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DAMAGE TOLERANCE OF THIN SKIN SANDWICH PANELS. (U)

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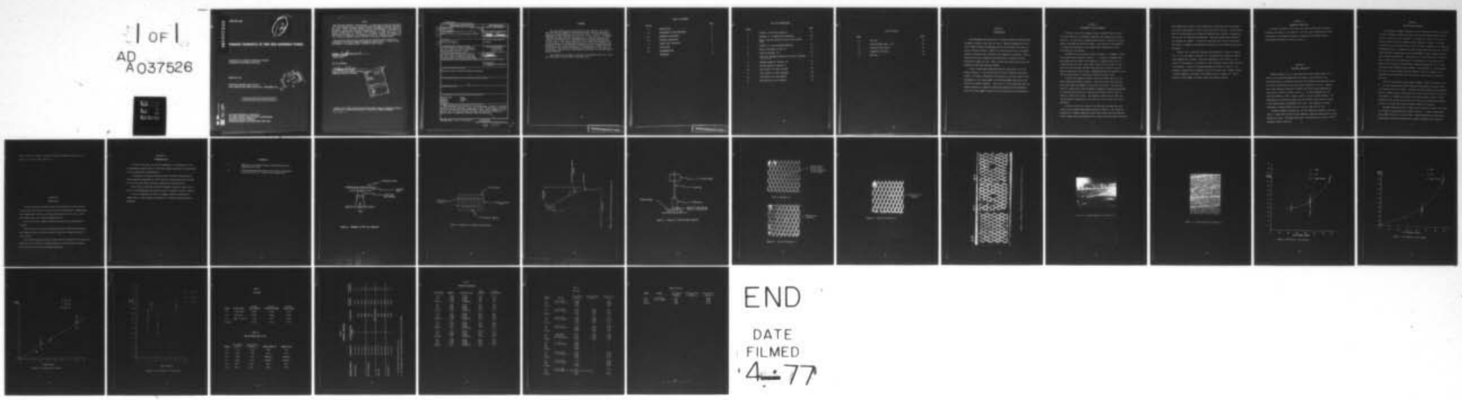

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DAMAGE TOLERANCE OF THIN SKIN SANDWICH PANELS

COMPOSITE AND FIBROUS MATERIALS BRANCH
NONMETALLIC MATERIALS DIVISION

FEBRUARY 1977

TECHNICAL REPORT AFML-TR-76-185
FINAL REPORT FOR PERIOD APRIL 1976 - SEPTEMBER 1976

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Andrew E. Steinmann

ANDREW E. STEINMANN
Project Monitor

FOR THE COMMANDER

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REPORT DOCUMENTATION PAGE

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14

1. REPORT NUMBER: AFML-TR-76-185

2. GOVT ACCESSION NO.

9

3. RECIPIENT'S CATALOG NUMBER

6

4. TITLE (and Subtitle): Damage Tolerance of Thin Skin Sandwich Panels.

5. TYPE OF REPORT & PERIOD COVERED: Final rept, Apr[redacted] – Sept[redacted]976

6. PERFORMING ORG. REPORT NUMBER

10

7. AUTHOR(s): Andrew E. Steinmann

8. CONTRACT OR GRANT NUMBER(s): In-House

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Air Force Materials Laboratory (AFML/MBC)
Air Force Wright Aeronautical Laboratories
Wright-Patterson AFB, Ohio 45433

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

12 33 p.

11. CONTROLLING OFFICE NAME AND ADDRESS:
Air Force Materials Laboratory (AFML/MBC)
Air Force Wright Aeronautical Laboratories
Wright-Patterson Air Force Base, Ohio 45433

11

12. REPORT DATE: Feb[redacted]77

13. NUMBER OF PAGES: 34

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Sandwich Panel, Aluminum, Honeycomb, Composite, Epoxy, Graphite, Glass

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An instrumented test procedure for low energy impact tolerance of thin skin sandwich panels was developed. Damage modes of this test were shown to correlate on a one-to-one basis with actual falling ball tests. Basic parameters of core density, cell size, skin thickness, and fiber orientation were examined and results useful to designing of sandwich panels are discussed.

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FOREWORD

The work reported here was performed in the Composite and Fibrous Materials Branch, Nonmetallic Materials Division, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio. Andrew E. Steinmann, AFML/MBC, was the principal investigator.. The author wishes to acknowledge George Husman for his invaluable help in both the planning and analysis of this work and in consultation and reviewing the preparation of this report. The author would also like to thank the Nondestructive Evaluation Branch of the Materials Laboratory for the C-scans and X-rays presented as well as Ron Esterline of the University of Dayton Research Institute for the testing of samples in the MTS phase of this work, and Ron Cornwell, University of Dayton Research Institute, for the photomicrographs presented.

This report was released by the author in September 1976, and covers the time period of April 1976 to September 1976.

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SECTION I

INTRODUCTION

The development and application of advanced composite materials has progressed rapidly in the last ten years. Advanced composites are currently being utilized in empennage and various secondary structures on several military aircraft. Many of the applications involve honeycomb sandwich structures with relatively thin composite face sheets. This is especially true for secondary structures where the design is often governed by weight and cost. Many of these structures utilize very low density core and very thin face sheets.

A major concern with using this type of construction is lack of damage tolerance. A thin and relatively brittle composite face sheet bonded to a fragile, low-density core produces a structure that is very susceptible to low energy impact and handling damage that may be very difficult to detect visually. Therefore, it is very important that the damage tolerance of composite sandwich structures and the parameters that affect this damage tolerance be well characterized and understood.

SECTION II

DEVELOPMENT OF TEST PROCEDURE

In the past, most impact damage testing on sandwich panels has been done with some type of falling-ball apparatus; the damage being visually inspected. In this study a technique better suited to analysis of failure modes by instrumented testing was sought. As a solution to this problem, a procedure was developed to test sandwich panel specimens on an MTS servo-hydraulic test machine.

A schematic of the specimen is shown in Figure 2. A schematic of the test machine setup is shown in Figure 1. A 0.8125 inch diameter ball was pressed into the center of the sample at a constant stroke rate of 0.00625 inches per second. While other stroke rates were tried, it was found that this rate gave the best load-deflection curve which could be used to characterize failure modes. Maximum deflection was limited to 0.25 inch by stroke control in the machine (accurate to about 1-2%).

A typical load versus deflection curve from the MTS test run at the above conditions is shown in Figure 3. The point at which the curve departs from linear was assumed to be initial core failure. Following this there is a small drop in load attributed to adhesive cracking and debonding. The specimen then continues to load until skin failure occurs, which is shown by a sharp drop in load. The energies at which each of these occur was calculated by measuring the area under the curve to that point with a planimeter.

In order to verify the results of the MTS test, specimens were also tested on the falling weight apparatus shown in Figure 4. The weight was dropped from a measured height and caught after it had struck the specimen. Rebound height was then estimated and net energy into the specimen calculated.

Drop heights were chosen so that energy into the specimen would be slightly more than energy needed to cause a particular type of failure. After testing, some of the specimens were X-rayed and examined with ultrasonic transmission C-scans for core buckling and debonding. The other samples were dissected and examined for damage. It should be noted here that no test to determine the effect of damage on the mechanical properties of the sandwich panels was performed.

Tables 1 and 2 show data obtained from both tests. X-rays of samples 2-5, 7, and 9 are shown in Figures 4-6. Increasing core failure is evident. Close examination of Figure 5 shows the beginning of core failure at the center of the specimen. In contrast to this is Figure 6 which shows extensive core buckling. C-scans of the same specimens are shown in Figure 7. Debonding is present only in samples 2-7 and 2-9 as predicted. Figure 8 shows a photomicrograph of the skin in the impacted area of sample 2-9. The beginning of skin damage is present along with adhesive failure.

SECTION III

PARAMETRIC EVALUATION

A series of parametric tests were run using the MTS test described to determine the effect of core density, cell size, skin thickness, and fiber orientation on the damage tolerance of composite skin sandwich panels. The parameters studied are listed in Table 3.

SECTION IV

SPECIMEN FABRICATION

Sandwich panels, 9" x 9", were fabricated with graphite/epoxy face sheets on one side and glass/epoxy face sheets on the opposite side. The graphite/epoxy face sheets were made from AS/3501-S prepreg manufactured by Hercules Incorporated, and cured using a modified cure cycle. Samples were taken from each laminate for density and fiber volume measurements; the results of which are shown in Table 4. Photomicrographs were also taken and showed no voids. Figure 9 shows a typical photomicrograph. The glass/epoxy face sheets were made from 3M Scotchply -1002 cured according to the manufacturer's recommended cure cycle. 5052 hexagonal aluminum honeycomb of varying density and cell size was used for the core.

Following laminate fabrication, the face sheets were bonded to the core with B. F. Goodrich's PL-729-3 epoxy adhesive, using the manufacturer's recommended cure cycle. Following fabrication, the panels were cut into 3" by 3" specimens using a band saw.

SECTION V

RESULTS AND DISCUSSION

A comparison of damage resistance to skin thickness and fiber orientation is shown in Figures 10 and 11 for both core and skin failure (Table 5) gives results of MTS test on all samples). The energy for initial core and skin failure increases with increasing laminate thickness. However, it should be noted that core failure occurs at very low impact energies for all laminate thicknesses tested. A comparison of ply lay-ups shows that both the $\pm$ 45 and quasi-isotropic orientations are more susceptible to impact damage (weaker) than the 0/90 configuration. This holds true for both skin and core failure. Most of this effect is probably due to distributing of the energy in the ribbon (0^{o}) direction by the 0/90 skin, thereby allowing the core to carry the load in the strongest manner possible. This happens to a lesser degree with the $\pm$ 45 and the quasi-isotropic tends to distribute energy in all directions, not allowing the core to carry the load in any one preferred direction.

A plot of core density versus impact energy is shown in Figures 12 and 13. The core failure point varies linearly with density, the size of the cell having little or no effect. The point at which laminate failure begins shows no apparent trend; the scatter in the data being too wide to draw any conclusions. It should be noted that core failure energy level is so low compared to skin failure (2 in/lb vs. 18 in/lb) that no appreciable support is given to the skin from even the higher density cores tested.

The above mentioned scatter could be due to several factors, most likely the varying of skin properties as shown in Table 4. Fiber volumes range from a high of 62.8% to a low of 46.8%. Other variables that could effect consistency of data are differences in cures for both skin and adhesives and on large cell sizes, the point at which the sample was tested (i.e., middle of cell,cell wall, node, etc.).

SECTION VI
CONCLUSIONS

The test procedure developed using the MTS machine provides load-deflection data with specific inflection points corresponding to damage modes. These damage modes have been correlated with those found to occur at the same energy levels in a falling weight-type test.

Both core and skin damage thresholds increase with increasing skin thickness.

Fiber orientation influences damage thresholds; 0/90 being strongest, most damage resistant,and quasi-isotropic being least damage resistant of those tested.

Core failure energy increases linearly with core density, but varying core density has little effect on energy required to produce laminate failure. Cell size had little effect on damage resistance.

SECTION VII

RECOMMENDATIONS

A study of the effect of the size (diameter) of the impactor on the failure modes should be done to learn how energy is absorbed and distributed by the sandwich panel configuration.

A comparison of fibers and resins as well as hybrid combinations of fibers should be undertaken to find a skin that distributes energy through the core more efficiently and has a high skin failure threshold.

Other types of adhesives should be examined, especially less brittle ones, so that debonding could be made less of a problem in impact failures.

A test to determine the effect of damage, perhaps as measured by energy input, on the mechanical properties of sandwich panels should be developed.

REFERENCES

1. "Mechanical Properties of Hexcel Honeycomb Materials", TSB120, Hexcel, 1972.

2. "Intermediate Heat Resistant Flexible Structure Bonding Aircraft Films", B. F. Goodrich Co. Product Data.

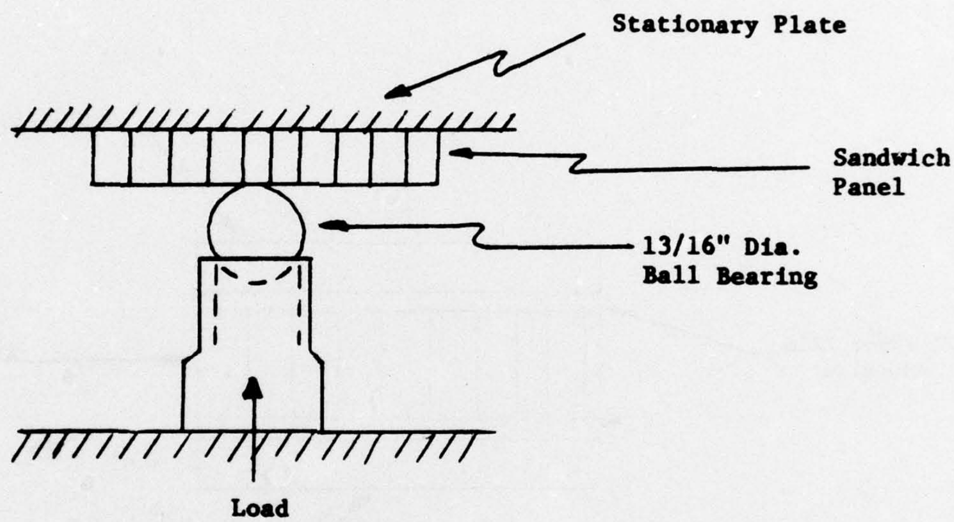


Figure 1. Schematic of MTS Test Apparatus

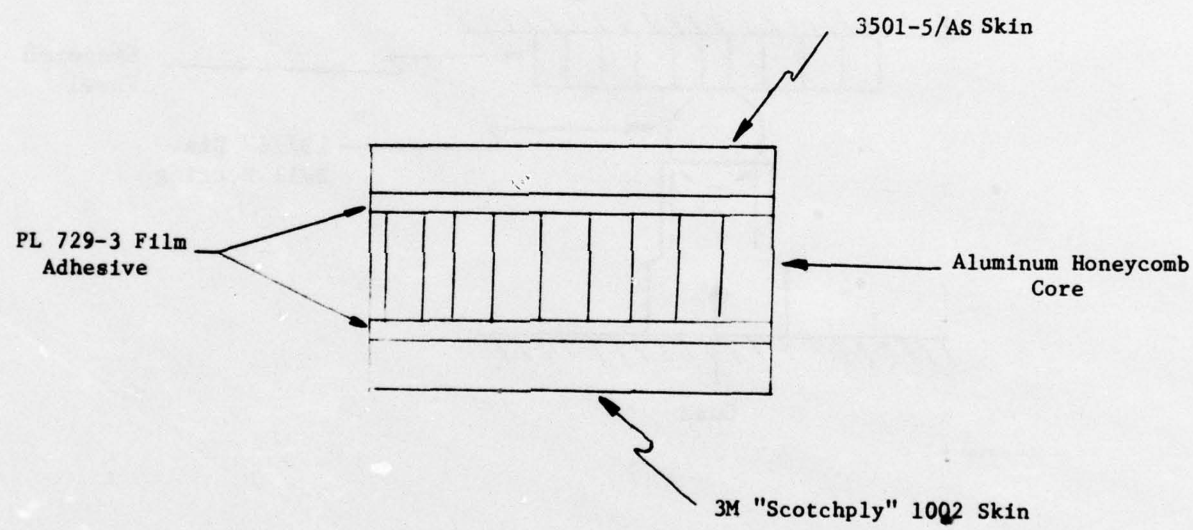


Figure 2. Schematic of a Sandwich Panel Specimen

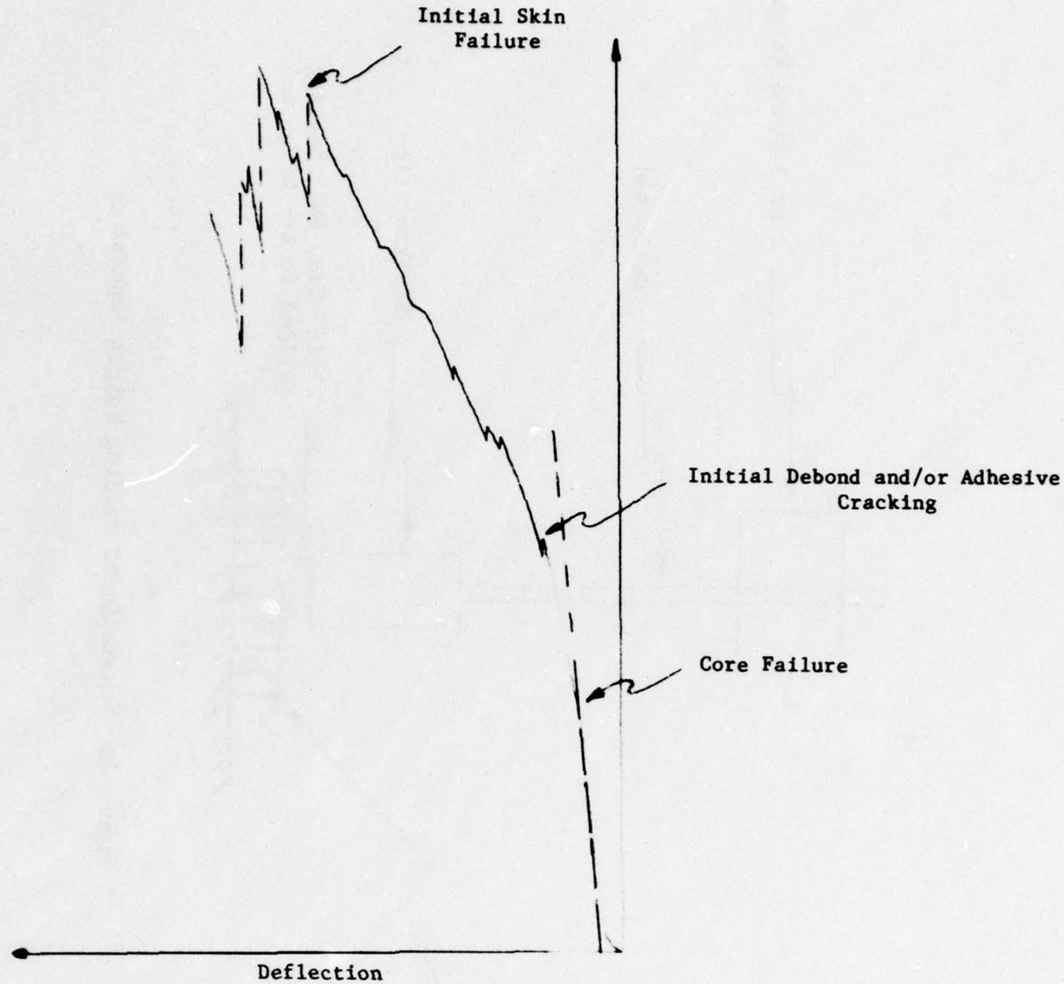


Figure 3. Typical Load vs. Deflection Curve Given by MTS Test

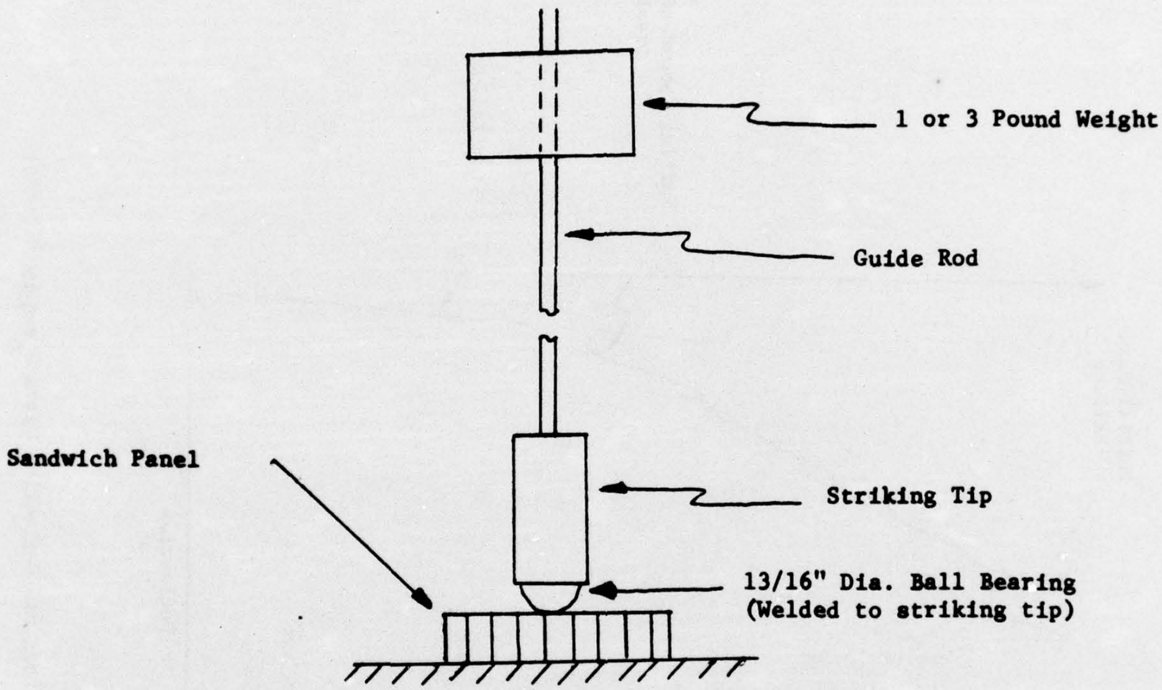
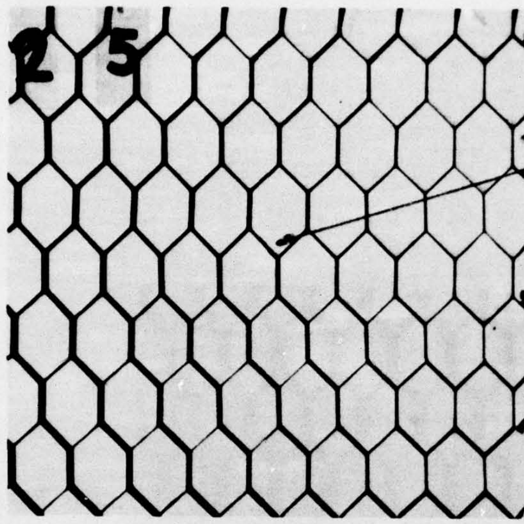


Figure 4. Schematic of Falling Weight Apparatus



X-Ray of Specimen 2-5

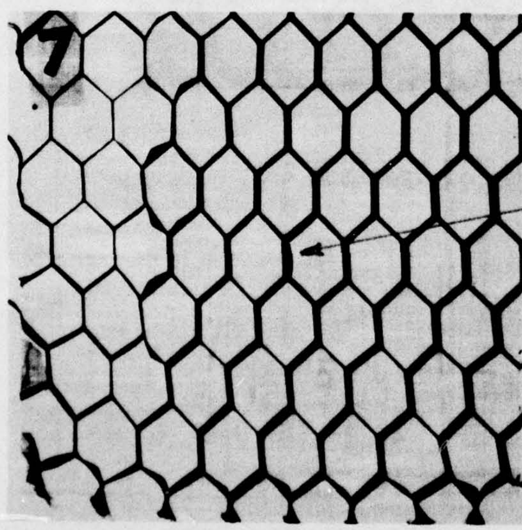


Figure 5. X-Ray of Specimen 2-7

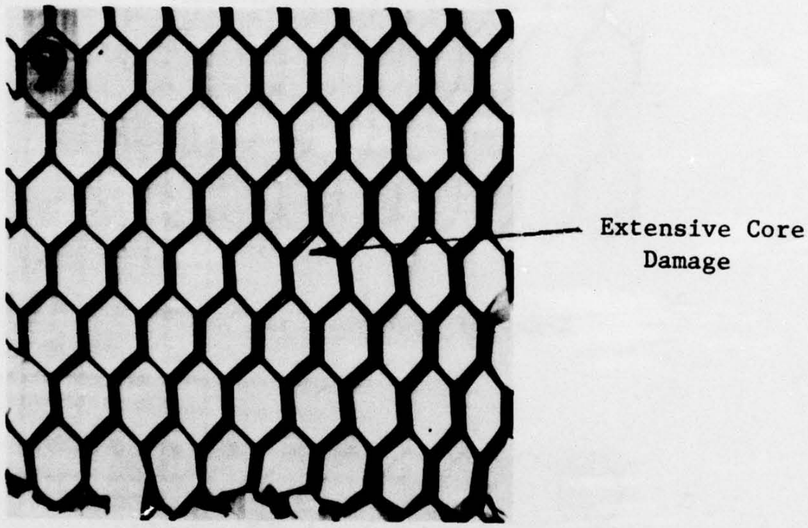


Figure 6. X-Ray of Specimen 2-9

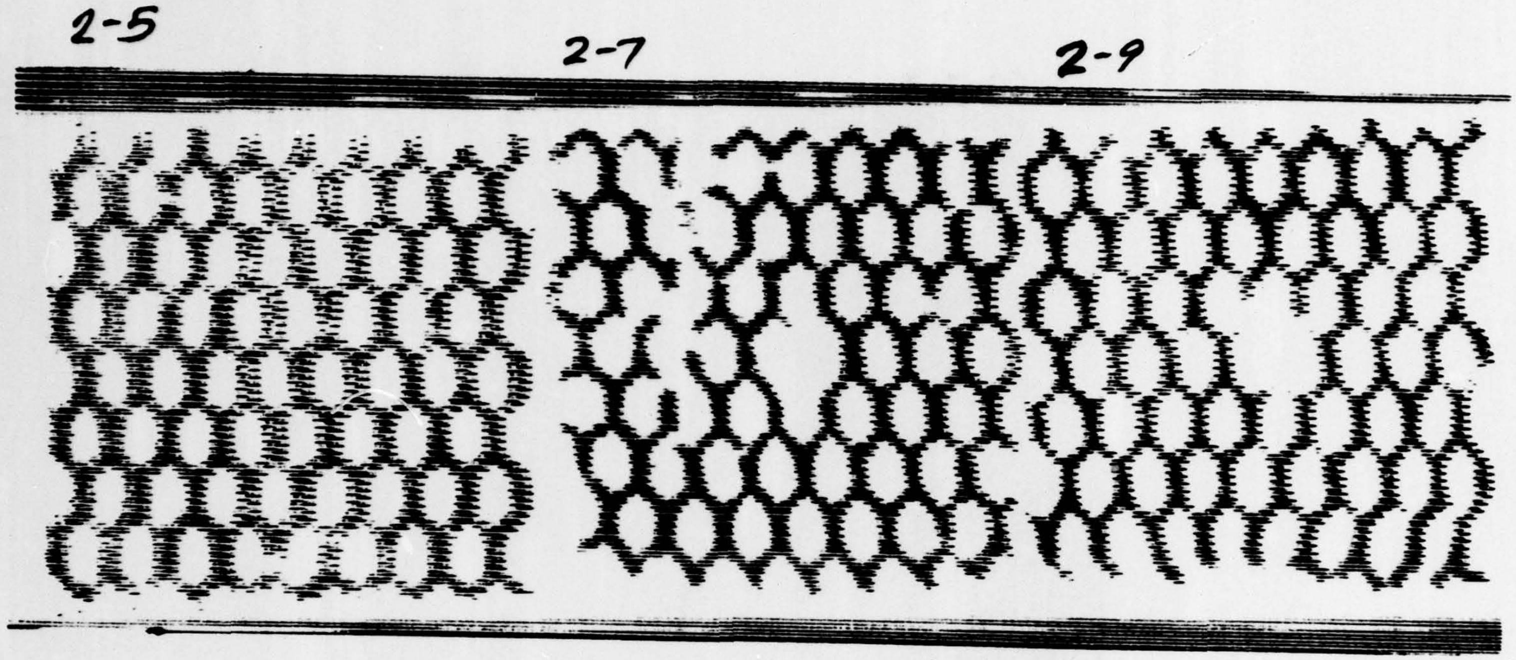


Figure 7. Ultrasonic Through-Transmission C-Scans of Samples 2-5, 7, & 9

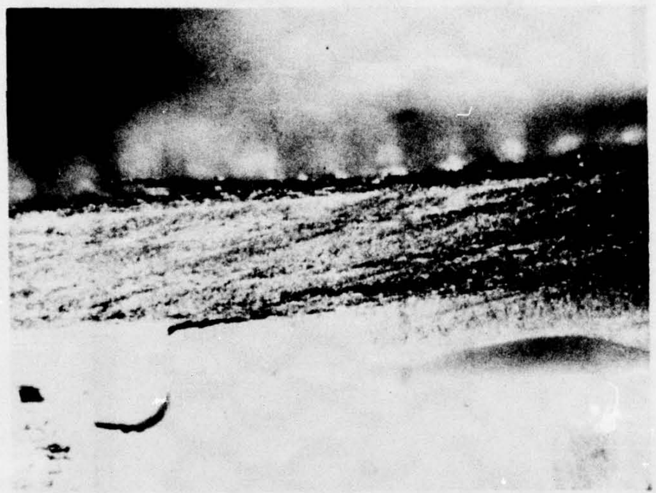


Figure 8. Photomicrograph of Specimen 2-9

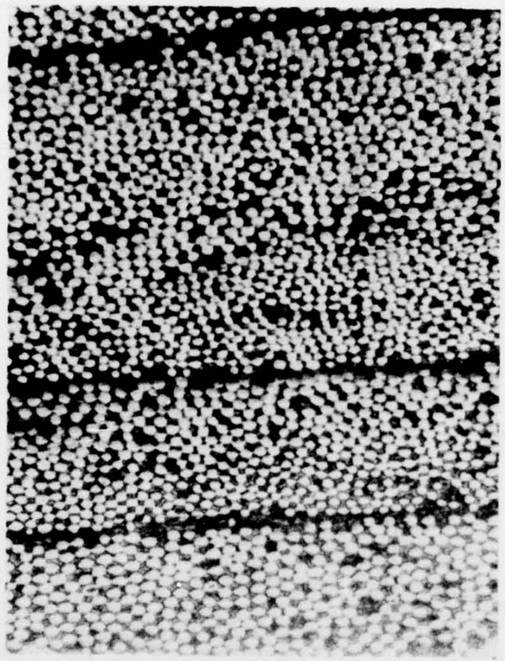


Figure 9. Photomicrograph of Sample 4-A

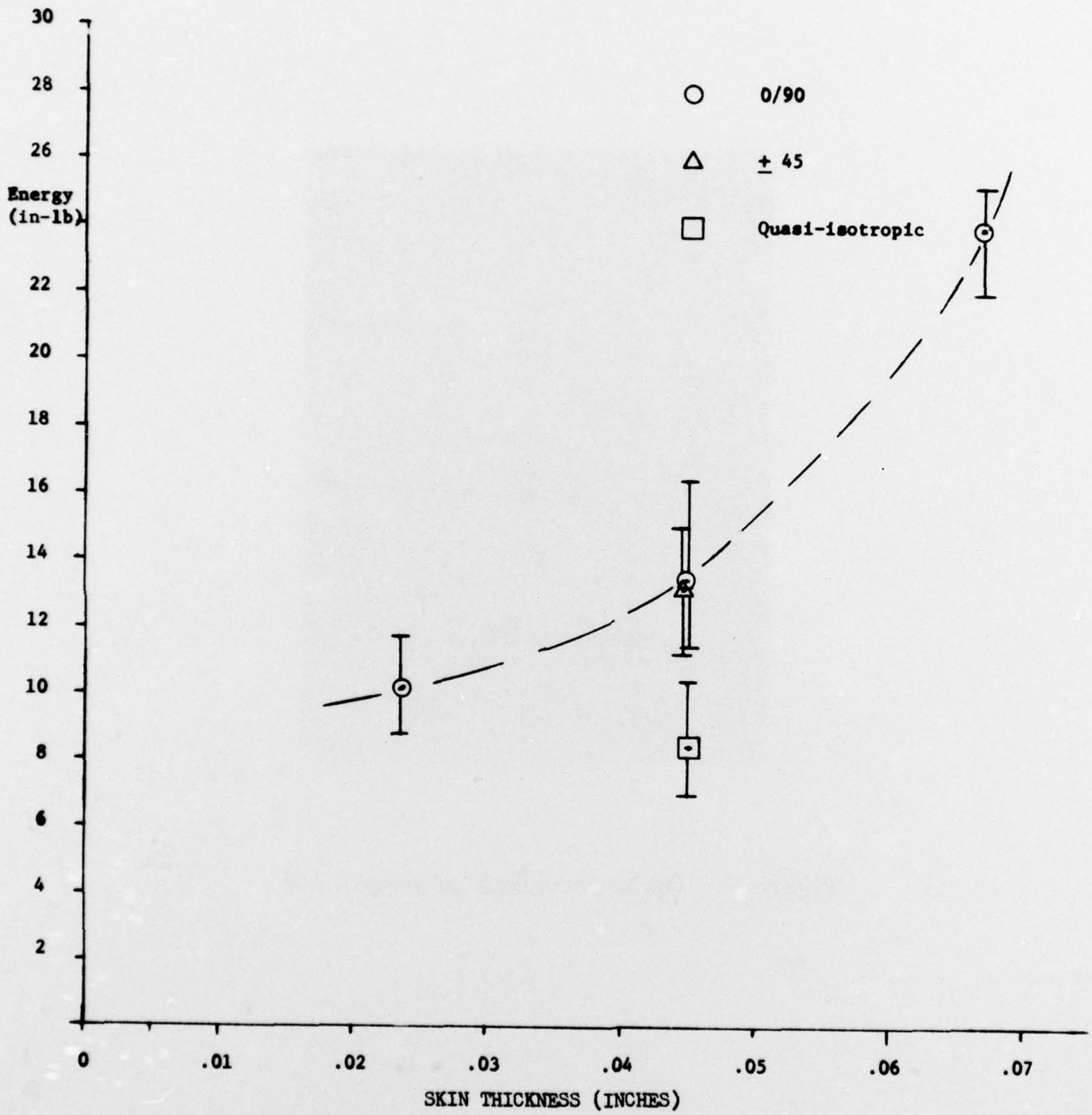


Figure 10. Skin Failure vs. Skin Thickness

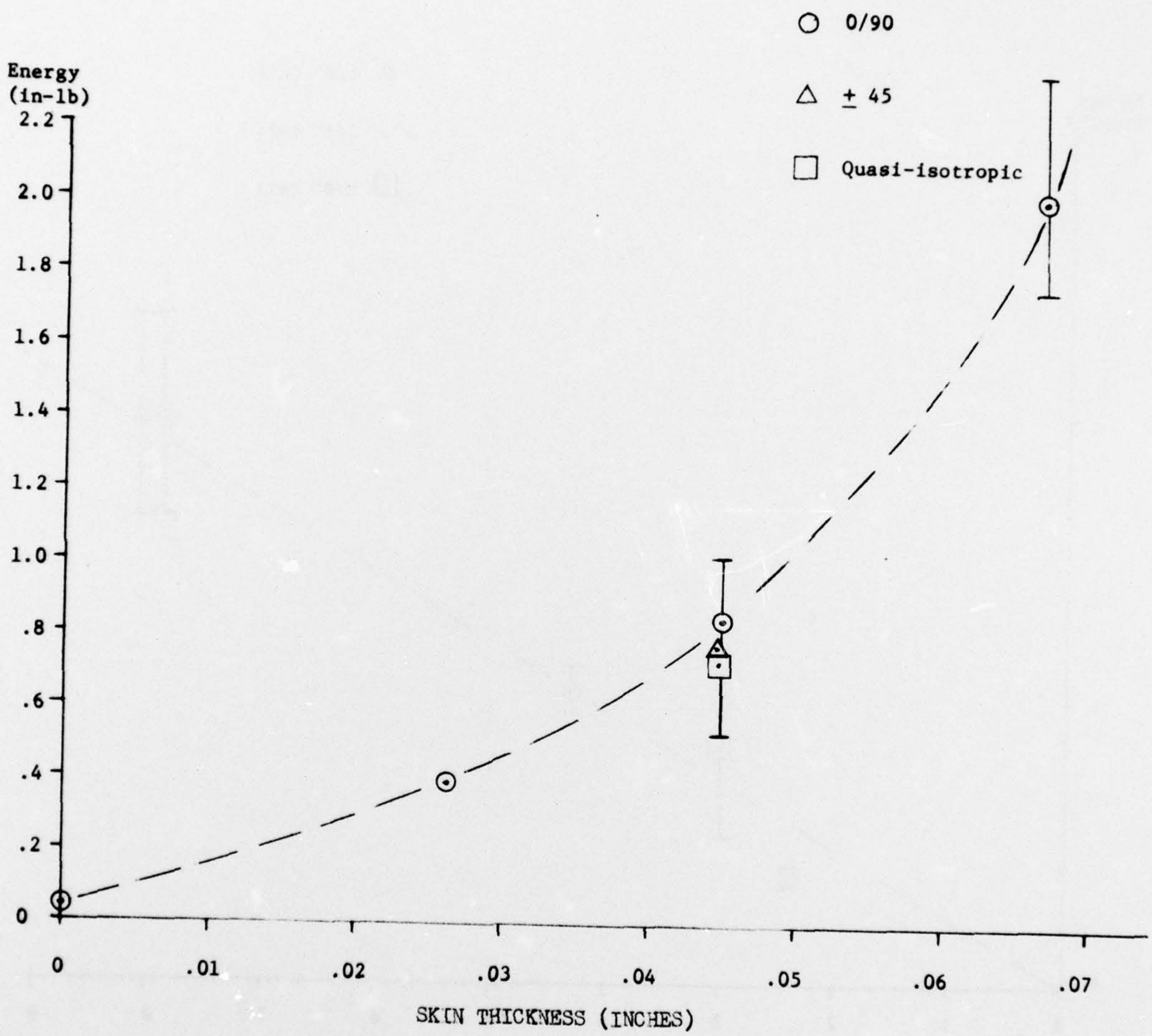


Figure 11. Core Failure vs. Skin Thickness

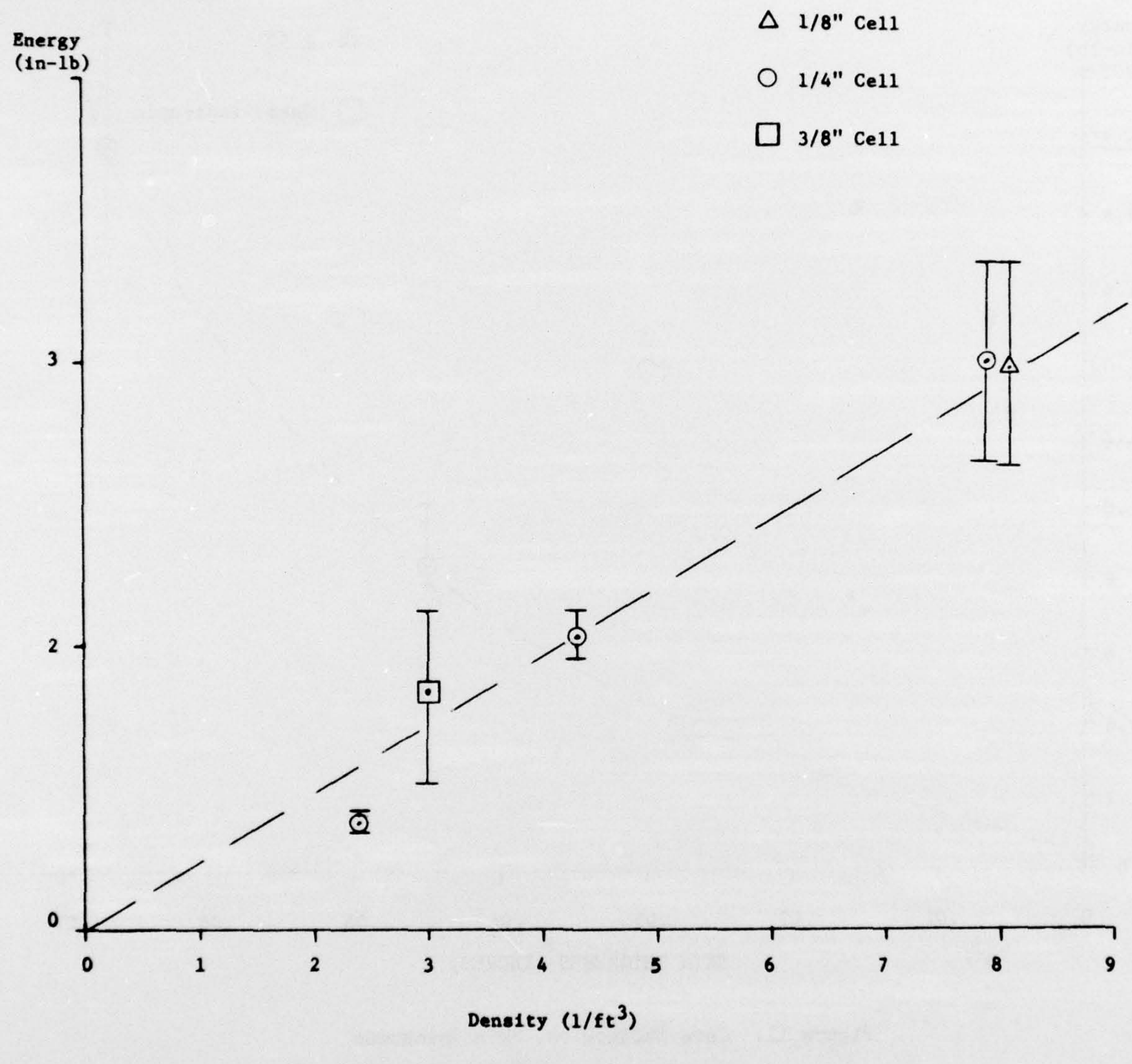


Figure 12. Core Failure vs. Core Density

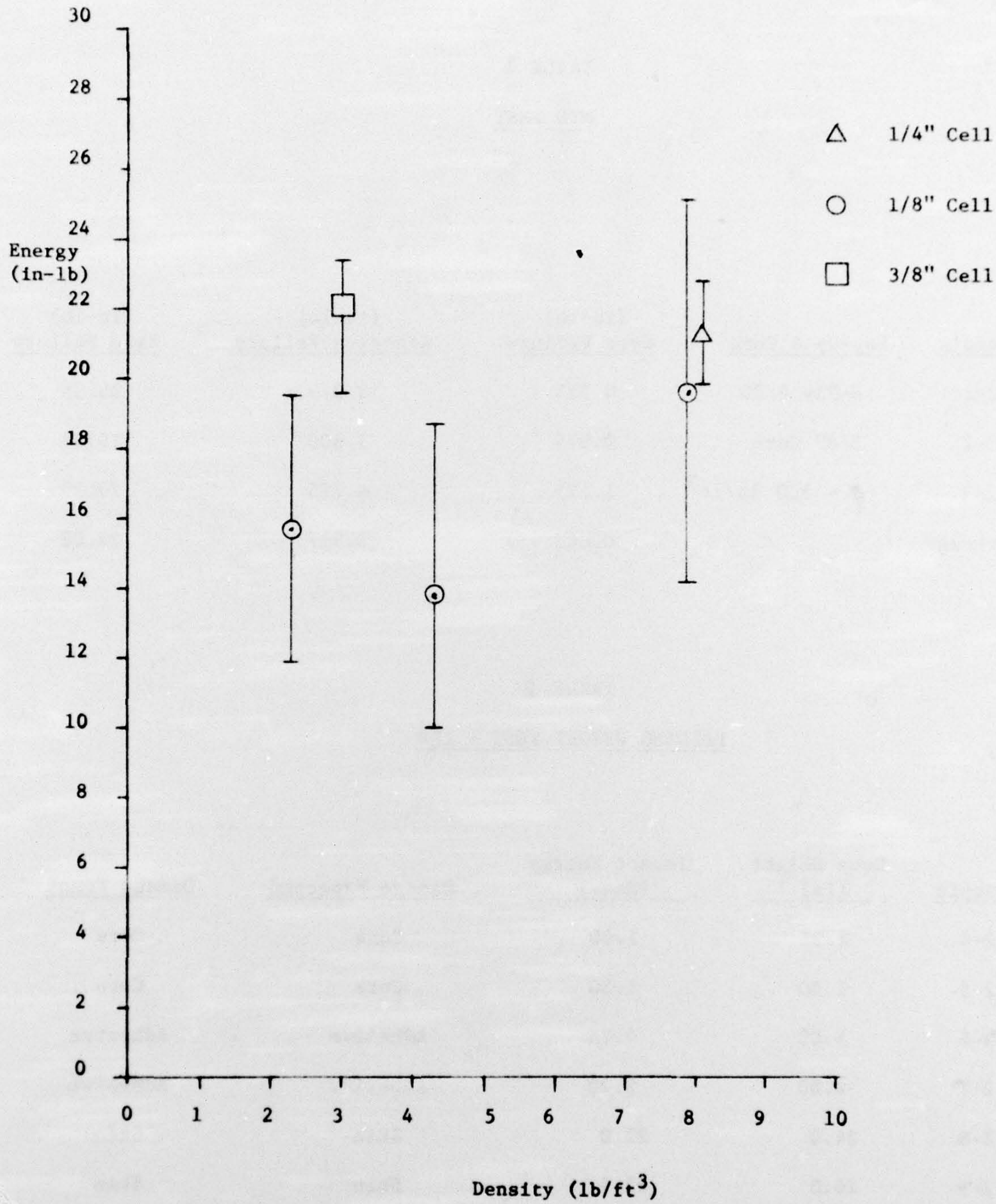


Figure 13. Skin Failure vs. Core Density

TABLE 1

MTS TEST

Sample	Lay-Up & Core	(in-lb) Core Failure	(in-lb) Adhesive Failure	(in-lb) Skin Failure
2-1	4-Ply 0/90	0.525	3.375	23.35
2-2	3/8" Core	0.875	3.600	19.58
2-3	ρ = 3.0 lb/ft^3	1.125	4.775	23.35
Average		0.842	3.917	22.08

TABLE 2

FALLING WEIGHT TEST - 1LB

Sample	Drop Height (In)	Impact Energy (Est.)	Damage Expected	Damage Found
2-4	1.25	1.00	Core	Core
2-5	1.50	1.30	Core	Core
2-6	5.00	4.25	Adhesive	Adhesive
2-7	6.00	5.20	Adhesive	Adhesive
2-8	24.0	22.0	Skin	Skin
2-9	26.0	23.5	Skin	Skin

TABLE 3

PARAMETRIC EVALUATION

Parameter Studied	Specimen Nrs.	Laminate Thickness (Plies)	Orientation*	Cell Size (Inches)	Core Density (lb/ft^3)
Skin Thickness	6-1 to 6-3	0	-	0.375	3.0
	1-1 to 1-3	4	0/90	0.375	3.0
	2-1 to 2-3	8	0/90	0.375	3.0
	3-1 to 3-3	12	0/90	0.375	3.0
Fiber Orientation	2-1 to 2-3	8	0/90	0.375	3.0
	4-1 to 4-3	8	± 45	0.375	3.0
	5-1 to 5-3	8	Quasi-isotropic	0.375	3.0
Cell Size	11-1 to 11-3	8	0/90	0.125	8.1 +
	8-1 to 8-3	8	0/90	0.250	4.3
	2-1 to 2-3	8	0/90	0.375	3.0
Core Density	7-1 to 7-3	8	0/90	0.250	2.3
	8-1 to 8-3	8	0/90	0.250	7.9

* - $0°$ Direction = Ribbon direction in core

+ - Foil thickness was the same although density varies for these samples.

TABLE 4

COMPOSITE PROPERTIES

Part-Sample	ρ(g/cc)	Thickness (in.)	Fiber Volume %	Resin (Calculated)
1-A	1.591	0.0234	62.2	37.8
1-B	1.594	0.0234	62.8	37.2
1-C	1.584	0.0240	60.8	39.2
Average	1.590	0.0059/ply	61.9	38.1
2-A	1.597	0.0453	63.4	36.6
2-B	1.591	0.0454	62.2	37.8
2-C	1.594	0.0441	62.8	37.2
Average	1.594	0.0056/ply	62.8	37.2
3-A	1.577	0.0451	59.4	40.6
3-B	1.579	0.0451	59.8	40.2
3-C	1.588	0.0437	61.6	38.4
Average	1.581	0.0056/ply	60.3	39.7
4-A	1.556	0.0451	55.2	44.8
4-B	1.576	0.0451	59.2	40.8
4-C	1.577	0.0437	59.4	40.6
Average	1.570	0.0056/ply	57.9	42.1
5-A	1.514	0.0453	46.8	53.2
5-B	1.569	0.0453	57.8	42.2
5-C	1.581	0.0441	60.2	39.8
Average	1.555	0.0056/ply	54.9	45.1
6-A	1.580	0.0427	60.0	40.0
6-B	1.564	0.0480	56.8	43.2
6-C	1.579	0.0460	59.8	40.2
Average	1.574	0.0057/ply	58.9	41.1

TABLE 5

MTS TEST

Sample	Lay-Up	Core Failure (in-lb)	Adhesive Failure (in-lb)	Fiber Failure (in-lb)
1-1	4-ply 0/90	0.400	-	11.74
1-2	3/8" cell, ρ=3.0	0.400	-	10.00
1-3		0.375	-	8.69
Average		0.392	-	10.14
2-1	8-ply 0/90	0.525	3.375	11.35
2-2	3/8" cell, ρ=3.0	0.875	3.600	12.55
2-3		1.125	4.775	16.40
Average		0.842	3.917	13.43
3-1	12-ply 0/90	2.375	4.850	24.73
3-2	3/8" cell, ρ=3.0	2.000	5.400	21.85
3-3		1.750	4.500	25.23
Average		2.042	4.917	23.93
4-1	8-ply $\pm$ 45	0.750	2.175	15.00
4-2	3/8" cell, ρ=3.0	0.750	2.750	19.00
4-3		0.800	3.850	11.25
Average		0.767	2.925	15.08
5-1	8-ply Quasi-	0.750	2.250	7.88
5-2	isotropic	0.775	2.125	10.40
5-3	3/8" cell, ρ=3.0	0.675	3.650	6.88
Average		0.733	2.675	8.38
6-1	None	0.050	-	-
6-2	3/8" cell, ρ=3.0	0.025	-	-
6-3		0.050	-	-
6-4		0.038	-	-
Average		0.041	-	-
7-1	8-ply 0/90	0.375	-	19.50
7-2	1/4" cell, ρ-2.3	0.350	-	15.78
7-3		0.425	-	11.93
Average		0.383	-	15.75
8-1	8-ply 0/90	1.125	-	18.68
8-2	1/4" cell, ρ=4.0	-	-	10.00
8-3		0.950	-	12.78
Average		1.030	-	13.82
9-1	8-ply 0/90	2.35	-	25.13
9-2	1/4" cell, ρ=7.9	Machine malfunction; no data		
9-3		1.65	-	14.13
Average		2.00	-	19.63

TABLE 5 (Cont'd)

Sample	Lay-Up	Core Failure (in-lb)	Adhesive Failure (in-lb)	Fiber Failure (in-lb)
11-1	8-ply 0/90	2.35	-	18.85
11-2	1/8" cell, ρ=8.1	1.63	-	21.88
11-3		1.95	-	22.80
Average		1.98	-	21.18

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