LTV Missiles and Electronics Group
Missiles Division

ACC MATERIAL CHARACTERIZATION TEST SPECIMEN DESIGN AND FABRICATION
PREPARATION OF STITCHED AND NON-STITCHED COMPRESSION PANELS

TASK ASSIGNMENT NO. III

LTV REPORT NO. 221RPA0095

NASA-LaRC NAS1-17079

JUNE 1987

Prepared by

R. O. Scott

R. E. Lee

LTV Missiles and Electronics
Dallas, Texas

FOREWORD

This study was conducted in the Missiles Division of LTV Missiles and Electronics Group under the NASA-Langley Research Center Contract NAS1-17079, Task Assignment III. Mr. J. W. Sawyer of NASA/LaRC was the Contract Task Technical Monitor.

Fabrication and densification of flat panels, shear panels, single stem compression segments and multi-stem compression panels were completed in the Carbon/Carbon Technologies Laboratory. Mr. R. O. Scott had the technical responsibility for this program under the management of Mr. D. W. Johnson, Engineering Project Manager - Shuttle and Mr. G. B. Whisenhunt, Deputy Director - Space Shuttle. This work was performed by personnel in the laboratory (specifically Mr. L. C. Boozer, T. M. Staples, and S. L. Whitcher) under the guidance and supervision of Mr. R. E. Lee.

It was the quality of workmanship provided by these individuals that made possible the integrity of the delivered parts.

The active participation by ILC Space Systems in their role of stitching the respective laminates was very beneficial in the accomplishment of the tasks. This activity would not have proceeded as smoothly without the assistance and support of Mr. Richard Cournoyer and Mr. Bob Goldstein of ILC Space Systems, Houston, Texas.

TABLE OF CONTENTS

1.0 SUMMARY

Work for the NASA-LaRC NAS1-17079 program began with the evaluation of various thread types by ILC Space Systems (Houston, Texas). The FDI 693 thread was selected based on mechanical strength and 'sewability.' Several stitching patterns were investigated using flat prepreg samples supplied by LTV. The inner and outer lock styles appeared to produce the best stitching configuration of the four stitches evaluated. It was subsequently found that the use of a light machine oil as a thread lubricant had a slight improvement on stitching quality and reduced thread damage. However, observation revealed that the damage to both thread and prepreg were much greater than anticipated. Mechanical test results of as-molded panels indicated no effect on interlaminar tensile strength due to stitching and a significant reduction in flexure strength. After processing to the ACC-4 state, retention of mechanical strength properties for stitched laminates appeared to be as good or better than for non-stitched panels. The impression was that stitching may be more compatible for laminates undergoing carbon/carbon processing rather than as-molded composites.

Single stem compression prepreg segments were sewn with inner-lock and outer-lock stitching patterns. The operation consisted of single row stitching on the stem and on the face at both sides of the stem of each segment. Two segments inner-lock stitched, two segments outer-lock stitched and two non-stitched segments were processed to the ACC-4 state by LTV. It was decided that the multi-stem compression panels be sewn using only the inner-lock method. Two panels inner-lock stitched and two non-stitched panels were processed to the ACC-4 state. In an unrelated task but under the same contract, the shear panels were fabricated and processed to the ACC-4 state. These six panels did not undergo any stitching operations and were to be used for large panel shear testing.

This report lent itself well to detailing the processing response from cure through ACC-4, in addition to describing the stitching activity. This information is not intended to dilute the stitching subject. It is included to show that flat panels and configured panels responded very much alike to the processing.

2.0 INTRODUCTION

This report covers the third and final task of contract NAS1-17079 with NASA Langely Research Center. This involved design and fabrication to produce 14 items as deliverables listed in Table 2.0-1. The deliverables are described as compression segments (single stem compression segments), compression panels (multi-stem compression panels), and shear panels. The panels represent nonstitched and transverse stitched fabrication. The stitching was localized near the root of the stem to face junction. All parts are 6-ply laminate construction.

In this program referred to as Task III, the objective is to show the influence of stitching compared to non-stitching in compression response of the geometrical carbon-carbon components. Task III prepared these articles to be tested at NASA Langely.

Stitching of carbon-carbon laminates is of importance since interlaminar properties are characteristically weak. In industry, there is considerable interest in stitching of reinforced plastic composites to enhance these properties. Initial tasks at NASA Langley reported in Reference (1) demonstrated further benefits of stitching. These trials involved graphite/epoxy laminate construction stitched with Kevlar thread. The presence of the stitching reduced the peel load experienced in lap shear with up to 38 percent improvement in failure loads compared to unstitched results. They also found that a single row of stitching near the end of the overlap was sufficient.

There are many goals sought in the stitching of laminates. In two dimensional constructions, resistance to shear failure in-plane with the matrix is needed. This simulative third dimension formed by stitching would be more attractive from an economical view point than the complex multi-directional weave 3D construction.

The panels were fabricated and processed over several cycles to a densified carbon-carbon state referred to as ACC-4. The reinforcement construction was eight harness woven, PAN based, heat stabilized fabric impregnated with phenolic resin. The 6-ply laminates were layed up in a cross ply construction molded, and converted to carbon-carbon. Densification involved impregnation with phenolic resin, cure, and pyrolysis. This required four cycles of densification to achieve the desired properties of flexure strength and density.

In References (2) and (3), processing techniques were developed for thin laminate construction. Additional development was required to produce stitching as an added feature.

It was determined that LTV sewing capabilities were not directed to handling prepreg so an outside supplier was sought. ILC Space Systems of Houston, Texas was found to be quite experienced in the sewing of various constructions and thus met NASA requirements. Moreover, they had some experience in stitching resin impregnated fabric. This experience included in-place machine capability plus access to outside machines for added capability.

The initial task was to arrive at a thread selection. This was performed by ILC with LTV and NASA Langley participating in the final thread selection. The report on this subject is enclosed as an appendix to this report.

The next task was to determine the stitch style most suitable for sewing prepreg layups. This was selected with the aid of flexure tests, interlaminar tensile (ILT) tests and lap shear tests. Tests were performed on as-molded laminates and ACC-4 laminates.

Single stem compression segments were then layed-up on aluminum tooling designed to produce "T" section type construction. Since inner-lock and outer-lock stitching styles appeared promising, both were utilized on the single stem segments.

The multi-stem compression panels were then layed-up, stitched (inner-lock only), molded, and processed to ACC-4.

The final requirement was the preparation of 17.5 inch x 17.5 inch flat panels processed to ACC-4. These were designated as shear panels.

TABLE 2.0-1

Description of Delivered Articles

NAME	IDENTIFICATION
Single Stem Compression Segment (non-stitched)	SSC-E
Single Stem Compression Segment (non-stitched)	SSC-F
Single Stem Compression Segment (stitched-inner)	SSC-G
Single Stem Compression Segment (stitched-inner)	SSC-H
Single Stem Compression Segment (stitched-outer)	SSC-I
Single Stem Compression Segment (stitched-outer)	SSC-J
Multi-Stem Compression Panel (non-stitched)	MSC-B
Multi-Stem Compression Panel (non-stitched)	MSC-E
Multi-Stem Compression Panel (stitched-inner)	MSC-C
Multi-Stem Compression Panel (stitched-inner)	MSC-D
Shear Panel (0° x 90°)	2000
Shear Panel (0° x 90°)	2001
Shear Panel ($\pm$45°)	2002
Shear Panel ($\pm$45°)	2003

3.0 RESULTS AND DISCUSSION

3.1 Thread Selection

Nine types of carbon threads were evaluated by ILC Space Systems (Houston) to determine which thread was most suitable for stitching ACC prepreg. The prepreg material used was 8 harness 1107 PAN based fabric with K640 resin as supplied by the Fiberite Corporation. The evaluation consisted of tests performed with each thread type on 6-ply samples of prepreg provided to ILC by LTV. Selection of the optimum thread type was based on (1) tensile test values (straight and knotted), and (2) 'sewability' which was defined during stitching based on the sewing operator's observations and afterwards by visual inspection and comparison to determine the extent of thread and material damage resulting from the sewing process. From the overall ranking, it was recommended by ILC that the Celion 693 fiber manufactured by Fabric Development (FDI 693) be utilized. The report for this study is attached as an appendix to this report.

It had been previously estimated by ILC that the tensile strength of the stitching thread decreased by about 50 percent after sewing into material. Damage to the prepreg material was a result of multiple puncture holes formed by the sewing needle. The sewing needle was about 0.09 inch in diameter and moved at a rate of 7 to 8 stitches per inch across the face of the sample. The use of water as a thread lubricant was beneficial but it was subsequently found during the flat panel trials that a light machine oil was more effective.

3.2 Flat Panel Trials

The flat panel series examined several stitch types for stabilizing through-the-thickness properties of carbon-carbon laminates. This task involved three areas of study: (1) cure method study to determine bagging procedure and autoclave conditions required to produce molded laminates of 12 to 12.5 mils per ply, (2) stitching investigation to determine optimum stitch type, pattern and density, and (3) testing in the as-cured and ACC-4 states consisting of thickness, density, porosity, resin content, net carbon gain, flexure, and ILT.

Results of the flat panel trials indicate that (1) an autoclave cycle similar to the LTV Specification 208-7-45A cycle augmented by 10 psi plus vacuum be used to produce laminates of 12 to 12.5 mils/ply, (2) the optimum stitching typesappeared to be inner-lock and outer-lock stitched in rows 1/4 to 1/2 inch apart across the laminate face (except for lap shear panels) at a stitch density of 7 to 8 stitches per inch using a light machine oil as a lubricant, and (3) through the thickness stitching of laminated prepreg produced a significant decrease in as-molded flexure strength with essentially no effect in ILT strength. However, the decrease in flexure strength due to carbon-carbon processing is slightly less for stitched laminates than for non-stitched laminates. Also, stitched laminates had a better appearance in the densified ACC-4 state than after autoclave cure.

Several stitching styles were used on 1107/K640 prepreg to determine its influence on laminate integrity. The FDI 693 thread (Reference Appendix A) was utilized to examine the effects of zig-zag, chain, outer-lock, and inner-lock stitching. Two types of flat panels were laid up and stitched with each stitching style; (1) standard 6 ply 0° x 90° cross-ply prepreg laminates were stitched in rows 1/4 to 1/2 inch apart across the laminate face, and (2) lap shear 0° x 90° cross-ply prepreg laminates were single row stitched 1/8 to 1/4 inch from each butt splice.

Lap shear laminates were laid up such that the need for cutting through three cured plies was eliminated. This was achieved during lay-up as illustrated in Figure 3.2-1.

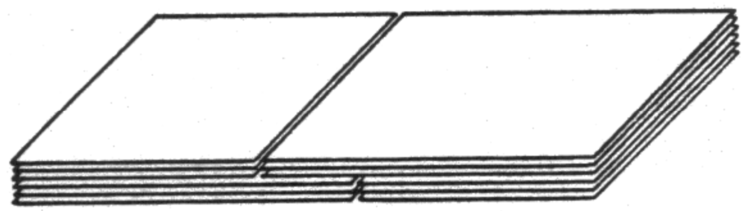


Figure 3.2-1 Lap Shear Panel Lay-up

Both lap shear and standard lay-ups were packaged in dry ice and shipped to ILC (Houston) for stitching operations. After stitching, the laminates were packaged in dry ice and shipped back to LTV for fabrication and densification. Dry ice was used to keep the laminates as low in temperature as possible to prevent resin advancement and to maintain laminate compactness. Figure 3.2-2 shows examples of both standard and lap shear prepreg lay-ups after stitching but before cure.

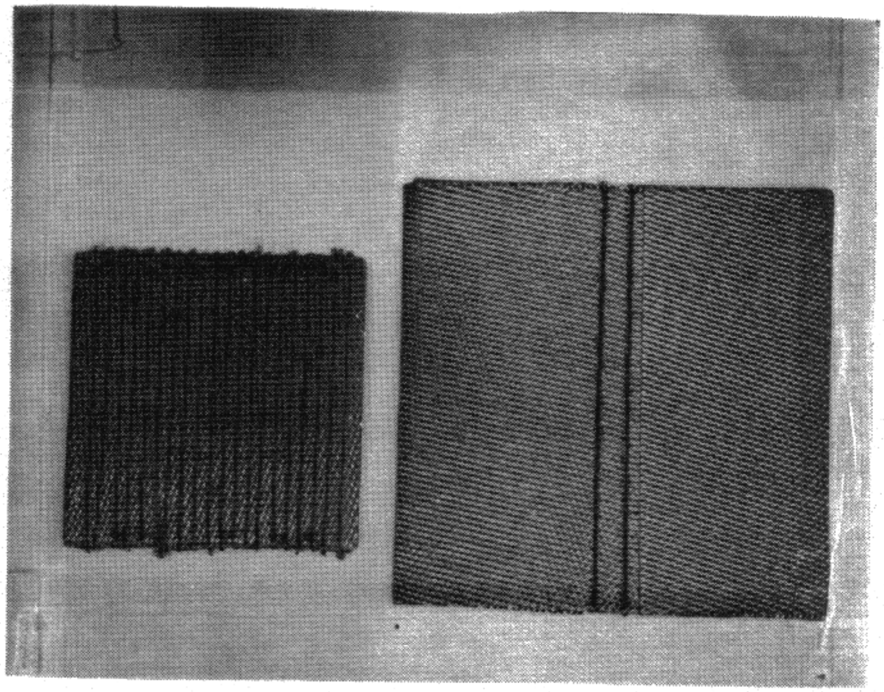


Figure 3.2-2 Stitched Lay-ups Prior to Autoclave Cure

Results for as-molded mechanical testing for all stitched panels are given in Table 3.2-1 and results for ACC-4 testing are in Table 3.2-2. The raw data used in these tables as shown in Tables 3.2-3, 3.2-4, and 3.2-5 at the end of this section for Flexure, ILT, and Lap shear, respectively.

TABLE 3.2-1

STITCH FLAT PANELS
AS-MOLDED MECHANICAL TEST DATA

PANEL I.D.	PRE-PUNCH	CAUL PLATE	LAY UP METHOD	STITCHING STYLE	FLEXURE STRENGTH (KSI)	FLEXURE MODULUS (MPSI)	ILT STRENGTH (PSI)	LAP SHEAR ULTIMATE LOAD (LBS)
1			STANDARD, 0°,90°	ZIG ZAG	23.7	7.80	1198	
2			LAP SHEAR 0°,90°	ZIG ZAG				622
3			STANDARD 0°,90°	CHAIN	31.7	10.1	1255	
4		✓	STANDARD 0°,90°	CHAIN	31.6	10.8	1161	
8		✓	LAP SHEAR 0°,90°	CHAIN				566
11	✓		STANDARD 0°,90°	INNER-LOCK	26.4	9.11	1320	
12	✓	✓	STANDARD 0°,90°	INNER-LOCK	29.0	10.3	1028	
13	✓		STANDARD 0°,90°	OUTER-LOCK	25.8	8.68	1105	
14	✓	✓	STANDARD 0°,90°	OUTER-LOCK	28.6	10.5	1259	
15	✓		LAP SHEAR 0°,90°	INNER-LOCK				633
16	✓	✓	LAP SHEAR 0°,90°	INNER-LOCK				663
17	✓		LAP SHEAR 0°,90°	OUTER-LOCK				489
18	✓	✓	LAP SHEAR 0°,90°	OUTER-LOCK				666
19			STANDARD 0°,90°	OUTER-LOCK	22.4	10.4	1280	
20		✓	STANDARD 0°,90°	OUTER-LOCK	31.4	11.3	1198	
22		✓	LAP SHEAR 0°,90°	OUTER-LOCK				690
23			STANDARD 0°,90°	INNER-LOCK	25.0	11.5	1317	
24		✓	STANDARD 0°,90°	INNER-LOCK	33.0	13.3	1242	
25			LAP SHEAR 0°,90°	INNER-LOCK				621
26		✓	LAP SHEAR 0°,90°	INNER-LOCK				620
27		✓	STANDARD 0°,90°	INNER-LOCK**	21.6	10.7	990	
28			LAP SHEAR 0°,90°	NO STITCHING				
29		✓	LAP SHEAR 0°,90°	NO STITCHING				
30			STANDARD 0°,90°	NO STITCHING	41.8	15.6	1126	
31		✓	STANDARD 0°,90°	NO STITCHING				

* ALL PANELS CURED AT 10 PSI/VACUUM EXCEPT 27 WHICH WAS CURED AT 30 PSI/VENTED
** LOCKING THREAD LUBRICATED WITH MACHINE OIL DURING STITCHING

TABLE 3.2-2

STITCHED FLAT PANELS
ACC-4 MECHANICAL TEST DATA

PANEL I.D.	PRE-PUNCH	CAUL PLATE	LAY UP METHOD	STITCHING STYLE	FLEXURE STRENGTH (KSI)	FLEXURE MODULUS (MPSI)	ILT STRENGTH (PSI)	LAP SHEAR ULTIMATE LOAD (LBS)
1			STANDARD, 0°,90°	ZIG ZAG	25.4	9.71	783	
2			LAP SHEAR 0°,90°	ZIG ZAG				528
3			STANDARD 0°,90°	CHAIN	24.2	10.3	740	
4		✓	STANDARD 0°,90°	CHAIN	29.8	13.7	825	
8		✓	LAP SHEAR 0°,90°	CHAIN				588
11	✓		STANDARD 0°,90°	INNER-LOCK	25.0	10.4	779	
12	✓	✓	STANDARD 0°,90°	INNER-LOCK	23.1	10.8	658	
13	✓		STANDARD 0°,90°	OUTER-LOCK	23.2	6.83	637	
14	✓	✓	STANDARD 0°,90°	OUTER-LOCK	21.9	10.3	612	
15	✓		LAP SHEAR 0°,90°	INNER-LOCK				560
16	✓	✓	LAP SHEAR 0°,90°	INNER-LOCK				665
17	✓		LAP SHEAR 0°,90°	OUTER-LOCK				490
18	✓	✓	LAP SHEAR 0°,90°	OUTER-LOCK				556
19			STANDARD 0°,90°	OUTER-LOCK	21.5	9.94	733	
20		✓	STANDARD 0°,90°	OUTER-LOCK	32.3	11.2	711	
22		✓	LAP SHEAR 0°,90°	OUTER-LOCK				616
23			STANDARD 0°,90°	INNER-LOCK	22.4	11.0	833	
24		✓	STANDARD 0°,90°	INNER-LOCK	26.0	12.0	868	
25			LAP SHEAR 0°,90°	INNER-LOCK				503
26		✓	LAP SHEAR 0°,90°	INNER-LOCK				475
27		✓	STANDARD 0°,90°	INNER-LOCK**	26.2	11.8	895	
28			LAP SHEAR 0°,90°	NO STITCHING				631
29		✓	LAP SHEAR 0°,90°	NO STITCHING				709
30			STANDARD 0°,90°	NO STITCHING	36.8	15.1	884	
31		✓	STANDARD 0°,90°	NO STITCHING	39.4	16.7	854	

* ALL PANELS CURED AT 10 PSI/VACUUM EXCEPT 27 WHICH WAS CURED AT 30 PSI/VENTED
** LOCKING THREAD LUBRICATED WITH MACHINE OIL DURING STITCHING
ILT SAMPLES 1 THROUGH 20 FAILED IN THE ADHESIVE
ILT SAMPLES 23 THROUGH 31 WERE SANDBLASTED PRIOR TO BENDING AND ALL FAILED WITHIN THE SAMPLE

Flexure strength for all stitched samples was significantly lower than those of non-stitched specimens (compare with the non-stitched control panel). This is due to the decrease in fiber tension strength resulting from the puncture holes of the sewing needle. Figures 3.2-3 and 3.2-4 illustrate cross-sectional views of stitched laminates taken from tested samples in the as-molded state and at ACC-4. Note the stitch thread path in these edge photographs. Close examination shows the laminate fiber encapsulation by the thread.

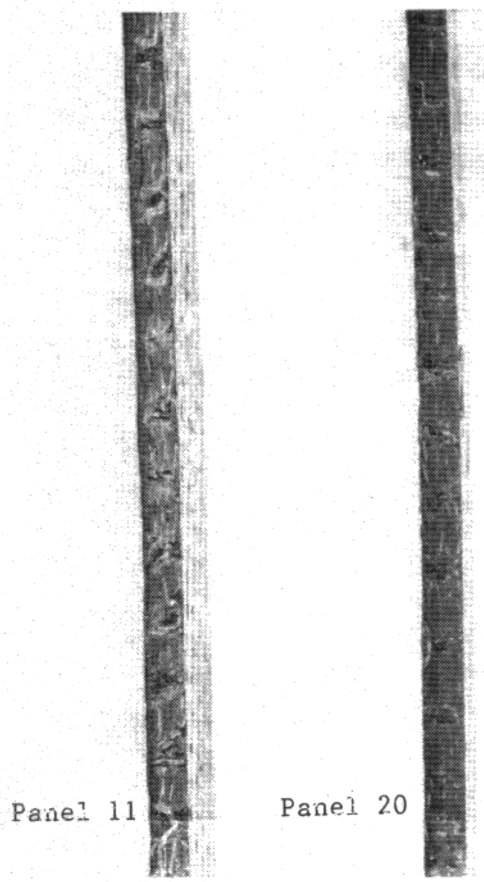


Figure 3.2-3 Tested As-Molded Flexure Specimens

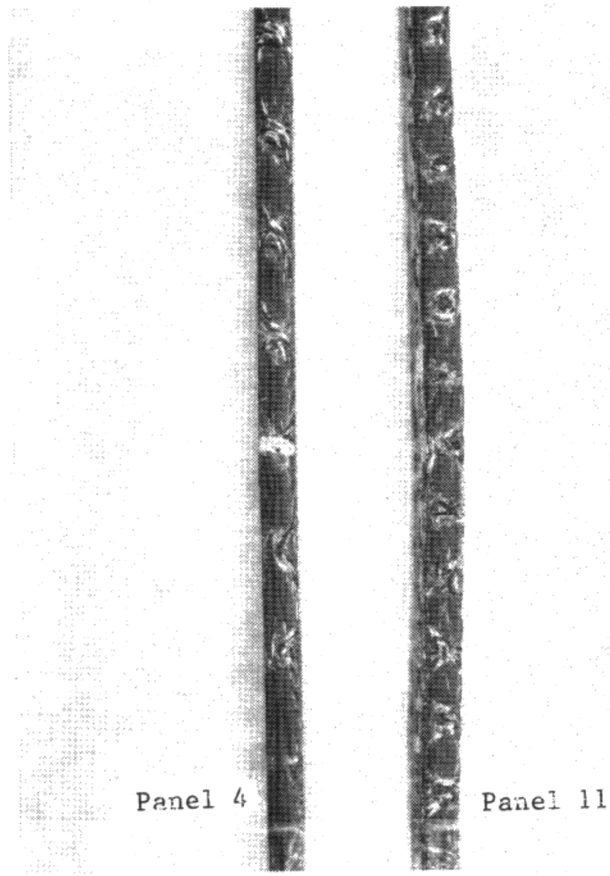


Figure 3.2-4 Tested ACC-4 Flexure Specimens

One by two inch ILT specimens were bonded onto steel blocks and tested in flatwise tension to produce interlaminar failure when loaded. Figures 3.2-5 and 3.2-6 show a specimen after bonding and after assembly in the test fixture apparatus prior to loading.

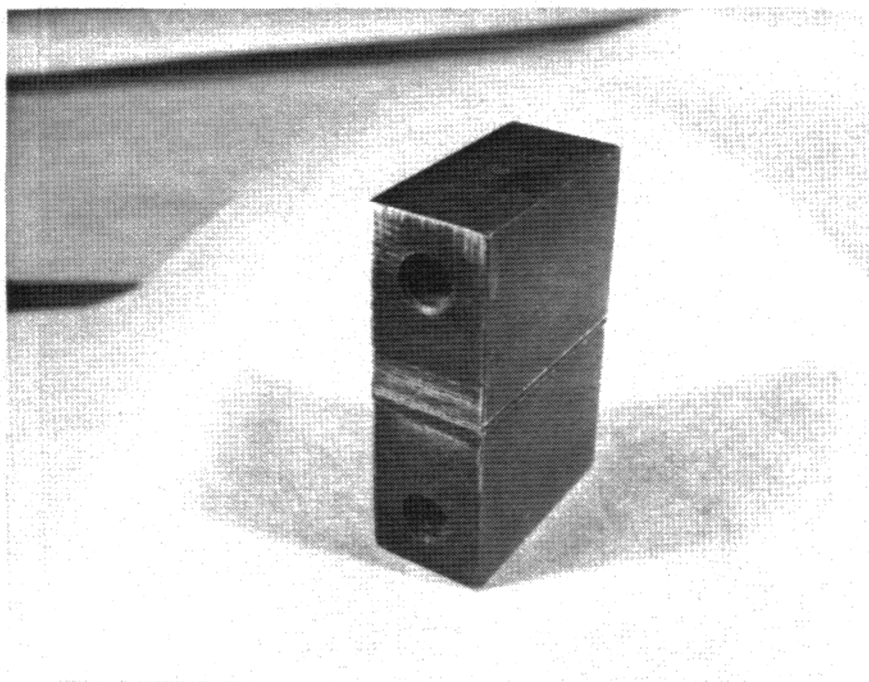


Figure 3.2-5 ILT Specimen Bonded to Steel Blocks and Ready for Test

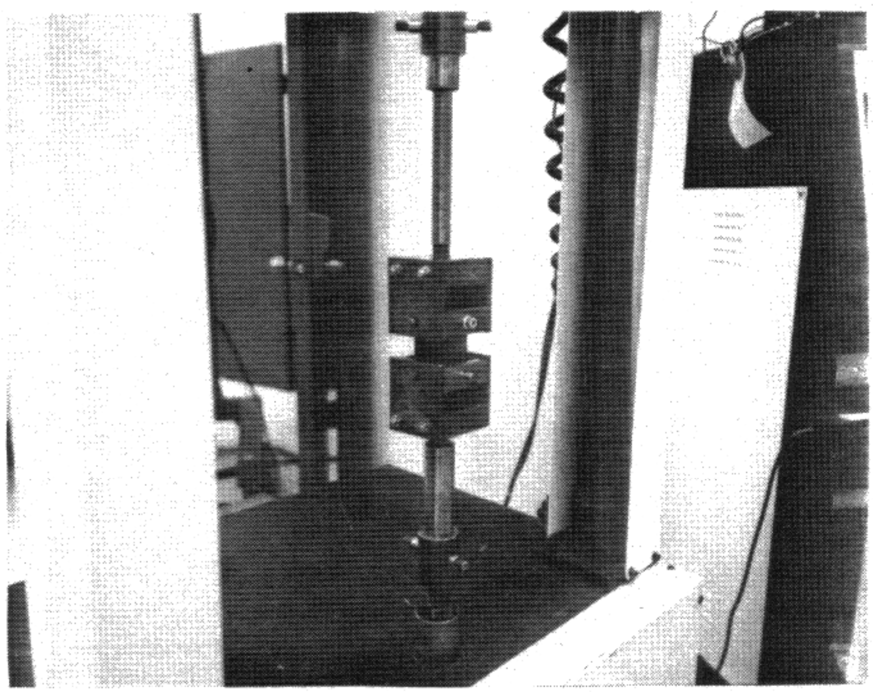


Figure 3.2-6 ILT Specimen in Test Fixture Prior to Loading

As noted in Tables 3.2-1 and 3.2-2, all cured ILT specimens failed in the adhesive as did the ACC-4 specimens except numbers 23 through 27 in which the surfaces were sandblasted prior to bonding. See Figures 3.2-7 and 3.2-8. Retesting of specimens that experienced adhesive band failure was not attempted. Prior experience showed that such efforts resulted in low values due to the initial loads applied.

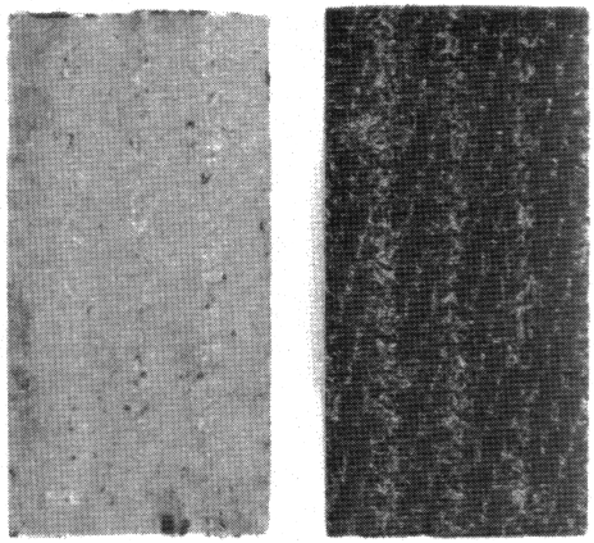


Figure 3.2-7 Tested ILT Specimens Showing Adhesive Failure

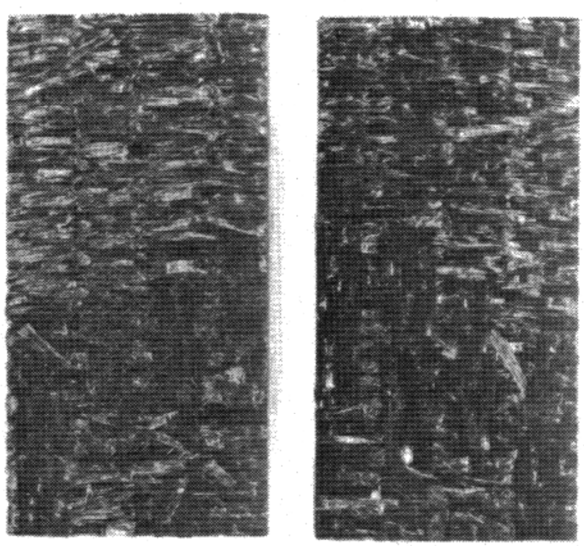


Figure 3.2-8 Tested ILT Spcimens Showing Specimen Failure

Lap shear specimens were cut from panels which were specially fabricated to promote ply to ply shear failure when loaded in tension as noted earlier. The test fixture assembly is shown in Figure 3.2-9 holding a specimen just prior to loading.

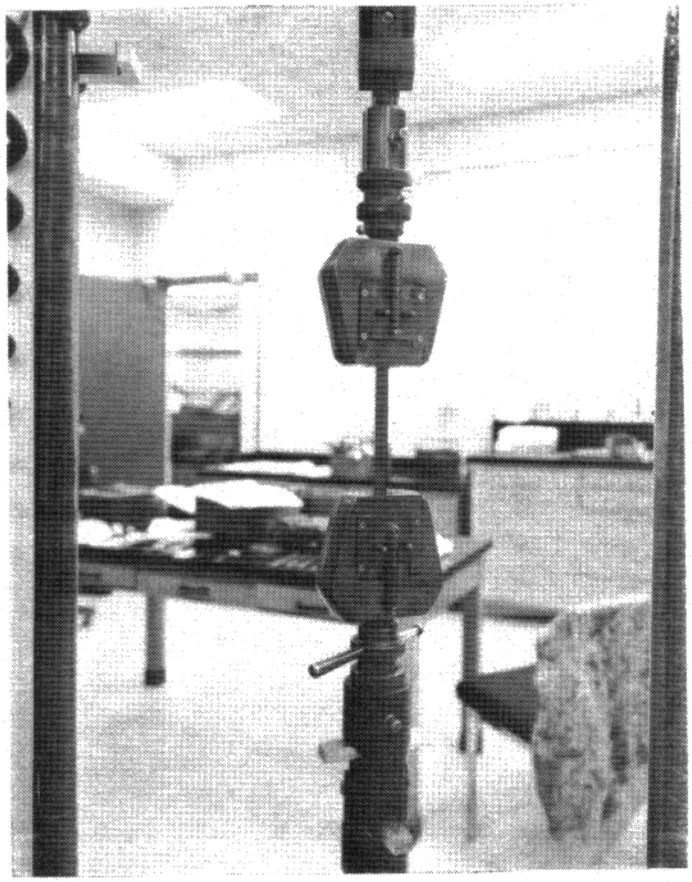


Figure 3.2-9 Lap Shear Specimen Test in Progress

Each specimen experienced a slight bending moment during loading which continually increased up to the point of failure (crosshead speed was 0.05 in/min). Shown in Figures 3.2-10 and 3.2-11 is a specimen from panel 16 (inner-lock) before and after loading.

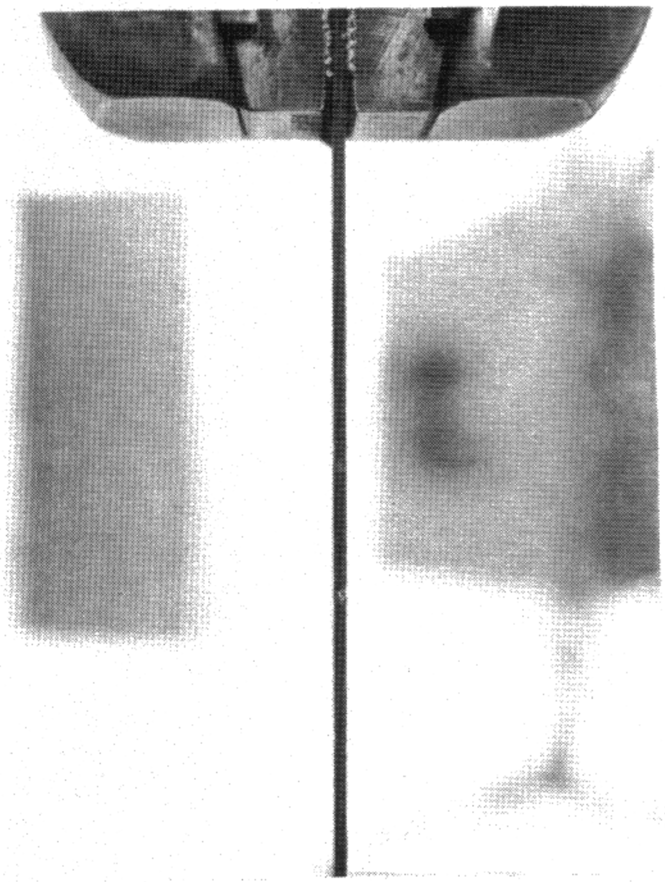


Figure 3.2-10 Lap Shear Test Specimen Before Loading

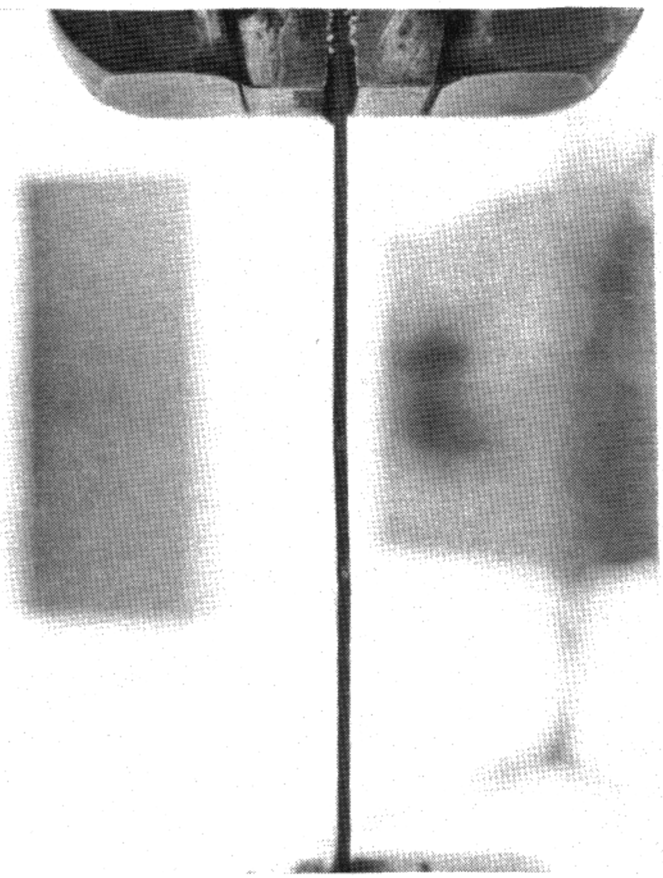


Figure 3.2-11 Lap Shear Test Specimen After Loading

Apparently, all stitched specimens sheared up to the stitch line and then broke in tension. This is illustrated in Figures 3.2-12, 3.2-13 and 3.2-14 for the specimen from panel 16 after failure.

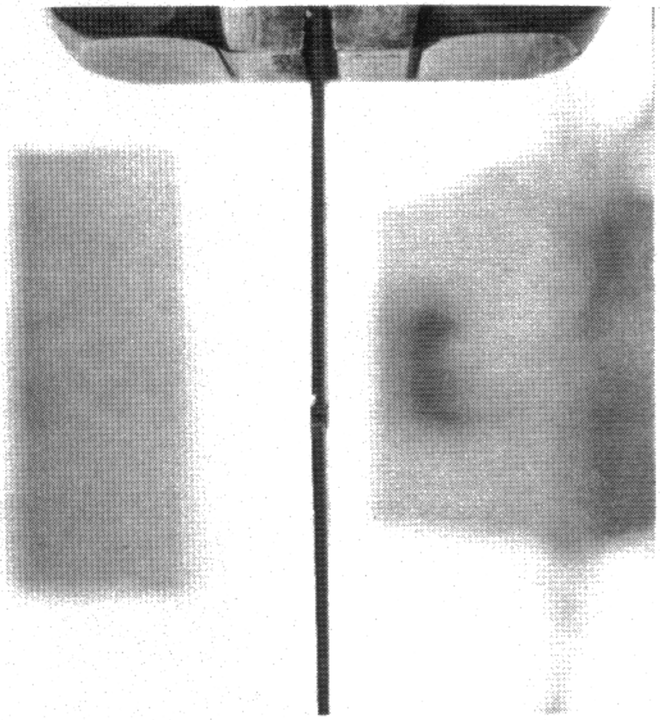


Figure 3.2-12 Lap Shear Failure

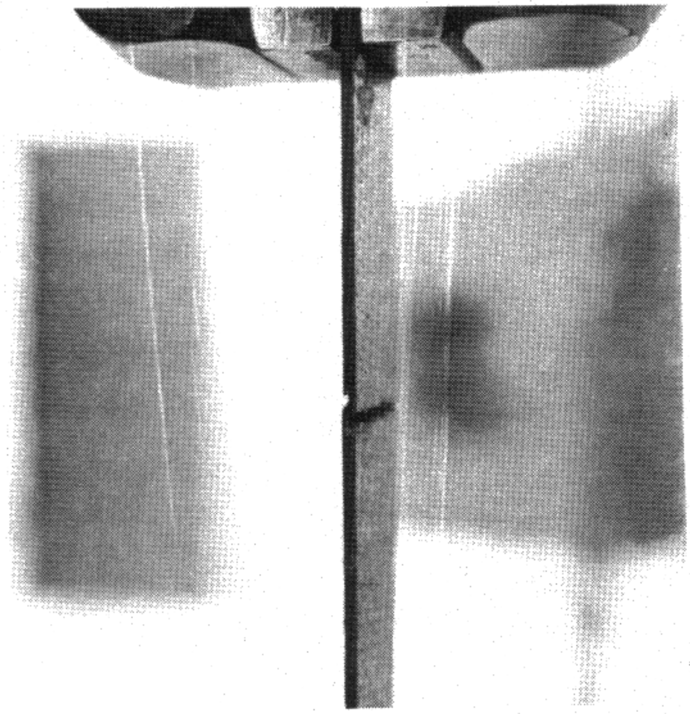


Figure 3.2-13 Lap Shear Failure (Edge View)

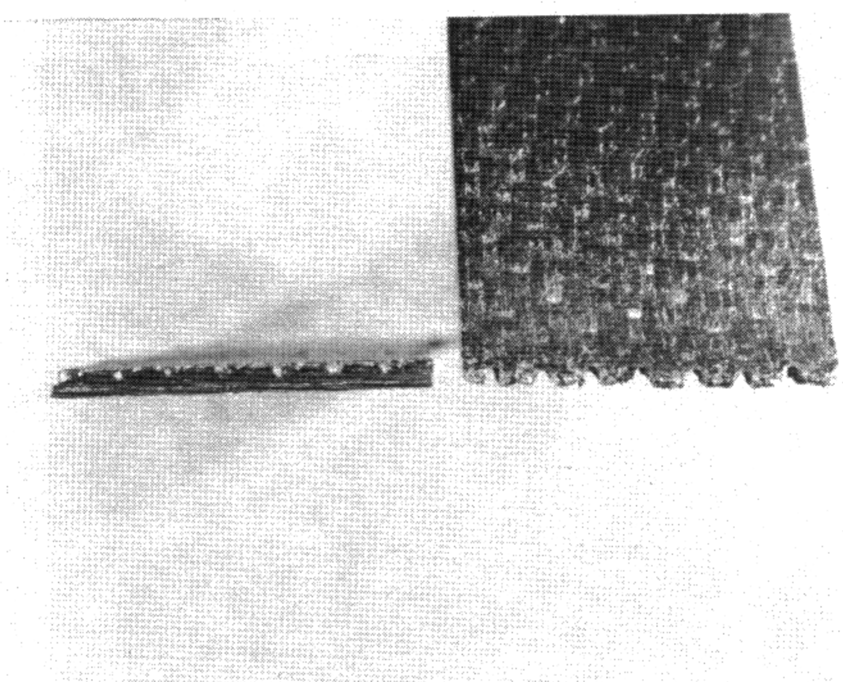


Figure 3.2-14 Lap Shear Specimen (Stitched) After Failure

As with the stitched samples, non-stitched specimens indicated a bending moment prior to failure. All non-stitched specimens underwent shear failure as shown in Figures 3.2-15 and 3.2-16 for a specimen taken from panel 28.

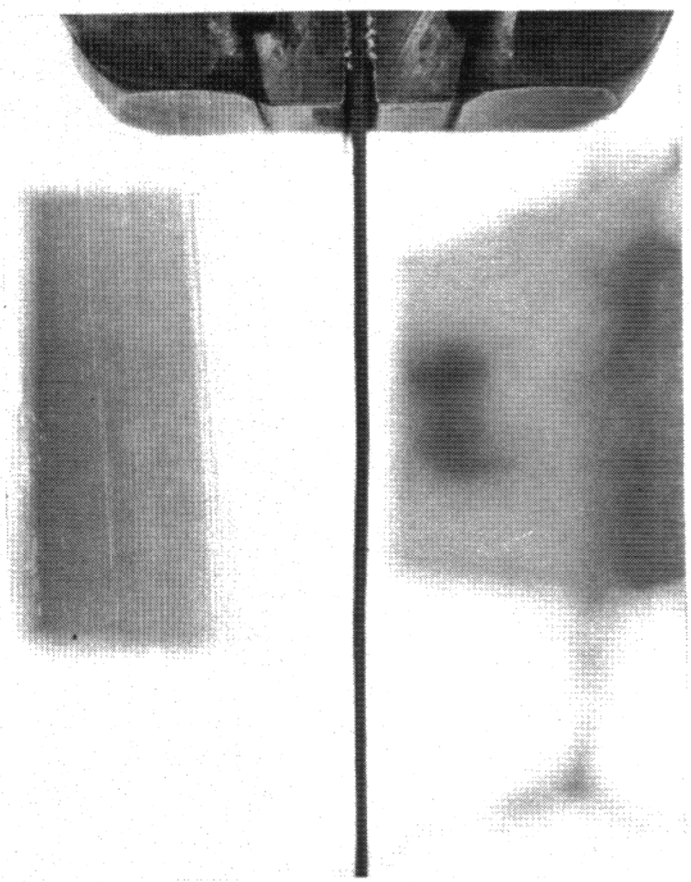


Figure 3.2-15 Lap Shear Specimen (Non-Stitched) After Loading

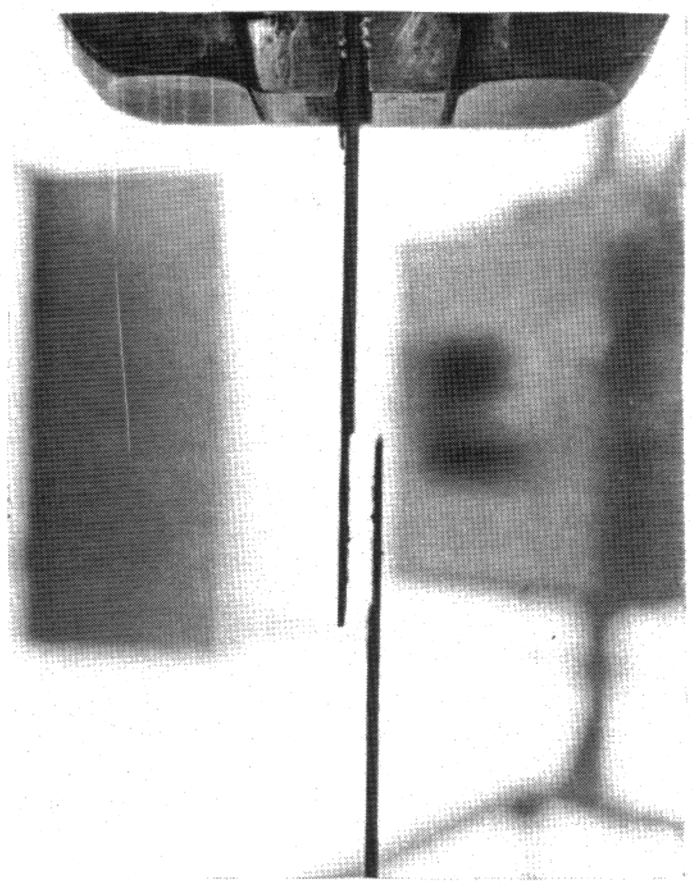


Figure 3.2-16 Lap Shear Specimen (Non-Stitched) After Failure

In spite of the obvious difference in failure mode between stitched and non-stitched specimens, load/deflection curves appear to be identical. Figure 3.2-17 shows the curves for control panel 28 and panels 18 and 20 (both outer-lock stitched).

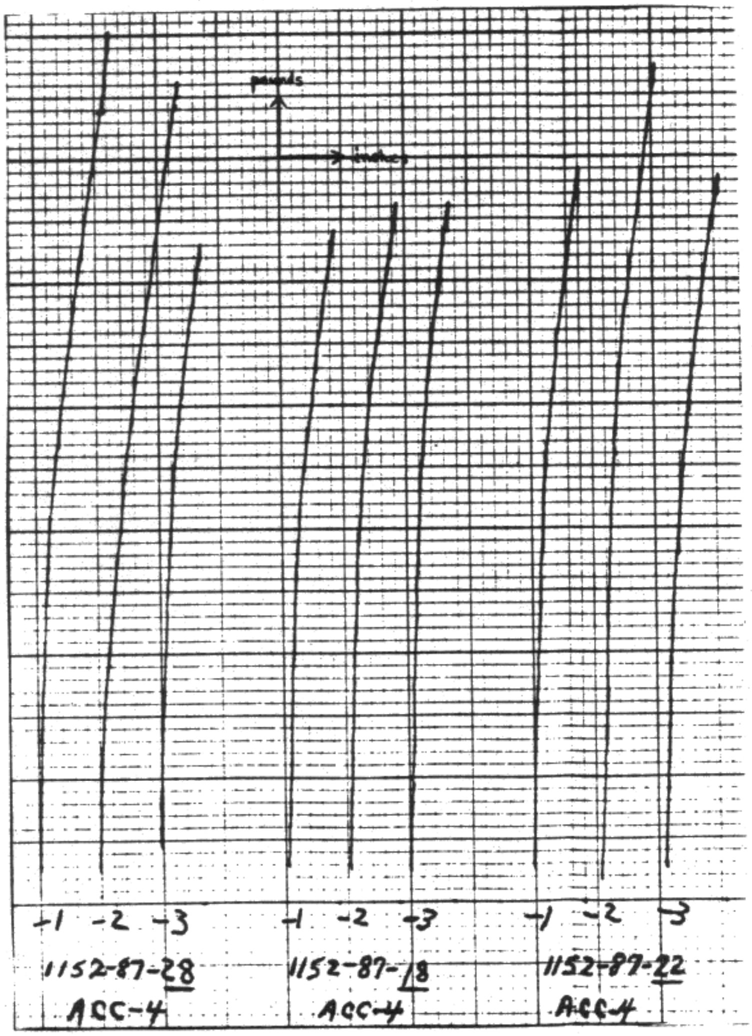


Figure 3.2-17 Load-deflection Curves for Stitched and Non-Stitched Lap Shear Specimens

TABLE 3.2-3
RAW FLEXURAL TEST DATA

AS-MOLDED

PANEL NUMBER	SPECIMEN NUMBER	THICKNESS (IN)	WIDTH (IN)	ULTIMATE LOAD (LBS)	FLEXURE STRENGTH (KSI)	FLEXURE MODULUS (MPSI)
1	a	.082	.509	39.3	22.9	7.45
	b	.082	.504	41.5	24.5	8.14
3	a	.079	.505	48.0	30.5	9.73
	b	.077	.511	49.8	32.8	10.6
4	a	.074	.510	41.0	29.4	9.19
	b	.074	.504	46.8	33.9	12.5
11	a	.080	.511	45.0	27.5	10.3
	b	.080	.505	40.8	25.2	7.95
12	a	.077	.525	44.8	28.8	10.2
	b	.077	.528	45.8	29.2	10.4
13	a	.081	.526	42.0	24.3	8.22
	b	.078	.524	42.8	26.8	9.13
14	a	.075	.508	37.3	26.3	9.96
	b	.073	.510	42.0	30.9	11.0
19	a	.080	.505	37.8	23.4	10.3
	b	.084	.501	38.0	21.5	10.5
20	a	.080	.502	49.3	30.7	11.9
	b	.082	.501	54.0	32.1	10.6
23	a	.080	.511	40.3	24.6	11.5
	b	.079	.510	40.3	25.3	11.6
24	a	.077	.504	42.5	31.8	13.2
	b	.076	.506	50.0	34.2	13.4
27	a	.072	.507	27.8	21.1	10.8
	b	.066	.505	24.3	22.1	10.7
30	a	.072	.508	54.8	41.6	15.5
	b	.073	.508	57.0	42.1	15.7
31	a	.075	.507	61.3	43.0	15.4
	b	.078	.508	54.8	40.5	16.3

4 POINT
2 INCH SUPPORT SPAN
0.67 INCH LOADING SPAN

ACC-4

PANEL NUMBER	SPECIMEN NUMBER	THICKNESS (IN)	WIDTH (IN)	ULTIMATE LOAD (LBS)	FLEXURE STRENGTH (KSI)	FLEXURE MODULUS (MPSI)
1	a	.078	.513	29.0	25.1	9.36
	b	.077	.504	28.5	25.8	10.1
3	a	.077	.451	25.8	28.9	11.7
	b	.076	.501	18.8	19.4	8.83
4	a	.072	.500	27.5	31.8	13.9
	b	.072	.452	21.8	27.9	13.5
11	a	.079	.506	26.5	22.7	10.2
	b	.077	.500	30.0	27.3	10.6
13	a	.079	.501	30.5	23.4	8.71
	b	.078	.509	29.8	23.1	4.95
14	a	.077	.452	18.0	20.2	10.2
	b	.077	.502	23.5	23.7	10.5
19	a	.081	.499	27.8	22.9	10.2
	b	.082	.505	25.3	20.1	9.70
20	a	.078	.499	35.3	31.4	10.9
	b	.079	.504	38.8	33.3	10.7
23	a	.078	.505	26.3	23.1	11.8
	b	.080	.499	25.8	21.8	10.3
24	a	.074	.498	27.0	26.7	12.4
	b	.076	.503	27.3	25.3	11.7
27	a	.066	.503	20.8	25.6	12.7
	b	.071	.498	25.0	26.9	11.0
30	a	.072	.510	36.3	37.0	15.3
	b	.072	.506	35.5	36.5	14.9
31	a	.067	.500	33.5	40.3	17.0
	b	.068	.504	33.3	38.5	16.4

3 POINT
1.8 INCH SUPPORT SPAN

TABLE 3.2-4
RAW ILT TEST DATA

AS-MOLDED

PANEL NUMBER	SPECIMEN NUMBER	TEST AREA (IN^2)	ULTIMATE LOAD (LBS)	ULTIMATE STRENGTH (PSI)
1	a	2.017	2274	1128
	b	2.017	2439	1210
	c	2.017	2536	1257
3	a	1.999	2576	1289
	b	2.017	2546	1262
	c	1.960	2381	1215
4	a	2.020	2474	1225
	b	2.007	2459	225
	c	2.010	2076	1033
11	a	2.015	2685	1333
	b	2.015	2655	1318
	c	2.007	2630	1310
12	a	2.014	1721	855
	b	2.017	2281	1131
	c	2.029	2226	1097
13	a	2.011	2146	1067
	b	2.015	2221	1102
	c	2.028	2326	1147
14	a	2.000	2525	1263
	b	2.012	2525	1255
	c	1.966	2325	1183
19	a	2.010	2491	1239
	b	2.016	2586	1283
	c	2.020	2663	1318
20	a	2.003	2192	1094
	b	2.011	2468	1227
	c	2.019	2573	1274
23	a	2.016	2615	1297
	b	2.012	2654	1319
	c	2.017	2695	1336
24	a	2.008	2565	1278
	b	2.017	2454	1217
	c	2.020	2491	1233
27	a	2.016	2355	1168
	b	2.038	1956	960
	c	2.018	1693	839
30	a	2.016	2163	1073
	b	2.013	2046	1017
	c	2.014	2594	1288

ACC-4

PANEL NUMBER	SPECIMEN NUMBER	THICKNESS (IN)	ULTIMATE LOAD	ULTIMATE STRENGTH
1	a	1.985	1479	745
	b	1.982	1590	802
	c	1.969	1578	801
3	a	2.033	1578	776
	b	1.995	1444	724
	c	2.008	1445	720
4	a	2.004	1601	799
	b	1.989	1620	814
	c	2.036	1751	860
11	a	2.002	1534	766
	b	1.990	1564	786
	c	1.984	1560	786
12	a	1.975	1394	706
	b	2.008	1281	638
	c	2.006	1264	630
13	a	1.853	1086	586
	b	2.006	1378	687
	c	2.057	1005	489
14	a	1.994	1233	618
	b	1.992	1193	599
	c	2.014	1248	619
19	a	1.995	1393	698
	b	1.976	1439	728
	c	1.993	1540	773
20	a	1.990	1499	753
	b	2.052	1244	606
	c	2.003	1548	773
23	a	2.001	1645	822
	b	1.997	1705	854
	c	1.978	1629	823
24	a	1.987	1651	827
	b	1.987	1768	890
	c	2.039	1813	889
27	a	2.010	1830	910
	b	1.965	1785	908
	c	1.996	1730	867
30	a	1.980	1589	802
	b	2.027	1809	892
	c	2.022	1934	956
31	a	2.010	1728	859
	b	2.015	1819	903
	c	1.975	1578	799

TABLE 3.2-5
RAW LAPSHEAR TEST DATA

AS-MOLDED

PANEL NUMBER	SPECIMEN NUMBER	DEPTH (IN)	WIDTH (IN)	ULTIMATE LOAD (LBS)	STRESS (PSI)
2	a	1	.761	488.8	642.2
	b	1	.753	453.8	602.6
8	a	1	.762	391.3	513.4
	b	1	.754	466.3	618.4
15	a	1	.756	488.5	593.3
	b	1	.757	500.0	660.5
	c	1	.755	487.5	645.7
16	a	1	.755	500.0	662.3
	b	1	.755	538.0	712.6
	c	1	.756	465.0	615.1
17	a	1	.756	311.3	411.7
	b	1	.756	428.8	567.1
18	a	1	.756	498.8	659.7
	b	1	.756	500.0	661.4
	c	1	.761	516.3	678.4
21	a	1	.759	548.8	723.0
	b	1	.756	515.0	681.2
	c	1	.755	543.8	720.2
22	a	1	.756	530.0	701.1
	b	1	.756	536.3	709.3
	c	1	.759	501.3	660.4
25	a	1	.754	470.0	623.3
	b	1	.758	465.0	613.4
	c	1	.754	471.3	625.0
26	a	1	.757	483.8	639.0
	b	1	.759	453.8	597.8
	c	1	.755	471.3	624.2

ACC-4

PANEL NUMBER	SPECIMEN NUMBER	DEPTH (IN)	WIDTH (IN)	ULTIMATE LOAD (LBS)	STRESS (PSI)
2	a	1	1	478.8	478.8
	b	1	1	593.8	593.8
	c	1	1	512.3	512.3
8	a	1	1	567.5	567.5
	b	1	1	588.8	588.8
	c	1	1	608.8	608.8
15	a	1	1	613.8	613.8
	b	1	1	598.8	598.8
	c	1	1	468.8	468.8
16	a	1	1	720.0	720.0
	b	1	1	645.0	645.0
	c	1	1	630.0	630.0
17	a	1	1	405.0	405.0
	b	1	1	581.3	581.3
	c	1	1	485.0	485.0
18	a	1	1	541.3	541.3
	b	1	1	563.8	563.8
	c	1	1	563.8	563.8
22	a	1	1	590.0	590.0
	b	1	1	673.8	673.8
	c	1	1	585.0	585.0
25	a	1	1	500.0	500.0
	b	1	1	540.0	540.0
	c	1	1	470.0	470.0
26	a	1	1	642.5	642.5
	b	1	1	411.2	411.2
	c	1	1	370.0	370.0
28	a	1	1	701.3	701.3
	b	1	1	661.3	661.3
	c	1	1	530.0	530.0
29	a	1	1	696.3	696.3
	b	1	1	722.5	722.5

3.3 Single Stem Compression Segments

This task addresses the fabrication and densification of delivered articles consisting of single stem compression (SSC) segments with and without stitching. All of the segments were processed identically so that the only difference is the presence and type of stitching utilized. Single stem compression (SSC) segments SSC-E and SSC-F were fabricated without stitching and are the non-stitched segments required for comparison testing.

Panels SSC-G and SSC-H underwent single row inner-lock stitching near both sides of the stem and on the stem itself. Panels SSC-I and SSC-J were stitched with the outer-lock method at the same locations. Panel SSC-B was an early trial which was processed without stitching to indicate possible processing problems and to provide baseline control data. This information is considered to be a more realistic representation of these segments than a flat control panel. However, a flat 0° x 90°, 6-ply control panel was fabricated and processed along with panels SSC-E and SSC-F which was tested in the as-molded state and at ACC-4.

The single stem segments were laid up and fabricated as 6 ply, 0° x 90° laminates on specially prepared aluminum tooling as illustrated in Figure 3.3-1. Three plies were applied around one radius of each stem bar. Two stem bars were then joined to form a single segment and held together with 'C' clamp pressure. The stem/web groove was overfilled with strips of prepreg of various widths. Three web plies were laid up followed by the aluminum web plate. The system was compacted under vacuum bag pressure prior to stitching and/or cure.

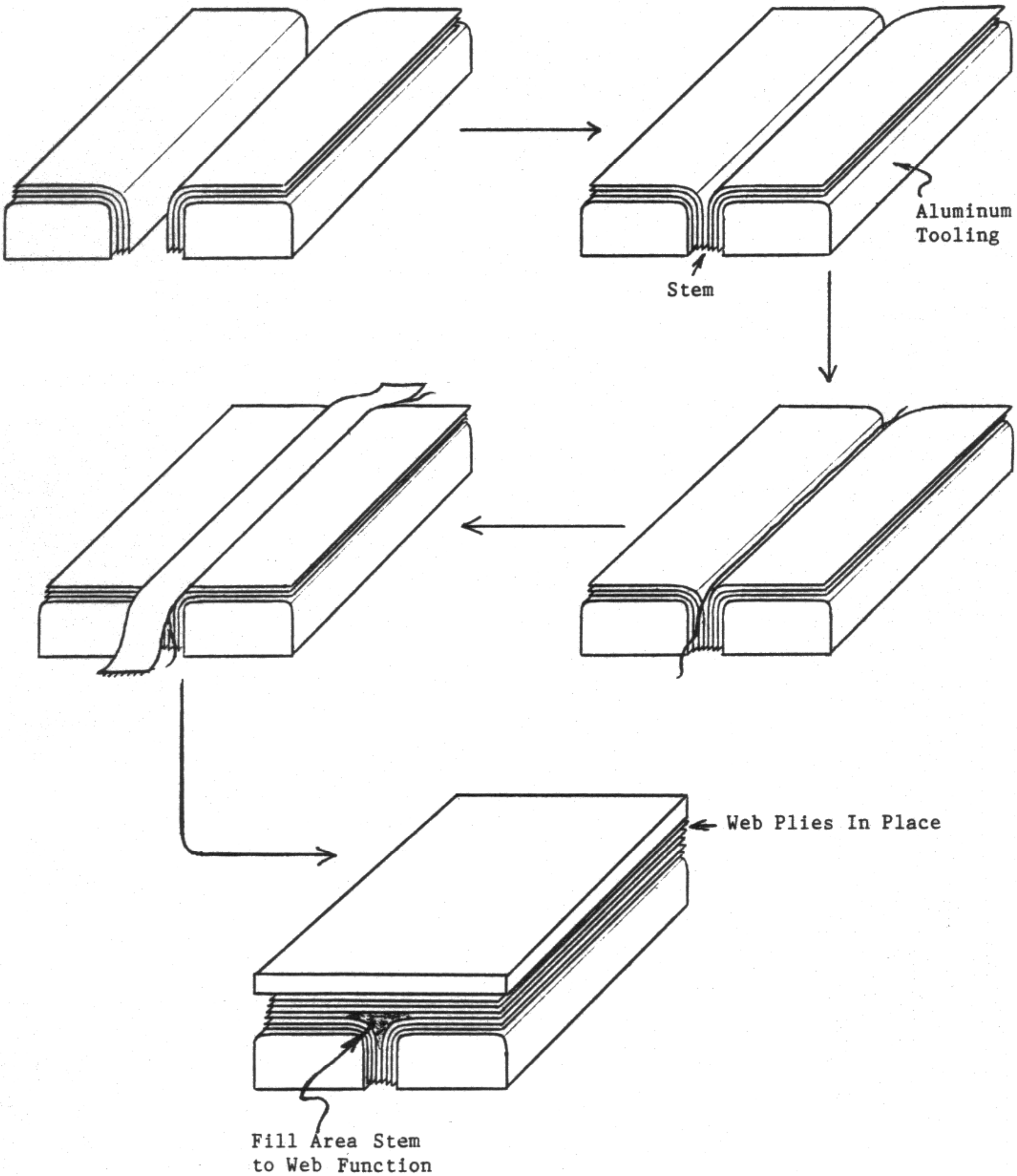


Figure 3.3-1 Lay-up on Aluminum Tooling

Panels SSC-E and SSC-F were each bagged for autoclave cure utilizing one ply of release fabric and one ply of bleeder canvas between the web lay-up and the web plate. Both parts were cured in the same run to 300°F under full vacuum and 10 psi with holds at 180°F (45 minutes) and 300°F (90 minutes). After autoclave cure, each segment was machined to final dimensions as shown in Figure 3.3-2.

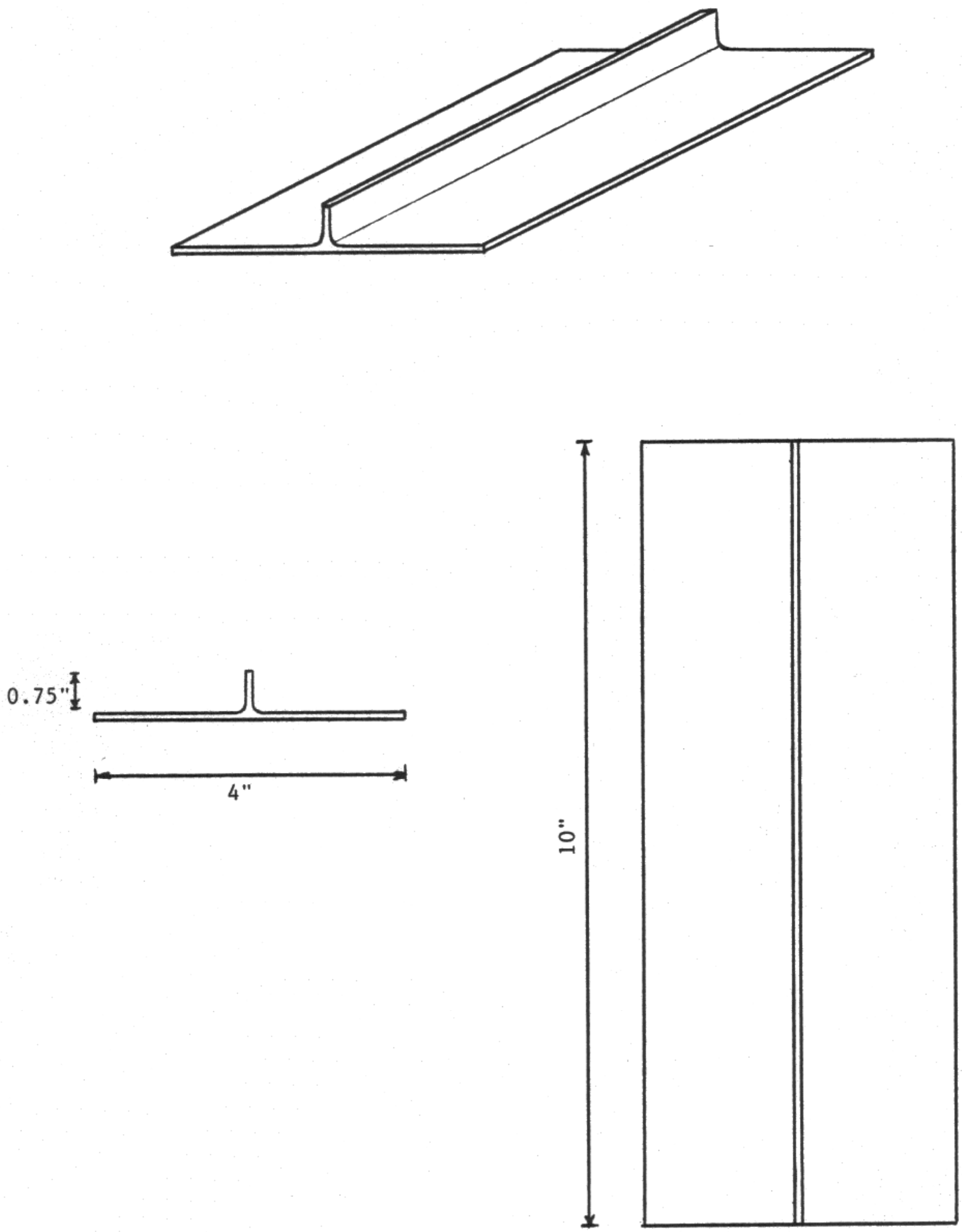


Figure 3.3-2 Machined Dimensions of SSC Segment

Panels SSC-G, SSC-H, SSC-I, and SSC-J were frozen to 0°F and transferred to specially prepared wood tooling for shipment to ILC (Houston). The assemblies were packaged in dry ice and kept in the frozen state until minutes before sewing operations began. For each segment, single row stitching was performed on the web at both sides of the stem and on the item itself. The stitching thread was saturated with lubricating oil prior to sewing. Approximate locations of stitching lines are illustrated in Figures 3.3-3.

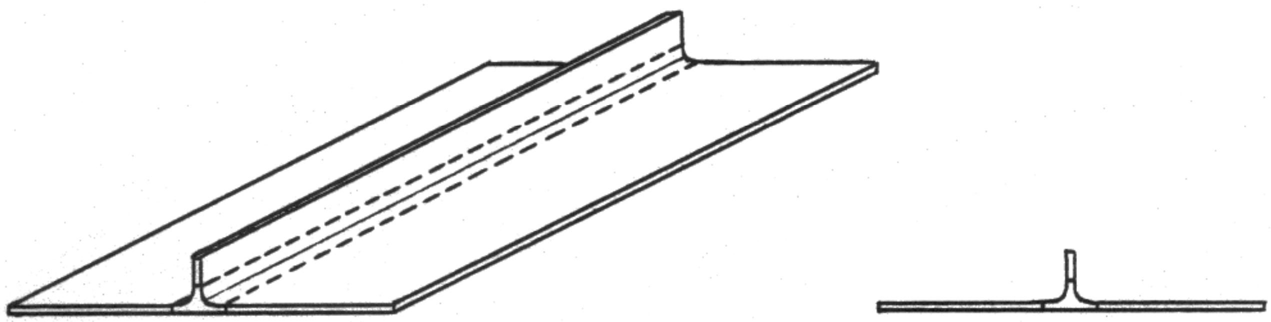
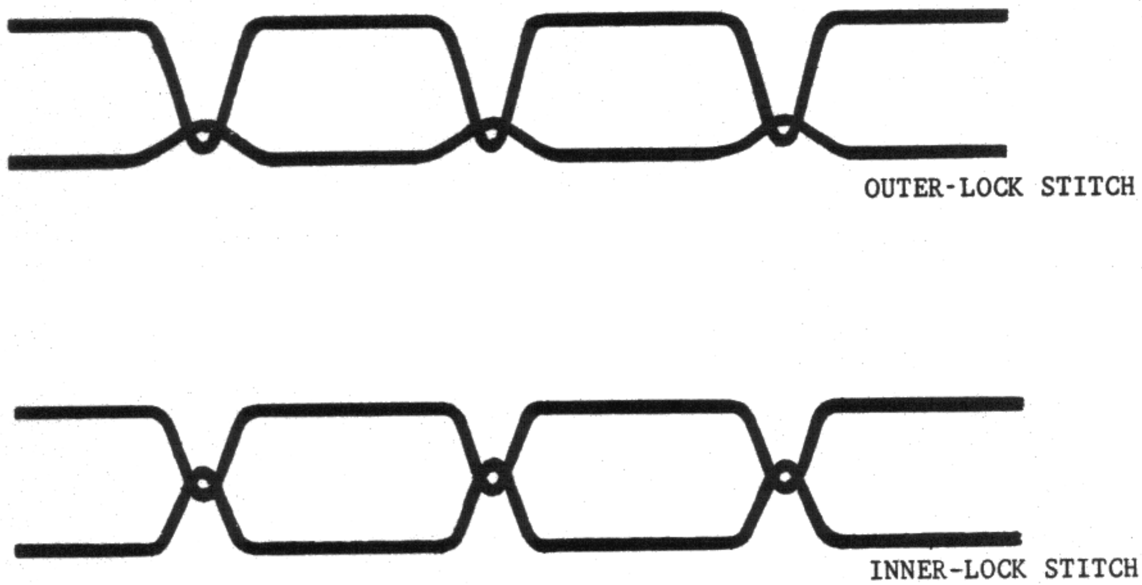


Figure 3.3-3 Stitching Configuration of SSC Segments

Segments G and H were sewn with the inner lock stitching style. Segments I and J utilized the looser outer lock method. These two styles are illustrated in Figure 3.3-4.



Figures 3.3-4 Inner Lock and Outer Lock Stitching Styles

The web stitch line was just over 1/8 inch from the radius and the stem stitch line was just under 1/4 inch from the radius. These spacings were the result of the sewing machine head space requirements. Even though the width of the presser foot was reduced, a stitch line at the tangent point of the radius was not achieved. After stitching, each segment was placed onto wood tooling and frozen prior to shipment back to LTV. In the carbon-carbon lab, the segments were transferred to aluminum tooling and each was bagged for cure utilizing one ply of bleeder canvas between the web lay-up and web plate. All four segments were cured in the same autoclave run to 300°F under full vacuum and 10 psi with holds at 180°F (45 minutes) and 300°F (90 minutes). After cure, each segment was machined to final dimensions as shown in Figure 3.3-2.

As mentioned earlier, segment B was an early trial segment fabricated to indicate possible processing problems and to provide control panel data for the other segments. This panel (non-stitched) was bagged and cured identically to the other segments. After cure, the panel was cut into two halves. One half was machined into physical property test specimens in the as-molded state as illustrated in Figure 3.3-5 and tested with results given in Table 3.3-1. The other half underwent ACC densification identically to the other segments. It was then machined into physical property test specimens as shown in Figure 3.3-6 and tested in the ACC-4 state with results given in Table 3.3-2. The results of the as-molded and ACC-4 tests are very typical of that representative for ACC-4 laminate processing. Bulk density and porosity at ACC-4 again are typical results.

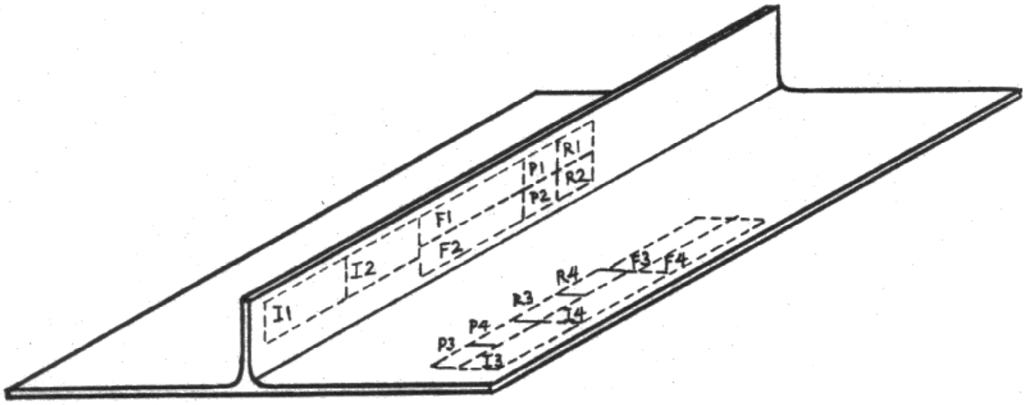


Figure 3.2-5 Test Specimen Location of
As-Molded Processed Segment

TABLE 3.3-1

AS-MOLDED TEST DATA

FLEXURAL 4-POINT			
SPECIMEN I.D.	MIL/PLY	FLEXURE STRENGTH (KSI)	FLEXURE MODULUS (MPSI)
F1	11.5	45.2	18.4
F2	11.7	46.7	18.6
F3	11.7	41.7	18.1
F4	11.5	46.5	18.1
1152-88	12.0	43.0	15.4

ILT 1" x 2"	
SPECIMEN I.D.	ILT STRENGTH (PSI)
I1	1336
I2	1286
I3	1169
I4	1142
1152-88	1288

APPARENT POROSITY ASTM C-20		
SPECIMEN I.D.	BULK DENSITY (G/CM^3)	APPARENT POROSITY (C/C)
P1	1.597	5.77
P2	1.595	6.67
P3	1.570	9.06
P4	1.587	7.18

RESIN CONTENT ASTM	
SPECIMEN I.D.	RESIN CONTENT (C/C)
R1	30.5
R2	28.7
R3	28.5
R4	27.4

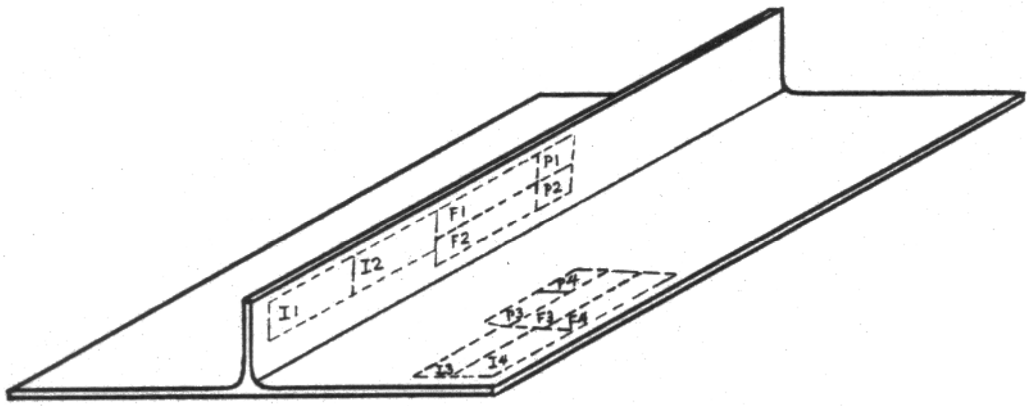


Figure 3.3-6 Test Specimen Location on ACC-4 Processed Segment

TABLE 3.3-2

ACC-4 TEST DATA

FLEXURAL 4-POINT			
SPECIMEN I.D.	MIL/PLY	FLEXURE STRENGTH (KSI)	FLEXURE MODULUS (MPSI)
F1	11.3	44.7	17.4
F2	11.2	43.4	16.8
F3	11.3	39.7	17.4
F4	11.3	41.8	16.6
1152-88	11.8	42.7	17.3

ILT 1" x 2"	
SPECIMEN I.D.	ILT STRENGTH (PSI)
I1	858
I2	909
I3	840
I4	862
1152-88	932

APPARENT POROSITY ASTM C-20		
SPECIMEN I.D.	BULK DENSITY (G/CM^3)	APPARENT POROSITY (C/C)
P1	1.622	9.27
P2	1.622	8.96
P3	1.659	8.37
P4	1.645	9.00

All segments underwent densification identically to the ACC-4 state. Each segment was double impregnated at ACC-0 and single impregnated at subsequent states. Densification consisted of 3-day calcine coke pyrolysis (using specially prepared graphite restraint tooling) and K640 phenolic resin impregnation. The weight of each panel was recorded at each state and fractional weight changes were computed throughout the process. Table 3.3-3 consist of percent laminate weight loss from pyrolysis, percent laminate weight gain from impregnation/cure and percent carbon gain for the SSC segments. These values represent process response of the respective laminates and are very typical of 6 ply ACC processing.

TABLE 3.3-3

DENSIFICATION DATA FOR SINGLE STEM SEGMENTS

PANEL I.D.	% WEIGHT LOSS FROM PYROLYSIS TO					% WEIGHT GAIN FROM IMPREGNATION AND CURE AT				% CARBON GAIN FROM PYROLYSIS/IMPREGNATION/CURE INCREMENTAL				CUMMULATIVE			
	ACC-0	ACC-1	ACC-2	ACC-3	ACC-4	ACC-0	ACC-1	ACC-2	ACC-3	ACC-0 to ACC-1	ACC-1 to ACC-2	ACC-2 to ACC-3	ACC-3 to ACC-4	ACC-0 to ACC-1	ACC-0 to ACC-2	ACC-0 to ACC-3	ACC-0 to ACC-4
SSC-B	12.0	7.5	4.0	3.1	2.6	15.5	7.2	5.1	3.6	6.9	2.9	1.8	0.9	6.9	10.0	12.1	13.1
SSC-E	10.4	7.8	4.0	3.2	2.7	15.2	5.9	5.2	4.0	6.2	1.4	1.8	1.1	6.2	7.7	9.7	10.9
SSC-F	11.5	8.1	4.0	3.8	2.1	17.6	6.2	5.7	3.0	8.1	1.9	1.7	1.0	8.1	10.2	12.1	13.1
SSC-G	11.6	7.0	4.0	2.2	1.7	14.9	7.4	3.6	2.7	6.8	3.1	1.3	0.9	6.8	10.0	11.5	12.5
SSC-H	11.8	7.3	3.6	2.3	1.8	15.2	7.0	3.8	2.9	6.8	3.1	1.4	1.1	6.8	10.1	11.6	12.8
SSC-I	11.6	7.2	4.1	2.5	1.9	15.4	7.8	4.0	3.1	7.1	3.3	1.4	1.1	7.1	10.7	12.2	13.4
SSC-J	12.3	7.1	3.8	2.4	1.7	15.7	7.3	3.8	2.8	7.5	3.1	1.4	1.0	7.5	10.8	12.4	13.5

3.4 Multi-Stem Compression Panels

This task addresses the fabrication and densification of delivered articles consisting of multi-stem compression (MSC) panels with inner-lock stitching and without stitching. Since inner-lock produced a tighter stitch configuration than the outer-lock method, it was selected as the style for stitching of the MSC panel. NASA monitor W. Sawyer concurred with this decision. Physical property information was obtained from flat panel portions trimmed off of each MSC panel.

All of the panels were processed identically so that the only difference is the presence and type of stitching utilized. Panels MSC-B and MSC-E were fabricated without stitching and are the non-stitched panels required for comparison testing.

Panels MSC-C and MSC-D underwent single row inner-lock stitching near both sides of each stem and on each stem itself. Flat regions were trimmed off from the excess width of each panel in the cured state. Each remnant was processed along with its respective panel to provide control panel data at the ACC-4 state. See Table 3.4-2.

The multi-stem panels were laid up and fabricated as 6 ply 0° x 90° laminates on specially prepared aluminum tooling as illustrated in Figure 3.4-1. Three plies were applied around two radii of three stem bars. Three plies were applied around one radius of two stem bars (these are the outside bars). The five stem bars were then joined to form a four stem panel and held together with 'C' clamp pressure. Each stem/web groove was overfilled with strips of prepreg of various widths. Three web plies were laid up followed by the aluminum web plate. The system was compacted under vacuum bag pressure prior to stitching and/or cure.

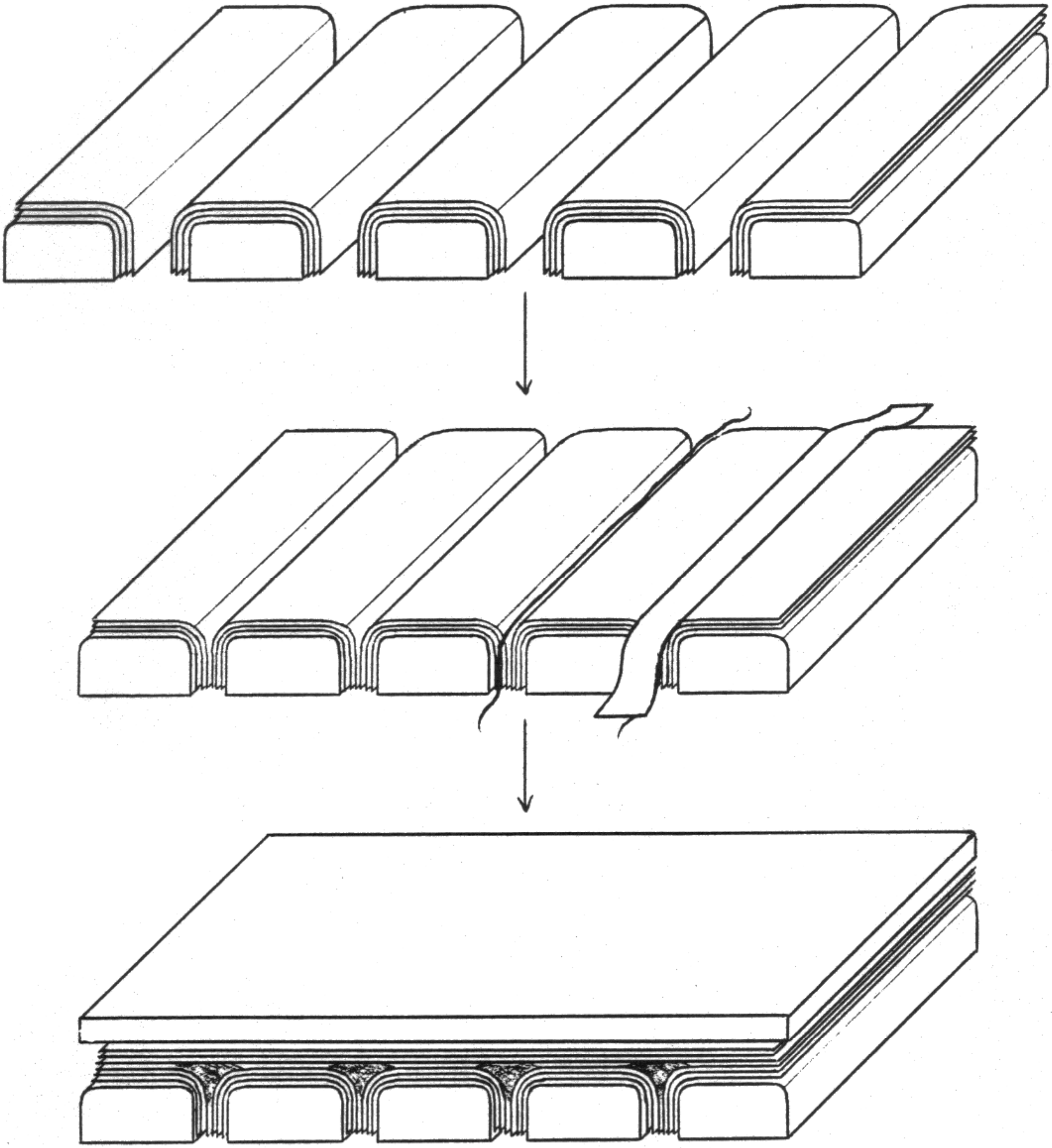


Figure 3.4-1 Lay-up of MSC Panels on Aluminum Tooling

Initially, panels MSC-A and MSC-B were to be the non-stitched panels. However, MSC-A experienced problems during densification and was rejected. So the replacement MSC-E was fabricated and processed as the second non-stitched panel. Panels MSC-B and MSC-E were each bagged for autoclave cure utilizing one ply of bleeder canvas between the web lay-up and the web plate. Each part was cured in a separate run to 300°F under full vacuum and 10 psi with holds at 180°F (45 minutes) and 300°F (90 minutes). Thermocouple readout problems associated with the cure of MSC-E prevented an accurate plot of the profile for this panel. After cure, each panel was machined to final dimensions as shown in Figure 3.4-2.

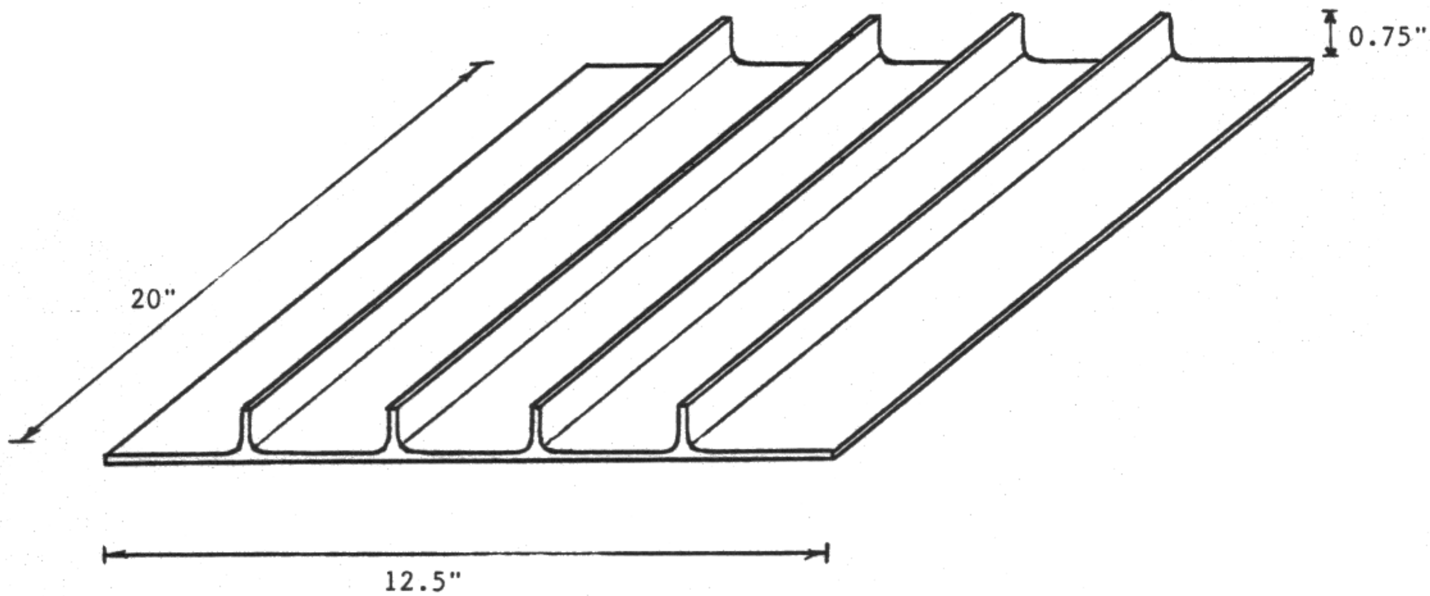


Figure 3.4-2 Machined Dimensions of MSC Panels

Panels MSC-C and MSC-D were frozen and transferred to specially prepared wood tooling for shipment to ILC (Houston). The assemblies were packaged in dry ice and kept in the frozen state until minutes before sewing operations began. For each panel, single row inner-lock stitching was performed on the web at both sides of each stem and on each stem itself. The stitching thread was saturated with lubricating oil prior to sewing. Approximate locations of the stitching lines are illustrated in Figure 3.4-3. Stitching on each stem of the MSC panels was more troublesome than the SSC segments, because adjacent stems became a hindrance. Some laminate deformation was required in order to accomplish the stitching of each stem.

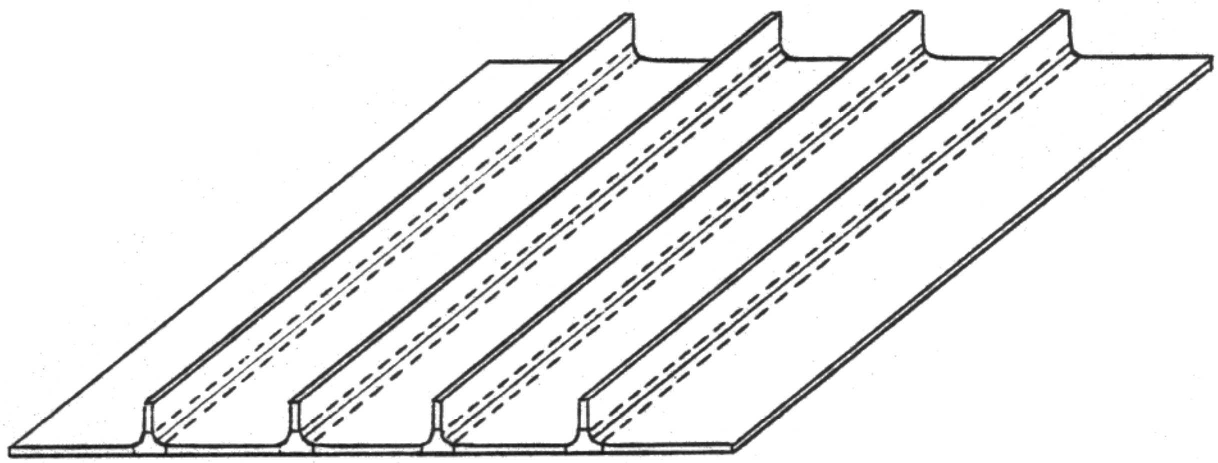


Figure 3.4-3 Stitch Configuration of MSC Panels

The web stitch line was just over 1/8 inch from the radius and the stem stitch line was just under 1/4 inch from the radius. After stitching, each panel was placed onto wood tooling and frozen prior to shipment back to LTV. In the carbon-carbon lab, the panels were transferred to aluminum tooling and each was bagged for cure utilizing one ply of bleeder canvas between the web lay-up and web plate. Both panels were cured in the same autoclave run to 300°F under full vacuum and 10 psi with holds at 180°F (45 minutes) and 300°F (90 minutes). After cure, each panel was machined to final dimensions as shown in Figure 3.4-2.

As mentioned earlier, panel MSC-A was rejected after two of the stems cracked due to inadequate restraint fixture loading prior to pyrolysis to the P-1 state. This initiated the fabrication of panel MSC-E after MSC-B and had been fully densified. The stitched panels MSC-C and MSC-D were densified together with no problems. Panels MSC-B and MSC-E underwent single impregnation and cure at ACC-0 since the bimatrix weight gain was sufficient (14.0 - 14.5%). However, panels MSC-C and MSC-D were impregnated and cured twice at P-0 to achieve sufficient weight gain (14 - 15%). Besides these differences, all of the panels were densified identically. Densification consisted of 3-day coke pyrolysis and K640 resin impregnation/cure. The weight of each panel and their respective control panels were recorded at each state so that fractional weight changes could be computed. Table 3.4-1 consist of percent laminate weight loss from pyrolysis, percent laminate weight gain from imrpregnation/cure and per cent carbon gain. These values represent process response of the respective laminate and are very typical of 6-ply ACC processing. Process control testing consisted of ILT, flexural, and ASTM C-20 porosity/density measurements of samples taken from each panel remnant at the ACC-4 state. Results of these tests are given in Table 3.4-2.

TABLE 3.4-1

DENSIFICATION DATA FOR MULTI-STEM PANELS

PANEL I.D. 1152-	% WEIGHT LOSS FROM PYROLYSIS TO					% WEIGHT GAIN FROM IMPREGNATION AND CURE AT				% CARBON GAIN FROM PYROLYSIS/IMPREGNATION/CURE							
										INCREMENTED				CUMMULATIVE			
	ACC-0	ACC-1	ACC-2	ACC-3	ACC-4	ACC-0	ACC-1	ACC-2	ACC-3	ACC-0 to ACC-1	ACC-1 to ACC-2	ACC-2 to ACC-3	ACC-3 to ACC-4	ACC-0 to ACC-1	ACC-0 to ACC-2	ACC-0 to ACC-3	ACC-0 to ACC-4
105B	12.6	7.3	4.9	3.6	2.3	14.4	8.8	5.7	3.5	6.1	3.5	1.9	1.1	6.1	9.8	11.9	13.1
C/P-B	12.4	6.3	4.6	3.0	1.6	12.4	8.2	4.7	3.0	5.4	3.2	1.6	1.3	5.4	9.0	10.7	12.3
105E	13.0	6.8	4.9	3.7	2.0	14.0	7.4	6.0	2.3	6.3	2.1	2.0	0.3	6.3	8.5	10.7	11.1
C/P-E	12.5	7.0	3.7	3.1	2.0	14.0	5.8	5.1	3.1	5.9	1.8	1.8	1.1	5.9	7.9	9.9	11.0
105C	12.1	7.3	3.8	2.9	2.3	15.6	6.7	5.1	3.4	7.1	2.7	2.1	1.1	7.1	10.0	12.3	13.5
C/P-C	11.4	6.8	3.3	2.0	1.8	15.0	5.9	3.6	2.3	7.2	2.4	1.7	0.5	7.2	9.7	11.6	12.1
105-D	12.4	7.6	3.7	2.7	2.0	15.6	6.5	5.1	3.1	6.8	2.6	2.3	1.0	6.8	9.6	12.1	13.1
C/P-D	11.3	6.8	3.3	1.9	1.5	14.7	5.9	3.6	3.2	6.9	2.4	1.6	0.5	6.9	9.5	11.3	11.9

TABLE 3.4-2

PHYSICAL PROPERTY DATA FOR MULTI-STEM COMPRESSION PANEL REMNANTS AT ACC-4

PANEL	MIL/PLY	ASTM C-20 APPARENT POROSITY (%)	ASTM C-20 BULK DENSITY (G/CM^3)	FLEXURAL STRENGTH (KSI)	FLEXURAL MODULUS (MPSI)	ILT STRENGTH (PSI)
C/P-B	11.2	6.81	1.711	40.4	17.2	693
C/P-E	12.1	9.98	1.641	36.5	18.2	817
C/P-C	11.3	8.78	1.68	39.1	18.6	854
C/P-D	10.9	10.2	1.66	40.0	18.0	928

3.5 Shear Panels

These six panels were fabricated as 6-ply cross-ply laminates and identified as illustrated in Figure 3.5-1.

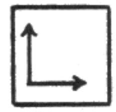
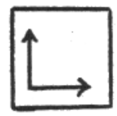
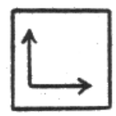
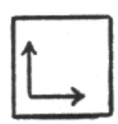
I. D.	Warp Orientation	
2000	0° x 90°	
2001	0° x 90°	
200A (Control Panel A)	0° x 90°	
2002	-45° + 45°	
2003	-45° + 45°	
200B (Control Panel B)	0° x 90°	

Figure 3.5-1 Shear Panel Lay-up Schematic

Each laminate was bagged utilizing one ply release fabric and one ply canvas for bleeding effects, barrier film, and then eight plies of canvas. Panels 2000, 2001, and 200A were cured in the first autoclave run; 2002, 2003, and 200B were cured in the second run. In both runs, the cure cycle consisted of full vacuum with 10 psi autoclave pressure; a cure temperature profile of 2°F - 4°F per minute part temperature with holds at 180°F (45 minutes) and 300°F (90 minutes). Laminate weight loss on cure was recorded for the control panel in each run. This value was 17.5 percent for panel 200A and 17.9 percent for panel 200B.

After all six panels were trimmed, portions of both control panels were utilized for as-molded process control testing. Results from these tests are given in Table 3.5-1. The four panels and control remnants were then densified to ACC-4 using 3-day coke pyrolysis, double impregnation/cure at ACC-0, single impregnation/cure through ACC-4. Physical property data was reported at ACC-0 and portions of both control panels were utilized for ACC-4 process control testing. Results of these tests are given in Table 3.5-1. Pyrolysis weight losses, bimatrix weight gains, and carbon gains were recorded for all six panels and are given in Table 3.5-2.

TABLE 3.5-1

SHEAR PANELS PHYSICAL PROPERTY DATA

PANEL I.D.	AS-MOLDED FLEXURE STRENGTH (KSI)	AS-MOLDED FLEXURE MODULUS (MPSI)	AS-MOLDED ILT STRENGTH (PSI)	AS-MOLDED PER PLY THICKNESS (MIL/PLY)	AS-MOLDED GEOMETRICAL BULK DENSITY (G/CM3)	AS-MOLDED ASTM C-20 BULK DENSITY (G/CM3)	AS-MOLDED ASTM C-20 APPARENT POROSITY (%)	AS-MOLDED RESIN* CONTENT (%)	ACC-0 THICKNESS DECREASE FROM PYROLYSIS (%)	ACC-0 PER PLY THICKNESS (MIL/PLY)	ACC-0 GEOMETRICAL BULK DENSITY (G/CM3)	ACC-4 FLEXURE STRENGTH (KSI)	ACC-4 FLEXURE MODULUS (MPSI)	ACC-4 ILT STRENGTH (PSI)	ACC-4 PER PLY THICKNESS (MIL/PLY)	ACC-4 GEOMETRICAL BULK DENSITY (G/CM3)	ACC-4 ASTM C-20 BULK DENSITY (G/CM3)	ACC-4 ASTM C-20 APPARENT POROSITY (%)
2000				12.4	1.511				2.4	12.1	1.368				12.2	1.574		
2001				12.4	1.507				1.6	12.2	1.351				12.1	1.585		
200A	45.2	15.0	1227	12.4	1.520	1.547	8.47	26.7	1.7	12.2	1.360	35.8	16.7	887	12.1	1.596	1.645	9.76
2002				12.2	1.534				1.4	12.1	1.356				12.0	1.598		
2003				12.2	1.537				1.1	12.0	1.362				12.0	1.590		
200B	48.7	15.6	1236	12.1	1.537	1.566	9.64	21.4	1.7	11.9	1.378	40.7	18.2	864	11.8	1.588	1.661	8.43

* CALCULATED FROM C-20 VALUES FOR BULK DENSITY AND APPARENT POROSITY WITH 1107 FIBER DENSITY 1.93 G/CM^3 AND CURED K640 RESIN DENSITY 1.26 G/CM^3

TABLE 3.5-2

SHEAR PANELS DENSIFICATION DATA

PANEL I.D.	% WEIGHT LOSS FROM PYROLYSIS TO					% WEIGHT GAIN FROM IMPREGNATION AND CURE AT				% CARBON GAIN FROM PYROLYSIS/IMPREGNATION/CURE INCREMENTAL				CUMMULATIVE			
	ACC-0	ACC-1	ACC-2	ACC-3	ACC-4	ACC-0	ACC-1	ACC-2	ACC-3	ACC-0 to ACC-1	ACC-1 to ACC-2	ACC-2 to ACC-3	ACC-3 to ACC-4	ACC-0 to ACC-1	ACC-0 to ACC-2	ACC-0 to ACC-3	ACC-0 to ACC-4
2000	11.7	8.6	5.1	3.6	2.2	18.4	9.3	6.0	3.5	8.1	3.7	2.3	1.3	8.1	12.1	14.7	16.1
2001	11.8	8.6	5.3	3.7	2.3	18.5	9.6	6.2	3.6	8.1	3.8	2.2	1.2	8.1	12.2	14.7	16.0
200A	12.0	8.2	5.5	4.1	1.8	17.6	9.8	6.6	3.3	8.0	3.7	2.3	1.4	8.0	12.0	14.5	16.2
2002	11.8	8.3	5.7	3.7	2.3	18.0	9.9	6.1	3.7	8.1	3.6	2.2	1.3	8.1	12.1	14.6	16.1
2003	11.8	7.8	5.5	3.7	2.1	17.5	9.6	6.1	3.6	8.2	3.5	2.2	1.4	8.2	12.1	14.6	16.2
200B	11.8	7.7	5.7	3.2	1.8	16.5	9.9	5.2	3.2	7.5	3.7	1.8	1.3	7.5	11.4	13.5	14.9

4.0 QUALITY ASSURANCE

Each laminate was carefully monitored throughout the course of processing to check for voids and discrepancies and to insure laminate integrity. All single stem and multi-stem panels as well as the shear panels underwent extensive tap testing and visual inspection at each step of the process. One of the multi-stem panels developed a significant warpage and two of the stems cracked during an early pyrolysis step. The problem was corrected and a replacement panel was subsequently fabricated. Flat control panels and panel remnants were processed along with each part to provide process control test data in the as-molded state and at ACC-4. These tests produced values for thickness, density, porosity, resin content, net carbon gain, flexure strength, and ILT strength. Also, a trial single stem segment was fabricated and machined into test coupons providing test data at the as-molded state and at ACC-4. At the ACC-4 state, ultrasonic inspection and x-ray examinations were performed on all single stem and multi-stem panels. There were no defects indicated by these tests for any of the panels.

5.0 RECOMMENDATIONS AND FURTHER DISCUSSION

A. Explore needle designs that will carry the thread through the material with minimal damage to the lay-up and stitching thread.

(Stitching was accomplished by using commercial sewing machines with relatively large diameter needles, for this program.)

B. Reduce the number of stitches per inch from 7 to 8 down to 3 to 4 and use double rows on approximately 0.25 inch spacing.

(A single row of stitching across the face of a prepreg panel produced a line of puncture holes which acted much like a perforation. The extent of prepreg fiber damage was so high that reduction in laminate tensile strength was not surprising.)

C. Stitching of dry lay-ups would reduce the material and thread damage experienced when sewing resin impregnated fabric.

(The current method of stitching would be most effective if stitching were performed on the dry fabric prior to impregnation. This is easily accomplished for flat laminates but would become more difficult for increasingly complex shapes. Other alternatives of increasing through-the-thickness laminate strength, ILT and shear properties include well known concepts such as the use of fasteners or the weaving of three dimensional preforms.)

D. Examine techniques that allow the fiber to be pushed aside. The prepunch needle approach was not satisfactory, but the idea still seems to be a good approach.

E. A localized warming of the prepreg to lower the viscosity is attactive, but a cooling method to prevent excessive resin advancement will be required.

6.0 REFERENCES

(a) J. W. Sawyer, "Effect of Stitching on the Strength of Bonded Single Lap Joints," AIAA Journal, Volume 23, November 1985.

(b) D. M. While, "Advanced Carbon-Carbon Coating Improvement Summary," Report No. 172271, December 1983.

(c) D. M. While, "Advanced Carbon-Carbon Test Article," Report No. 221RPTA018, May 1983.

APPENDIX A

COVER SHEET

DOCUMENT NO. 12707-70023A

RELEASE DATE September 5, 1986

ILC SPACE SYSTEMS 16665 Space Center Boulevard, Houston, Texas 77058

REINFORCED CARBON-CARBON

TASK A-I THREAD EVALUATION REPORT

FOR

LTV AEROSPACE

P.O. NO. P-817740

Prepared By: ______________________

Dana Godwin - Project Engineer

Approved By: ______________________

Billy Lapham - Engineering Manager

1.0 INTRODUCTION

Thread sewn through prepreg carbon cloth layups is being considered to reinforce carbon-carbon material parts. The thread, constructed of carbon fibers, is expected to increase the interlaminar and shear strength of the carbon-carbon material improving torsion, compression, and impact properties. The thread is machine sewn placing fibers normal to the material surface or in the "Z"-axis in flat pieces. In this task, various types of carbon threads are evaluated to optimize the thread selection for use in reinforced carbon-carbon test samples that will later be produced and tested.

Nine thread samples were chosen for the thread evaluation. The nine samples represent thread from four manufacturers. Threads vary in size, construction and fiber type.

Thread evaluation is performed by testing and review of both Space Systems' test results and manufacturers' product data. Space Systems testing includes tensile tests, sewing, magnified examination of stitched prepreg, and lapped seam testing. A trade study was conducted to rank the thread samples. A thread is recommended based on the results of the data and trade study.

2.0 THREAD COMPARISON

2.1 MANUFACTURER DATA

Thread was obtained from four manufacturers: Albany International, Fabric Development, Coats and Clark, and Fiber Materials. The data provided by these companies relating strength, construction and fiber type is given in Table 1.

TABLE 1
MANUFACTURER THREAD DATA

MANUFACTURER	STYLE	FIBER	CARBON CONTENT	CONSTRUCTION	DIAMETER (IN.)	TENSILE STRENGTH (LB.)	KNOT STRENGTH (LB.)	TWIST (PER IN.)
Albany	T-300	Thornel Carbon	95	3-ply continuous filament	.028	N/A	N/A	12S/6.7Z
Albany	1000	Celion Carbon	95	3-ply continuous filament	.028	N/A	N/A	12S/6.7Z
Fabric Development	767	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fabric Development	693	Celion Carbon	95	3-ply continuous filament	.017	40.4	13.6	7Z
Fabric Development	692	Celion Carbon	95	2-ply continuous filament	N/A	N/A	N/A	9Z
Fiber Materials	4-K	Pan Carbon	95	Braided	.025	35	11	N/A
Fiber Materials	4-K, Microfil 40	Pan Carbon	95	Braided	.018	26	10	N/A
Coats & Clark	140 Matrix	Celion G-30-400	95	2-ply continuous filament, 1K	.013	N/A	N/A	9S/6Z
Coats & Clark	208 Matrix	Celion G-30-400	95	3-ply continuous filament, 3K	.016	N/A	N/A	9S/6Z

2.2 ILC TEST RESULTS

Testing was performed on the carbon thread samples to determine tensile strengths, both straight and knotted. ILC's Instron Model 1123 was used for the testing. Tests were performed according to ASTM test methods D-578 (straight) and D-2256 (knot). The results of this testing are given in Table 2 and Graph 1.

2.3 DETERMINATION OF OPTIMUM THREAD

It is concluded that those threads exhibiting the higher straight tensile strengths and knotted tensile strengths will be the best candidates for use in sewing the prepregs. The knotted tensile strength may give the more realistic guide as to the strength of the thread in stitchline configuration.

3.0 SEWING EVALUATION

3.1 SAMPLE PREPARATION

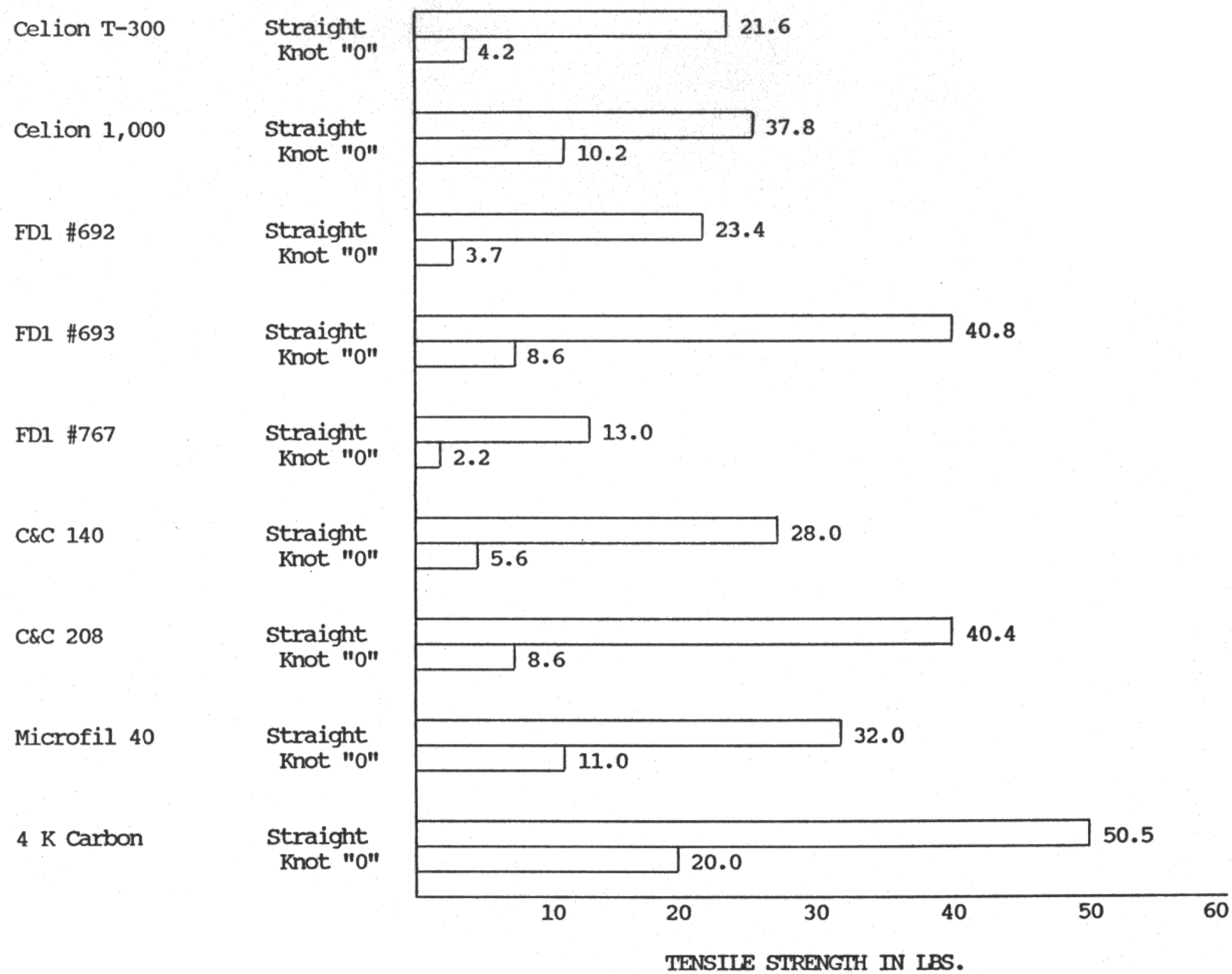
The "sewability" of the nine thread samples was tested on 6-ply prepreg samples. The stitching was accomplished using sharp point needles and Type 301 modified lock stitch. The modified lock stitch differs from the normal lock stitch in that the interlock of the top and bobbin threads occurs on the bottom surface of the prepreg. This stitch is produced by reducing the top thread tension. For each thread, several rows of stitching were made across a 6-inch square piece of material. The rows were tagged to allow evaluation after all the stitching was complete.

"Sewability" of each thread was determined during preparation of the samples and afterward by visual inspection and comparison. During preparation of the samples, the sewer made note as to the ease of stitching, rating the thread "sewability" good, fair or poor. The rating for each thread is given in Table 3.

TABLE 2

ILC TESTING
TENSILE AND KNOT STRENGTH
(AVERAGE BASED UPON 5 SAMPLES)

TYPE/DIAMETER (IN)	TENSILE STRENGTH (LBS)	
	STRAIGHT	KNOT TYPE O"
Celion T-300/.028	21.6	4.2
Celion 1000/.028	37.8	10.2
FDI 767/N/A	13.0	2.2
FDI 693/.017	40.8	8.6
FDI 692/N/A	23.4	3.7
FM Carbon 4K/.025	50.5	20.0
FM Carbon 4K/.018 Microfil 40	32.0	11.0
C&C 140/.013	28.0	5.6
C&C 208/.016	40.4	8.6



GRAPH 1
STRAIGHT TENSILE AND KNOT STRENGTH

TABLE 3

STITCHING TEST RESULTS

THREAD	SEWABILITY	MAGNIFICATION OBSERVATIONS
Celion T-300	Good	Thread filament splintering along entire stitchline, thread/fiber buildup on bottom.
Celion 1000	Good	Thread filament splintering intermittent along stitchline; overall appearance good.
FDI 767	Poor	Material abraded badly; thread filament splintering very bad, very apparent.
FDI 693	Good	Minimal thread filament splintering; material shows minimal abrasion at stitch holes; overall good appearance.
FDI 692	Good	Minimal thread filament splintering; minimal material abrasion at stitch holes; overall good appearance.
C&C 140	Fair	Material abrasion poor on underside and some stitch holes.
C&C 208	Fair	Excessive splintering of thread filaments on top and bottom surfaces; minor material damage on bottom.
FM Carbon 4K	Good	Thread filament splintering along stitchline; minor material wear on underside.
FM Carbon 4K Microfil 40	Good	Minimal thread filament splintering and stitch hole abrasion; very good stitching appearance overall.

3.2 VISUAL EXAMINATION OF STITCHING

The stitching samples were inspected visually using the unaided eye and 10X magnification. Table 3 relates the observations made. All of the samples showed some degree of material damage at the stitch holes. This could be minimized by the use of ball point needles instead of the sharp which tend to cut the cloth as they enter. A ball point needle spreads yarns apart to make space for the two threads and needle in each stitch hole.

3.2.1 Thread Damage

Thread damage was apparent where fibrils of carbon protruded from the stitchline between stitch holes. This occurred on all samples to some degree. The FDI 693 and 692, FM Carbon 4K Microfil, and Albany style Celion 1000 showed minimal surface thread splintering, under magnification. To the extreme contrast, FDI style 767 exhibited severe thread damage. It is possible that use of rounded needles could eliminate thread breakage in the 693, 692, Carbon 4K Microfil, and 1000 styles. Use of distilled water lubricant applied at a thread retention point on the machine has been suggested to minimize thread damage as well.

3.2.2 Material Damage

Under 10X magnification, the apparent cause of material damage on samples was deflection of warp and fill yarns. Tension of the stitchline and separation of warp and fill yarns by needle and thread resulted in bunching of yarns at stitch holes. This was pronounced in the FDI style 767 and Albany T-300 samples. Some material damage on the bottom side of these samples appeared to be caused by abrasion from machine surfaces as well.

4.0 LAPPED SEAM EVALUATION

4.1 SELECTION OF THREAD CANDIDATES

A trade study was performed to narrow the field of thread candidates for seam testing. The nine samples were ranked according to manufacturers' and ILC's tensile strength test reports, "sewability", and thread/ material damage. Table 4 relates these respective 1 to 3 scores for each thread. In cases where tensile strength or knot strength reported by manufacture and by ILC differed, the conservative lower value was used for ranking purposes.

As Table 4 reveals, the higher four total rankings were FDI style 693, FM Carbon 4K, 4K Microfil 40, and Albany style Celion 1000. The four ranked closely together with FM Carbon 4K Microfil 40 showing less tensile and FDI 693 having the lowest knot strength.

4.2 SAMPLE PREPARATION

Samples for each of the four selected thread styles were prepared for lapped seam testing. The samples consisted of two 3" x 4" pieces of 3-ply prepreg material joined along the 3" width by a lapped seam. The pieces were overlapped one inch and joined with two rows of stitching, 1/4" gauge, centered on the overlap. Type 301 modified lock stitch was used. Stitch pitch was 6 stitches per inch.

Using the Instron 1123 with 3" gauge length and 2 in./min. crosshead speed, the samples were pulled to the break point according to ASTM test method D-1683. Averages of the results are tabulated in Table 5 and charted in Graph 2.

TABLE 4

THREAD SAMPLE TRADE STUDY

THREAD TYPE	STRAIGHT TENSILE	KNOT TENSILE	SEWABILITY	THREAD/ MATERIAL DAMAGE	TOTAL
Albany T-300	2	1	3	2	8
Albany Celion 1000	3	2	3	2	10
FDI 767	1	1	1	1	4
FDI 693	3	2	3	3	11
FDI 692	2	1	3	3	9
FM Carbon 4K	3	2	3	2	10
FM Carbon 4K Microfil 40	2	2	3	3	10
C&C 140 Matrix	2	1	2	1	6
C&C 208 Matrix	3	2	2	1	8

Ranking ranges used:

Tensile 1 = 1-19 lbs.
2 = 20-34 lbs.
3 = 35-50 lbs.

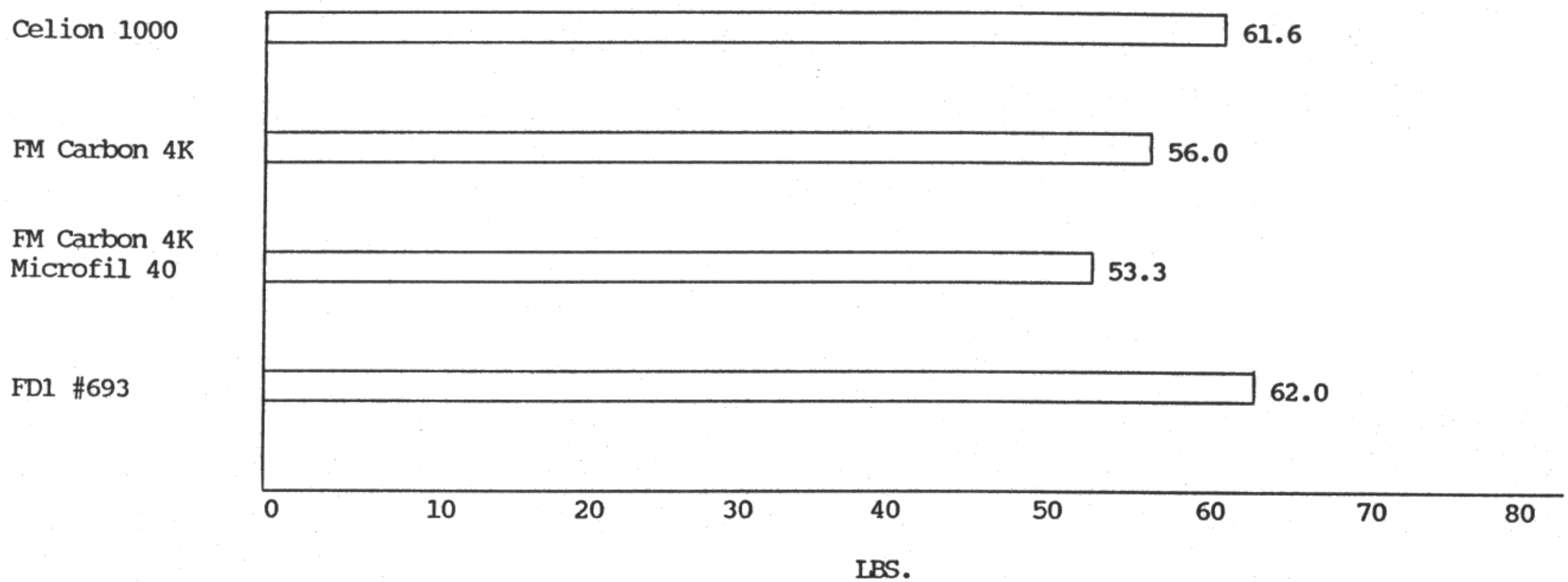
Knot 1 = 1-6 lbs.
2 = 7-12 lbs.
3 = 13-20 lbs.

TABLE 5

LAPPED SEAM PULL TESTS
(AVERAGE BASED UPON THREE SAMPLES)

THREAD	SEAM BREAKING STRENGTH (LBS)	COMMENTS
FDI 693	62.0	Damage apparent; material pulled out at stitch holes.
Celion 1000	61.6	Thread pulled to one side; material pulled and torn from stitchlines outward.
FM Carbon 4K	56.0	Material tearing horizontally along stitchline; minimal longitudinal shredding of material.
FM Carbon 4K Microfil 40	53.3	Longitudinal shredding of material on one side; other side shows no apparent damage other than thread break.

Machine Settings: 200 lbs. full scale
2 in./min. crosshead speed
3 in. gauge length



GRAPH 2
LAPPED SEAM TESTS

5.0 THREAD SELECTION/RECOMMENDATIONS

The results of the lapped seam testing reveal the highest seam strength in the FDI style 693. This thread also had the highest overall ranking as shown in Table 4. Although the lower knot strength value of 8.6 lbs. was used to rank in the trade study, the FDI 693 thread has been tested to 13.6 lb. knot tensile strength by the manufacturer.

Three threads ranked second to the FDI 693 thread in the trade study: Albany Celion 1000, FM Carbon 4K, and 4K Microfil 40. Each of these tested to seam strengths valuing at least 85% of the FDI 693 seam strength.

Based upon the overall ranking and seam testing results, it is recommended that further testing utilize the FDI 693 thread. It is possible that use of the ball point needle and lubrication of the carbon thread with distilled water will improve the stitching quality; therefore, these methods will be tried in subsequent sewing trials.