJS-2558-1	OHC strength	RT	TM-172
JJS-2558-2	OHC strength	350°F wet	TM-172
JJS-2558-3	OHC strength	350°F wet	TM-172
JJS-2554-3	OHC strength	350°F wet	TM-172

Previously used humidity treatment procedure is required for preparing 350°F wet test specimens. Please check orientation of each specimen, drill a 1/4" hole and perform the test. This is a priority task and we appreciate your immediate attentions. If you have any questions, please call.

Best regards.

Open Hole Compression Test Results

PETI5 -A1-2-PA (060796)

$[\pm 45/90/(0/\pm 45)_2/0]_s$

177°C

Preconditioned at 71°C, 98% RH for 14 days

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
JJS-2519-3	0.141	36.0
JJS-2521-2	0.135	44.1
JJS-2521-3	0.135	40.6

Open Hole Compression Test Results

PETI5-A1-2-PAA (060796)

$[\pm 45/90/(0/\pm 45)_2/0]_s$

177°C

Preconditioned at 71°C, 98% RH for 14 days

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
JJS-2554-3	0.129	43.2
JJS-2558-2	0.132	41.5
JJS-2558-3	0.131	44.3

Open Hole Compression Test Results

PETI5 -A1-2-PA (060796)

$[\pm 45/90/(0/\pm 45)_2/0]_s$

Room Temperature

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
JJS-2519-1	0.140	60.2
JJS-2519-2	0.139	60.1
JJS-2521-1	0.135	60.7

Open Hole Compression Test Results

PETI5-A1-2-PAA (060796)

$[\pm 45/90/(0/\pm 45)_2/0]_s$

Room Temperature

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
JJS-2554-1	0.131	58.5
JJS-2554-2	0.130	63.8
JJS-2558-1	0.131	61.5

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 7/11/96

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott: I am shipping 12 OHC specimens for you to test. Lot designations are shown below.

IAX3-4%NMP (071196)			
Specimen	Property required	Test condition	Note
JJS-2621-1	OHC strength	RT	TM-165
JJS-2621-2	OHC strength	RT	TM-165
JJS-2628-1	OHC strength	RT	TM-165
JJS-2621-3	OHC strength	350°F wet	TM-165
JJS-2628-2	OHC strength	350°F wet	TM-165
JJS-2628-3	OHC strength	350°F wet	TM-165
IAX3-5%NMP (071196)			
JJS-2613-1	OHC strength	RT	TM-166
JJS-2613-2	OHC strength	RT	TM-166
JJS-2614-1	OHC strength	RT	TM-166
JJS-2613-3	OHC strength	350°F wet	TM-166
JJS-2614-~~1~~ 3	OHC strength	350°F wet	TM-166
JJS-2614-2	OHC strength	350°F wet	TM-166

Previously used humidity treatment procedure is required for preparing 350°F wet test specimens. Please check orientation of each specimen, drill a 1/4" hole and perform the test. If you have any questions, please call.

I also include two CAI panels for you to test at RT. These panels have been impacted and instrumented. Panel designations are 8515-4.5%-071196.

Best regards.

Open Hole Compression Test Results

8515-4.5%-071196

$[\pm 45/90/(0/\pm 45)_2/0]_s$

Room Temperature

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
JJS-2613-1	0.125	57.1
JJS-2613-2	0.124	55.7
JJS-2614-1	0.129	54.3
JJS-2621-1	0.126	55.3
JJS-2621-2	0.125	55.4
JJS-2628-1	0.127	55.8

Open Hole Compression Test Results

8515-4.5%-071196

$[\pm 45/90/(0/\pm 45)_2/0]_s$

177°C

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
JJS-2613-3	0.123	*
JJS-2614-2	0.127	37.5
JJS-2614-3	0.126	32.9
JJS-2621-3	0.124	33.0
JJS-2628-2	0.126	37.4
JJS-2628-3	0.125	30.0

* Specimen broke while loading in test frame.

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 7/23/96

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping following composite specimens for IITRI compression tests at RT and 177°C dry:

LARC-IAX3-072396

Panel ID	Mechanical test	Specimen ID	
		RT	177°C
JJS-2630	IITRI strength & modulus	1, 3, 5, 7, 9	2, 4, 6, 8, 10

You may want to use zone heating for 177°C measurement as you did before. If you have any questions, please call me.

Best regards.

IITRI Compression Test Results
IAX3-(072396)
177°C

Specimen Number	Stress (ksi)	Strain @ Failure (percent)	Modulus (Msi)
2630-2	158	0.80	20.7
2630-4	*		
2630-6	182	0.89	20.7
2630-8	167	0.92	20.2
Average	**169**	**0.87**	**20.5**
Std.dev.	**12**	**0.06**	**0.3**
CV (%)	**7**	**7**	**1**

* Premature failure due to temperature spike.

IITRI Compression Test Results
IAX3-(072396)
Room Temperature

Specimen Number	Stress (ksi)	Strain @ Failure (percent)	Modulus (Msi)
2630-1	197	0.98	21.6
2630-3	190	1.00	20.6
2630-5	189	1.03	20.4
2630-7	198	1.10	20.6
2630-9	192	1.00	21.0
Average	**193**	**1.02**	**20.8**
Std.dev.	**4.1**	**0.05**	**0.5**
CV (%)	**2**	**5**	**2**

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 7/23/96

No. Pages: Lead + 1

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott: I am shipping 30 0° tensile specimens for you to test. Lot designations are shown below.

Specimen	Property required	Test condition	Note
IAX3-4%NMP (072396)			
JJS-2629-1	0° tensile strength & modulus	RT	TM-165
JJS-2629-2	0° tensile strength & modulus	RT	TM-165
JJS-2629-3	0° tensile strength & modulus	RT	TM-165
JJS-2635-1	0° tensile strength & modulus	RT	TM-165
JJS-2635-2	0° tensile strength & modulus	RT	TM-165
JJS-2629-4	0° tensile strength & modulus	350°F	TM-165
JJS-2629-5	0° tensile strength & modulus	350°F	TM-165
JJS-2635-3	0° tensile strength & modulus	350°F	TM-165
JJS-2635-4	0° tensile strength & modulus	350°F	TM-165
JJS-2635-5	0° tensile strength & modulus	350°F	TM-165
IAX3-5%NMP (072396)			
JJS-2615-1	0° tensile strength & modulus	RT	TM-166
JJS-2615-2	0° tensile strength & modulus	RT	TM-166
JJS-2615-3	0° tensile strength & modulus	RT	TM-166
JJS-2616-1	0° tensile strength & modulus	RT	TM-166
JJS-2616-2	0° tensile strength & modulus	RT	TM-166
JJS-2615-4	0° tensile strength & modulus	350°F	TM-166
JJS-2615-5	0° tensile strength & modulus	350°F	TM-166
JJS-2616-3	0° tensile strength & modulus	350°F	TM-166
JJS-2616-4	0° tensile strength & modulus	350°F	TM-166
JJS-2616-5	0° tensile strength & modulus	350°F	TM-166
IAX3-5%GBL (072396)			
JJS-2481-1	0° tensile strength & modulus	RT	TM-151
JJS-2481-2	0° tensile strength & modulus	RT	TM-151
JJS-2481-3	0° tensile strength & modulus	RT	TM-151
JJS-2482-1	0° tensile strength & modulus	RT	TM-151

GR & SCI. TEL:804-766-9601 Jul 24'96 8:29 No.002 P.02

JJS-2482-2	0° tensile strength & modulus	RT	TM-151
JJS-2481-4	0° tensile strength & modulus	350°F	TM-151
JJS-2481-5	0° tensile strength & modulus	350°F	TM-151
JJS-2482-3	0° tensile strength & modulus	350°F	TM-151
JJS-2482-4	0° tensile strength & modulus	350°F	TM-151
JJS-2482-5	0° tensile strength & modulus	350°F	TM-151

Best regards.

Tensile Test Results for NASA
IAX3-5% GBC (072396)
Room Temperature

Specimen Number	Stress (ksi)	Modulus (Msi)	Strain @ Failure (%)
2481-1	398.3	23.7	1.9
2481-2	373.2	23.8	1.4
2481-3	349.1	23.6	1.0
Average	373.5	23.7	1.4
Std. Dev.	24.6	0.1	0.4
CV (%)	7	0.4	28
2482-1	338.5	22.4	1.5
2482-2	362.7	23.6	0.9
Average	350.6	23.0	1.2
Std. Dev.	17.1	0.8	0.4
CV (%)	5	3	33
2629-1	423.1	25.1	1.6
2629-2	409.8	24.6	1.6
2629-3	405.8	25.0	1.5
Average	412.9	24.9	1.6
Std. Dev.	9.0	0.3	0.06
CV (%)	2	1	4
2635-1	398.9	25.2	1.5
2635-2	362.4	24.7	1.5
Average	380.6	24.9	1.5
Std. Dev.	25.8	0.4	0
CV (%)	7	2	0
2615-1	338.9	22.7	1.4
2615-2	350.0	22.6	1.5
2615-3	347.5	24.7	1.4
Average	345.5	23.3	1.4
Std. Dev.	5.8	1.2	0.1
CV (%)	2	5	7
2616-1	304.4	22.6	1.4
2616-2	328.4	22.3	1.2
Average	316.4	22.4	1.3
Std. Dev.	17.0	0.2	0.1
CV (%)	5	1	8

Tensile Test Results for NASA
IAX3-5% GBC (072396)
177°C

Specimen Number	Stress (ksi)	Modulus (Msi)	Strain @ Failure (%)
24814-4	353.2	23.6	1.4
2481-5	349.9	23.9	1.4
Average	351.6	23.7	1.4
Std. Dev.	2.3	0.2	0
CV (%)	1.0	1	0
2482-3	341.0	24.4	1.8
2482-4	325.8	23.5	1.3
2482-5	362.6	23.6	1.5
Average	343.1	23.8	1.5
Std. Dev.	18.5	0.5	0.2
CV (%)	5	2	13
2629-4	379.3	24.6	1.5
2629-5	402.4	25.7	1.5
Average	390.8	25.2	1.5
Std. Dev.	16.3	0.8	0
CV (%)	4	3	0
2635-3	353.9	25.2	1.3
2635-4	346.4	24.8	1.3
2635-5	337.2	25.0	1.3
Average	345.8	25.0	1.3
Std. Dev.	8	0.2	0
CV (%)	2	1	0
2615-4	306.5	24.1	1.3
2615-5	290.9	22.6	1.3
Average	298.7	23.4	1.3
Std. Dev.	11.0	1	0
CV (%)	4	4	0
2616-3	322.8	22.3	1.5
2616-4	339.7	25.9	1.3
2616-5	340.0	23.9	1.3
Average	334.2	24.0	1.4
Std. Dev.	9.8	1.8	0.1
CV (%)	3	8	7

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 7/30/96

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312
804 864-5541

Remarks:

Scott:

I am shipping 10 OHC specimens for you to test. Lot designations are shown below.

PETI5-Aging (073096)			
Specimen	Property required	Test condition	Note
AU-2473-1	OHC strength	RT	Control
AU-2473-2	OHC strength	RT	Control
AU-2473-3	OHC strength	RT	Control
AU-2504-1	OHC strength	RT	Control
AU-2504-2	OHC strength	RT	Control
AU-2473-4	OHC strength	350°F wet	Control
AU-2473-5	OHC strength	350°F wet	Control
AU-2504-3	OHC strength	350°F wet	Control
AU-2504-4	OHC strength	350°F wet	Control
AU-2504-5	OHC strength	350°F wet	Control

Previously used humidity treatment procedure is required for preparing 350°F wet test specimens. Please check orientation of each specimen: $[+45/0/-45/90]_{3s}$, drill a 1/4" hole and perform the test. If you have any questions, please call.

Best regards.

Open Hole Compression Test Results

PETI5-Aging (073096)

$[+45/0/-45/90]_{3s}$

Room Temperature

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
AU-2473-1	0.130	51.1
AU-2473-2	0.132	49.8
AU-2473-3	0.131	50.1
AU-2504-1	0.127	51.9
AU-2504-2	0.134	48.6

Open Hole Compression Test Results

PETI5-Aging (073096)

$[+45/0/-45/90]_{3s}$

177°C

Preconditioned at 71°C, 98% RH for 14 days

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
AU-2473-4	0.130	38.2
AU-2473-5	0.125	33.4
AU-2504-3	0.135	27.9
AU-2504-4	0.134	29.5
AU-2504-5	0.130	31.1

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 9/16/96

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
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FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping 10 OHC specimens for you to test. Lot designations are shown below.

PETI5-1000 (091696)			
Specimen	Property required	Test condition	Note
AU-2473-11	OHC strength	RT	1000 hrs ar 350°F
AU-2473-12	OHC strength	RT	
AU-2473-14	OHC strength	RT	
AU-2504-10	OHC strength	RT	
AU-2504-11	OHC strength	RT	
AU-2473-15	OHC strength	350°F wet	
AU-2473-18	OHC strength	350°F wet	
AU-2504-14	OHC strength	350°F wet	
AU-2504-15	OHC strength	350°F wet	
AU-2504-18	OHC strength	350°F wet	

Previously used humidity treatment procedure is required for preparing 350°F wet test specimens. Please check orientation of each specimen: $[+45/0/-45/90]_{3s}$, drill a 1/4" hole and perform the test. If you have any questions, please call.

Best regards.

Open Hole Compression Test Results

PETI5-1000 (091696)

$[+45/0/-45/90]_{3s}$

Room Temperature

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
2473-11	0.125	50.7
2473-12	0.125	53.3
2473-14	0.130	56.5
2504-10	0.129	55.0
2504-11	0.130	53.2

Open Hole Compression Test Results

PETI5-1000 (091696)

$[+45/0/-45/90]_{3s}$

177°C

Preconditioned at 71°C, 98% RH for 27 days

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
2473-15	0.130	30.8
2473-18	0.130	30.8
2504-14	0.127	32.5
2504-15	0.132	30.6
2504-18	0.131	36.2

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 11/14/96

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
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FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping following composite specimens for IITRI compression, 0° tensile and OHC tests.

LARC™-SI-111496

Mechanical test	Specimen ID	
	RT	177°C (wet)
OHC	GD-1771-1, 2 GD-1772-1	GD-1771-3 GD-1772-2, 3

6 x 120.00
720.00

Mechanical test	Specimen ID	
	RT	177°C (dry)
IITRI	5 specimen as labeled	5 specimen as labeled
0° tensile	5 specimen as labeled	5 specimen as labeled

180.00 x 5 = 900
105.00 x 5 = 525
136.00 x 5 = 680
211.00 x 5 = 1055

3100.00

OHC specimen need a 0.25" holes in center. Also 177°C (wet) specimen require humidity conditioning for a maximun of 2 weeks.

Zone heating for IITRI compression test at 177°C (dry) may be used.

If you have any questions, please call me.

Best regards.

FAXED 11/14/96 yk

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 11/15/96

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping you a CAI panel for measurement:

- Composite: IM7/LARC™-SI (3% offset).
- Panel: $[-45/0/45/90]_{4s}$ - 6" x 4".
- Impacting needed: Boeing D6-55587 and BSS 7260. Impacted with a 0.625" diameter spherical-tip indenter to yield a normalized impact energy of 1500 in-lb per inch of specimen thickness.
- Testing: Measure CAI strength at RT.

If you have any questions, please call me.

Best regards.

IITRI Compression Test Results
NASA SI(TM-180)
Room Temperature

SPECIMEN NUMBER	STRESS (ksi)	MODULUS (Msi)	POISSONS RATIO
1	133	19.8	0.39
3	141	21.6	0.37
5	154	21.7	0.37
7	148	22.2	0.33
9	176	22.4	0.36
Average	150	21.5	0.36
Std. Dev.	16.3	1.0	0.02
%CV	11	4	5

IITRI Compression Test Results
NASA SI(TM-180)
177°C

SPECIMEN NUMBER	STRESS (ksi)	MODULUS (Msi)	POISSONS RATIO
2	129	21.6	0.40
4	128	21.4	0.43
6	119	25.7	0.47
8	125	22.3	0.42
10	115	27.8	0.44
Average	123	23.8	0.43
Std. Dev.	6	2.8	0.02
%CV	5	12	5

Compression-After-Impact Test Results
IM7/LARC-SI (3% offset)
RT

SPECIMEN	STRESS (ksi)	IMPACT ENERGY (in-lb/in thickness)	FAILURE MODE
GD-1776	45.8	1629	End Crush with failure away from impact zone

Tensile Test Results for NASA
SI (TM-180)
Room Temperature

Specimen Number	Stress (ksi)	Modulus (Msi)		Poisson's Ratio	
		Front Gage	Back Gage	Front Gage	Back Gage
GD1768					
1	403	27.2	27.2	0.33	0.31
3	378	25.8	25.8	0.37	0.34
5	383*	25.9	25.7	0.31	0.31
Average	388	26.3		0.33	
Std. Dev.	13	0.7		0.02	
CV (%)	3	3		6	
GD1767					
2	387	25.8	25.4	0.37	0.38
4	417*	26.9	26.7	0.35	0.32
Average	402	26.2		0.36	
Std. Dev.	21	0.7		0.03	
CV (%)	5	3		8	

* Estimated value due to data truncation during testing.

Tensile Test Results for NASA
SI (TM-180)
177°C

Specimen Number	Stress (ksi)	Modulus (Msi)		Poisson's Ratio	
		Front Gage	Back Gage	Front Gage	Back Gage
GD1768					
2	393	30.0	31.7	0.46*	0.33
4	353	28.9	28.7	0.38	0.38
Average	373	29.8		0.36	
Std. Dev.	28	1.4		0.03	
CV (%)	8	5		8	
GD1767					
1	385	31.4	29.8	0.29	0.30
3	375	29.6	#	0.32	#
5	384	#	28.4	#	0.31
Average	381	29.8		0.30	
Std. Dev.	5.5	1.2		0.01	
CV (%)	1	4		3	

*Not included in average due to non-linearity of strain vs strain curve.
#Only one active gage during testing.

Open Hole Compression Test Results

LARC-SI-111496

$[+45/0/-45/90]_{3s}$

Room Temperature

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
GD1771-1	0.144	45.6
GD1771-2	0.145	44.0
GD1772-1	0.144	44.8

Open Hole Compression Test Results

LARC-SI-111496

177°C

Preconditioned at 71°C, 98% RH for 27 days

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
GD1771-3	0.143	30.4
GD1772-2	0.143	32.3
GD17723	0.143	27.8

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 11/27/96

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping you a 5 specimens for DCB measurement at RT. The composite is LARC-SI/IM7 (specimen ID GD-1778). These specimens have a 1" Kapton film insert in the midplane at one end edge. Layup is $[0]_{24}$.

If you have any questions, please call me.

Best regards.

DCB TEST RESULTS FOR LARC-SI/IM7, PANEL GD-1778

Specimen		Extension 1	Extension 2	Extension 3	Extension 4	Extension 5			
GD1778-1									
Width(in)	1.004								
Initial Crack (in)	0.35								
Crack Length(1)		0.748	1.284	1.969	2.55	3.108			
Crack Length(2)		0.664	1.339	1.982	2.82	3.267			
Ave		0.706	1.3115	1.9755	2.685	3.1875			
Crack Extension		0.356	0.6055	0.664	0.7095	0.5025			
Area (in lb)		4.57	7.426	5.274	6.262	3.974	Ave	St. Dev.	%cv
G_{IC} (lb/in)		12.785935	12.2153829	7.91112658	8.790770673	7.8769499	9.916033	2.396199	24.16489

GD1778-2									
Width(in)	1.007								
Initial Crack (in)	0.35								
Crack Length(1)		0.753	1.284	1.723	2.32	2.742			
Crack Length(2)		0.876	1.267	1.732	2.236	2.634			
Ave		0.8145	1.2755	1.7275	2.278	2.688			
Crack Extension		0.4645	0.461	0.452	0.5505	0.41			
Area (in lb)		4.549	3.807	3.65	4.451	3.463	Ave	St. Dev.	%cv
G_{IC} (lb/in)		9.7252494	8.20072938	8.01908763	8.029172721	8.3876281	8.472373	0.716339	8.454996

GD1778-3									
Width(in)	1.007								
Initial Crack (in)	0.35								
Crack Length(1)		0.877	1.553	1.942	2.384	2.808			
Crack Length(2)		0.571	1.197	1.711	2.155	2.748			
Ave		0.724	1.375	1.8265	2.2695	2.778			
Crack Extension		0.374	0.651	0.4515	0.443	0.5085			
Area (in lb)		2.431	4.034	4.599	3.984	4.306	Ave	St. Dev.	%cv
G_{IC} (lb/in)		6.4548163	6.15354576	10.1152398	8.930713	8.409179	8.01	1.68	21

COMPOSITE MATERIALS RESEARCH GROUP
2/7/97

DCB TEST RESULTS FOR LARC-SI/IM7, PANEL GD-1778

GD1778-4									
Width(in)	1.007								
Initial Crack (in)	0.35								
Crack Length(1)		0.8	1.304	1.783	2.228	2.635			
Crack Length(2)		1.043	1.527	2.044	2.517	2.948			
Ave		0.9215	1.4155	1.9135	2.3725	2.7915			
Crack Extension		0.5715	0.494	0.498	0.459	0.419			
Area (in lb)		5.203	5.286	4.091	5.138	5.245	Ave	St. Dev.	%cv
G_{IC} (lb/in)		9.0408262	10.6260227	8.15775515	11.11608717	12.430884	10.27	1.69	16

GD1778-5									
Width(in)	1.007								
Initial Crack (in)	0.35								
Crack Length(1)		0.815	1.297	1.794	2.233	2.75			
Crack Length(2)		0.718	1.229	1.626	2.071	2.547			
Ave		0.7665	1.263	1.71	2.152	2.6485			
Crack Extension		0.4165	0.4965	0.447	0.442	0.4965			
Area (in lb)		12.423	5.786	5.416	5.674	6.593	Ave	St. Dev.	%cv
G_{IC} (lb/in)	*	29.619792	11.5725671	12.0321064	12.74786899	13.186646	12.38	0.72	6

* Fiber Bridging Occurred. First extension left out of average.

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 3/3/97

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
NASA Langley Research Center
Mail Stop 226
144 Research Drive, Hampton, VA 23681

TEL: (804) 864-4251
FAX: (804) 864-8312

Remarks:

Scott:

I am shipping 10 OHC specimens for you to test. Lot designations are shown below.

PETI-5 Aging 5000		
Specimen	Property required	Test condition
AU-2473-13	OHC strength	RT
AU-2473-16	OHC strength	RT
AU-2473-17	OHC strength	RT
AU-2504-12	OHC strength	RT
AU-2504-13	OHC strength	RT
AU-2473-19	OHC strength	177°C wet
AU-2473-20	OHC strength	177°C wet
AU-2504-16	OHC strength	177°C wet
AU-2504-18	OHC strength	177°C wet
AU-2504-19	OHC strength	177°C wet

Previously used humidity treatment procedure is required for preparing 350°F wet test specimens. Please check orientation of each specimen, drill a 1/4" hole and perform the test. If you have any questions, please call. I hope that you can complete these tests in two weeks.

Best regards.

Open Hole Compression Test Results

PETI5-5000 hours aging

$[+45/0/-45/90]_{3s}$

Room Temperature

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
2473-13	0.125	54.8
2473-16	0.128	47.2
2473-17	0.128	51.4
2504-12	0.133	50.0
2504-13	0.128	51.8

Open Hole Compression Test Results

PETI5-5000 hours aging

$[+45/0/-45/90]_{3s}$

177°C

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
2473-19	0.131	42.5
2473-20	0.128	41.6
2504-16	0.134	36.7
2504-18	0.133	40.3
2504-19	0.133	42.9

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 10/20/98

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
Lockheed Engineering & Sciences Co
144 Research Drive, Hampton, VA 23666

TEL: 757 ~~(804)~~ 864-4251
FAX: ~~(804)~~ 757 864-8312

Remarks:

Scott: I am shipping 15 OHC and 2 CAI specimens for you to test. Lot designations are shown below.

Specimen	Property required	Test condition	Note
SMB-292-1	OHC strength	RT	THH
SMB-292-2	OHC strength	RT	
SMB-293-1	OHC strength	RT	
HL-251-1	OHC strength	RT	BC
HL-255-1	OHC strength	RT	
HL-306-1	OHC strength	RT	BC
HL-306-2	OHC strength	RT	
HL-306-3	OHC strength	RT	
HL-306-4	OHC strength	RT	
HL-306-5	OHC strength	RT	
SMB-292-3	OHC strength	350°F wet	THH
SMB-293-2	OHC strength	350°F wet	
SMB-293-3	OHC strength	350°F wet	
HL-251-2	OHC strength	350°F wet	
HL-255-2	OHC strength	350°F wet	
SMB-304	CAI	RT	THH
SMB-307	CAI	RT	

Previously used humidity treatment procedure is required for preparing 350°F wet test specimens. Please check orientation of each OHC specimen, ie., $[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$. If you have any questions, please call.

I also include two CAI panels, $[-45/90/45/0]_{4s}$, for you to test at RT. The impact energy should be 1500 in-lb per in of specimen thickness with a 5/8" dia spherical indenter.

Best regards.

Open Hole Compression Test Results

$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$

Room Temperature

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
HL-306-1	0.157	49.6
HL-306-2	0.158	47.3
HL-306-3	0.158	46.2
HL-306-4	0.159	52.4
HL-306-5	0.159	51.2
SMB292-1	0.139	56.1
SMB292-2	0.138	55.7
SMB293-1	0.141	54.4
HL251-1	0.139	59.3
HL255-1	0.139	55.4

Open Hole Compression Test Results

$[\pm 45/90/0/0/\pm 45/0/0/\pm 45/0]_s$

177°C

Specimen Number	Specimen Thickness (inch)	Compressive Strength (ksi)
SMB-293-2	0.140	44.3
SMB-293-3	0.141	44.1
SMB-292-3	0.138	48.2
HL-255-2	0.140	42.6
HL-251-2	0.138	49.2

Compression After Impact Test Results

Specimen ID	Width (inch)	Thickness (inch)	Load (pound)	Stress (ksi)	Specific Impact Energy (in-lb/in)
SMB304	3.962	0.181	43,000	60	1524
SMB307	3.969	0.176	38,500	55	1465

FACSIMILE TRANSMISSION
COMPOSITES AND POLYMERS BRANCH

NASA Langley Research Center
Mail Stop 226
Hampton, VA 23665-5225

Date: 11/13/98

No. Pages: Lead + 0

TO:

Professor D. F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071

TEL: (307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 (Ronda)
FAX: (307) 766-4444

From:

T. H. Hou
NASA Langley Research Center
Composites and Polymers Branch
Hampton, Virginia

TEL: (757) 864-4251
FAX: (757) 864-8312

Remarks:

Scott: I am shipping 10 specimens for IITRI compression tests. You may use zone heating for tests at elevated temperatures. Lot designations are shown below.

Specimen	Property required	Test condition	Note
SMB-290-1	IITRI compres. strength	RT	THH
SMB-290-2	IITRI compres. strength	RT	
SMB-290-3	IITRI compres. strength	RT	
SMB-290-4	IITRI compres. strength	RT	
SMB-290-5	IITRI compres. strength	RT	
SMB-290-6	IITRI compres. strength	~~350°F~~ 150°C	
SMB-290-7	IITRI compres. strength	~~350°F~~ "	
SMB-290-8	IITRI compres. strength	~~350°F~~ "	
SMB-290-9	IITRI compres. strength	~~350°F~~ "	
SMB-290-10	IITRI compres. strength	~~350°F~~ "	

My tel and fax area code has been changed to 757. Sorry for the confussions.

Best wishes.

IITRI Compression Test Results
Room Temperature and 150°C
PETI-5 (Salt Like) CA-9142

Specimen ID	Width (inch)	Thickness (inch)	Stress (ksi)	Modulus (Msi)	Poisson's Ratio
SMB-290-1	0.247	0.096	158	20.6	0.33
SMB-290-2	0.246	0.096	166	21.1	0.32
SMB-290-3	0.248	0.096	157	21.9	0.33
SMB-290-4	0.250	0.096	176	21.2	0.32
SMB-290-5	0.251	0.096	159	22.9	0.35
		AVERAGE	163	21.5	0.33
		STD. DEV.	8	0.9	0.01
		%CV	5	4	4
SMB-290-6	0.250	0.095	182	*	*
SMB-290-7	0.244	0.095	153	19.6[1]	0.44
SMB-290-8	0.249	0.096	148	20.5[2]	0.31
SMB-290-9	0.247	0.095	153	25.1[3]	0.44
SMB-290-10	0.250	0.095	196	20.8[4]	0.38
		AVERAGE	166	21.5	0.39
		STD. DEV.	21	2	0.06
		%CV	13	11	16

* No strain data, lost strain gage at 177°C which was the initial test temperature requested.
[1] Modulus taken over strain range of 1000-3000με.
[2] Modulus taken over strain range of 1500-3500με.
[3] Modulus taken over strain range of 1700-3700με.
[4] Modulus taken over strain range of 500-3000με.

Memorandum

November 23, 1998

To: Professor D.F. Adams
Dept. of Mechanical Engineering
University of Wyoming
Laramie, WY 82071
(307) 766-2371
(307) 766-2431 (Scott)
(307) 766-4266 FAX

From: Roberto J. Cano
Mail Stop 226
Composites and Polymers Branch
NASA Langley Research Center
Hampton, VA 23681
(757) 864-3951
(757) 864-8312 FAX

Subject: OHC Testing

Please perform mechanical testing on the supplied IM7/polyimide composite specimens according to the table below.

Specimen	Property Required	Test Condition
316-OHC-1	Open Hole Compression Strength	RT
316-OHC-2	Open Hole Compression Strength	RT
316-OHC-3	Open Hole Compression Strength	RT
315-OHC-1	Open Hole Compression Strength	350°F
315-OHC-2	Open Hole Compression Strength	350°F
315-OHC-3	Open Hole Compression Strength	350°F
300-OHC-3	Open Hole Compression Strength	RT
300-OHC-4	Open Hole Compression Strength	RT
300-OHC-5	Open Hole Compression Strength	RT
300-OHC-1	Open Hole Compression Strength	350°F
300-OHC-2	Open Hole Compression Strength	350°F

If you require any further information, please contact me at the above number.

Thank you,
Bert

Open Hole Compression Test Results
Room Temperature

Specimen ID	Width (inch)	Thickness (inch)	Stress (ksi)
316-1	1.005	0.136	65.5
316-2	1.002	0.126	64.9
316-3	1.004	0.127	61.2
		Average	***63.9***
		Std. Dev.	***2***
		%CV	***4***
300-3	1.004	0.136	64.4
300-4	1.004	0.138	62.1
300-5	1.003	0.139	63.8
		Average	***63.4***
		Std. Dev.	***1***
		%CV	***2***

Open Hole Compression Test Results
350°F

Specimen ID	Width (inch)	Thickness (inch)	Stress (ksi)
315-1	1.002	0.127	55.8
315-2	1.002	0.129	61.0
315-3	1.002	0.130	51.4
		Average	***56.1***
		Std. Dev.	***5***
		%CV	***8***
300-1	1.004	0.137	59.6
300-2	1.004	0.137	51.6
		Average	***55.6***
		Std. Dev.	***6***
		%CV	***10***

COMPOSITE MATERIALS RESEARCH GROUP
University of Wyoming

Box 3295
Laramie, Wyoming 82071
(307) 766-2371, 766-2221

June 24, 1999

Harry Belvin
Mail Stop 226
Composites and Polymers Branch
NASA Langley Research Center
Hampton VA 23681

Harry:

Enclosed, please find the results of the compression tests we performed on the small strips of IM7/polyimide material you provided. As you recall, the initial room temperature tests raised some questions, namely, the failure stresses seemed too low. The initial specimens tested were 5.0 inches long by 0.25 inch wide. We applied tapered tabs to the specimens creating a 0.5 inch untabbed gage section. Due to the tab taper, the effective unsupported gage length is somewhat longer than 0.5 inch. The high modulus values for specimens 5 and 9 may be due to bending that occurred in the specimen prior to failure.

It was decided that a change in test method was needed. Subsequent test specimens were tabbed with blunt-ended tabs to achieve a true 0.5 inch gage section. We also decided it would be beneficial to apply a combined load to the specimens, both end loading and shear loading. This would reduce the load on the tab bondline and decrease the chance of tab failure when testing at 350°F. The specimens were too short to be used in anything but the IITRI fixture. Fortunately, this fixture can accommodate some end loading when the proper inserts are used. The ends of the specimens were machined flat and parallel to ensure proper end-loading. The results of this testing, both room temperature and at 350°F, are also listed in the enclosed table. These test results are not significantly different from the original set.

This set of tests presented many difficult challenges, most due to the geometry of the received material. A six inch long panel at least a few inches wide would have been the ideal starting place from which to fabricate specimens that were better suited to the standard test fixturing. Please contact if you have questions about the testing or the results.

Sincerely,

Scott L. Coguill
Senior Engineer

Compression Test Results
ASTM D 3410
IM7/polyimide
IITRI Fixture

Specimen ID	Width (inch)	Thickness (inch)	Stress (ksi)	Modulus (Msi)	Poisson's Ratio
Room Temperature					
5.0 Inch Specimens, Tapered Tabs					
NBCR-3	0.256	0.092	140	22.8	0.40
NBCR-4	0.255	0.092	143	20.2	0.33
NBCR-5	0.256	0.091	146	37.0*	0.61*
NBCR-6	0.256	0.091	144	20.2	0.39
NBCR-7	0.256	0.092	165	20.3	0.37
NBCR-8	0.253	0.092	138	24.5	0.26
NBCR-9	0.252	0.090	146	31.6*	0.33
		Average	**146**	**21.6**	**0.35**
		%CV	**6**	**9**	**14**
4.5 Inch Specimens, Blunt Tabs, Combined Loaded					
NBCH-11	0.256	0.088	174	27.8	0.35
NBCH-12	0.256	0.086	162	25.9	No gage
NBCH-13	0.258	0.088	116	22.3	0.31
		Average	**151**	**25.3**	**0.33**
		%CV	**20**	**11**	**8**
350°F					
NBCH-14	0.255	0.087	156	22.1	0.37
NBCH-15	0.253	0.085	90	21.8	0.28
NBCH-16	0.257	0.088	149	22.0	0.36
		Average	**132**	**22**	**0.34**
		%CV	**27**	**1**	**15**

*Values not included in average.