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Investigation of the Effect of Resin Material on Impact Damage to Graphite/Epoxy Composites

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16. Abstract

This report describes the results of an experimental program that establishes the feasibility and guide lines for new resins development. The objective was to identify the basic epoxy neat resin properties that will improve low velocity impact resistance and toughness to graphite/epoxy laminates and, at the same time, maintain useful structural laminate mechanical properties. Material tests from twenty-three toughened epoxy resin matrix systems are included in this investigation.

The apparent desirable neat resin properties to obtain the best combination of impact and mechanical composite properties are tensile strength above 6.89×10^7 Newtons/m^2 (10,000 psi), tensile modulus above 3.10×10^9 Newtons/m^2 (450,000 psi), and tensile elongation between 5 and 6%.

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FORWARD

This document is the final report on research into the effect of modified tough resins on the damage tolerance of graphite/epoxy laminates conducted under task 56 of contract NAS1-12675. The work was conducted from June, 1978 to Sept, 1980. Jerry G. Williams of Langley Research Center, Hampton, Virginia was the NASA technical monitor of the contract.

Mr. C.Y. Kam of the Douglas Aircraft Company was the program manager with technical activity being accomplished under the direction of Mr. R.J. Palmer. Materials and Process Engineering. Principle contributors to the Douglas activities were Mr. T. Loffenberg and G. Rodgers of Materials and Process Engineering. Thanks is expressed to all those in industry who supplied materials and data to enrich the development.

American Cyanamid, Havre de Grace, MD.
Air Logistics, Pasadena, Calif.
Ciba Ceigy, Ardsley NY and Duxford, England
Fiberite, Winona, Minn.
Hexcel, Dublin, Calif.
Narmco, Costa Mesa, Calif.
U.S. Polymeric Co., Santa Ana Calif.

Special acknowledgement is express to Dr. Bill Landrum, Ciba Ceigy, Corp for his continued support throughout the program.

The international system of units is used through this report.

SUMMARY

The results of an experimental program are described to evaluate the effects of "toughened" epoxy resin matrix systems (twenty-three in all) on both their ability to reduce the damage caused by low velocity impact and to retain high mechanical properties in graphite/epoxy laminates. The results of this program are intended to assist in establishing the guidelines for new resin developments.

The program was conducted in a series of five tasks as folows:

TASK 1	Basic neat resin properties of tensile, tensile modulus of elasticity and percent elongation were measured on most of the materials. Resin systems were selected with a wide variation of tensile properties.
TASK 2	These materials were obtained in prepreg tape form on Thornel 300 graphite and fabricated into thin isotropic fiber pattern plates, and tested for tolerance to free-fall round and blunt end impact damage.
TASK 3	These same materials were also fabricated into plates, cut into coupon size and tested for tensile, compression, shear and flexural mechanical properties.
TASK 4	These same materials were also fabricated into thick orthotropic plates and tested for impact damage tolerance and retained compressive strength after impact. The thick laminate plates were tested at NASA-Langley, and results will be published under a separate NASA report.
TASK 5	The data gathered during Task 1, 2, and 3 were assessed and a discussion presented on correlation of test results.

The significant conclusion of this investigation is that modification of the epoxy resin matrix properties used in a graphite composite laminate can reduce the damage caused by low velocity impact. This can be achieved with minimal changes in room temperature mechanical properties. The apparent desirable neat resin propeties to obtain the best combination of impact and mechanical composite properties are resin tensile strength above 6.89×10^7 N/m^2 (10,000 psi), tenesile modulus above 3.10×10^9 N/m^2 (450,000 psi), and tensile elongation between 5 and 6%.

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1.0 INTRODUCTION

Advanced composite materials are now being used in structural applications on a routine basis in military aircraft and are being applied to commercial aviation. Graphite/epoxy is the leading material to offer lightweight, strong, rigid structure and, at the same time, offer the potential for low-cost fabrication. It is expected that the surfaces of these structural components will be subjected to foreign object impact. This impact could cause significant damage at any time during initial fabrication and assembly operations, ground handling and take off, in-flight and landing operating conditions.

Studies, such as those sponsored by NASA and the Naval Air Development Center, have been conducted to determine the impact tolerance of current in use graphite/epoxy materials. (References 1, 2 and 4). These studies have shown that low velocity, hard object impact damage causes significant reduction of retained tensile and compression strength, even when the damage levels cannot be visually observed. Thin laminates showed decreasing residual tensile strength as the impact energy was increased beyond the visual threshold through extensive fracture of the fibers in the laminate. (Reference 3.) Thick 3.2 mm (1/4 inch) composite panels showed as much as 50 % reduction in retained compression strength and strain even when no visual surface damage was in evidence. (Reference 2.) NDT techniques using ultrasonic C-scan were used to exhibit the extent of internal damage.

The reduction in retained strength of less than visual impact damaged panels places a limiting strain factor in the structural component design that reduces the potential weight savings of the composites.

The objective of this program was to establish if a "toughened" resin matrix system could improve the impact resistance of a graphite/epoxy laminate. It has been observed that low level of impact failure in both thin and thick laminates is associated with brittle resin failure, that is, resin cracking (crazing) and interlaminar failure prior to actual fiber breakage that occurs at higher impact loads. It was projected that a combination of higher resin tensile, lower modulus or higher elongation should add toughness to the resin and improve impact properties of the resultant laminates. This was the logic that directed the development of a "tough" resin system.

The "toughening" was accomplished by resin and prepreg manufacturers who varied by any means at their disposal the neat resin tensile, modulus and percent elongation propeties with damage tolerance improvements as the singular objective. The materials, twenty-three in all, were supplied to Douglas as "B" stage unidirectional Thornel 300 tape. The materials were made into 8 and 48 ply panels for thin and thick laminate impact study. Thin laminate impact evaluations were made at Douglas. Thick laminate impact studies were made at NASA-Langley and are not repeated herein. In addition, unidirectional fiber orientation panels were fabricated and tested for flexural strength and modulus, short beam shear strength, tensile and compression strength and modulus at room temperature.

The data was reduced to determine any correlation between neat resin properties and the extent of impact damage to thin panels, and between neat resin properties and laminate mechanical properties.

2.0 TECHNICAL APPROACH AND TEST RESULTS

This section covers the detail of the technical approach and a summary of the test results to determine the effects of resin modification (toughened matrix) on impact resistance and mechanical properties of graphite/epoxy composites.

The program was conducted and is reported in a series of 5 tasks:

TASK 1 - Material Selection and Neat Resin Properties
TASK 2 - Thin Laminate Impact Properties
TASK 3 - Laminate Mechanical Properties
TASK 4 - Thick Laminate Impact Resistance
TASK 5 - Correlation of Test Results

2.1 TASK 1 - MATERIAL SELECTION

A survey was first made to select the epoxy resin manufacturers and graphite prepreg material suppliers that had active in-house resin development programs aimed at formulating improved "tough" graphite/epoxy material systems. The selected organizations that were interested in working on this NASA-sponsored program were then presented a summary of the objectives, scope, and limitations of the expected work. Narmco 5208/T-300 material was selected as a baseline material with which to compare test results. It is a widely used material with a large available data base.

The basic objective was to identify and establish the credibility of the assumption that modification of resin matrix properties of tensile strength, modulus of elasticity and/or percent tensile elongation properties could have significant effect on the impact resistant properties of graphite/epoxy structure. The program has considered only one variable, namely the resin matrix system. The same Thornel 300 (3000 filament) fiber was used throughout the program and although not from the same batch was assumed to be of consistant quality. There was no limit placed on processing cycles, and there was no attempt requested to optimize material handling properties. It was expected that new laboratory-prepared resins, with tailored "toughness" properties, might be difficult to handle in preparation of test panels. There was no request for any type of temperature or liquid enviornmental resistant properties, and no such tests were conducted. The long process for optimization of a potential new "tough" resin matrix system to obtain the most desirable handling, processing, and environmental characteristics could follow only after it was proven that such effort could be expected to be worthwhile. Such development would not be a part of this program.

The participating organizations were asked to supply 1.36 Kg (3-pounds) quantities of each modified resin system in a unidirectional prepreg tape form between 2.54 and 30.5 cm. (1 and 12 inches) in width, 150 ± 5 grams/square meter Thornel 300 fiber areal weight which corresponds to .13 mm (.005 inch) per ply cured laminate thickness, and between 35 and 45% resin content. In addition, complete processing instructions were supplied for each material. Some materials were supplied as "no charge" samples and others were purchased.

Finally, each supplier was asked to furnish, where possible, tensile properties of the neat resin system used. Preferably, the information was requested to be in the form of a stress vs. strain curve with data reduction for tensile ultimate, tensile modulus of elasticity, and percent elongation at failure.

A total of 23 different modified resin systems were obtained and tested during work on this program. Several systems were tested for effect of high and low resin content. The list of suppliers participating in the program along with their material identification numbers are listed in Table 1. In addition, a summary of all available neat resin properties and the general approach taken to provide the resin toughening mechanism are recorded in Table 1.

All available neat resin stress/strain curves are plotted in Figure 1. All neat resin properties, including stress/strain curves, were supplied by the individual suppliers. The neat resins were cast by most suppliers to the desired thickness and cured by a slow process in an oven to the final curing temperature. Coupons were machined to dog bone specimen configuration and tested for tensile load vs. deflection to failure.

Identification of commercial products in this report is used to adequately describe the test materials. Neither the identification of these commercial products nor the results of the investigation published therein constitute official endorsement, expressed or implied, of any such product by either The Douglas Aircraft Company or NASA.

2.2 TASK 2 -THIN LAMINATE IMPACT PROPERTIES

Materials were received from each of the suppliers along with quality control data of prepreg resin content and a recommended processing cycle. All plates required for the impact evaluation tests and the mechanical property tests were manufactured in a single processing cycle for each material system. All plates for thin laminate impact study were 8 ply [0,45,-45,90]s fiber pattern and all plates for mechanical property evaluation were of 0^o fiber pattern. Every curing cycle was monitored as to time, temperature, and pressure to be sure that the exact specificaton suggested by each of the suppliers was followed. These curing cycles were not optimized for the new laboratory scale toughened resin systems, and the possibility exists that an altered curing cycle investigation could have revised the impact and or mechanical property test results obtained on the cured laminates. Observe the effect presented later in Section 2.6 of this report of the altered slow cure cycle for Narmco

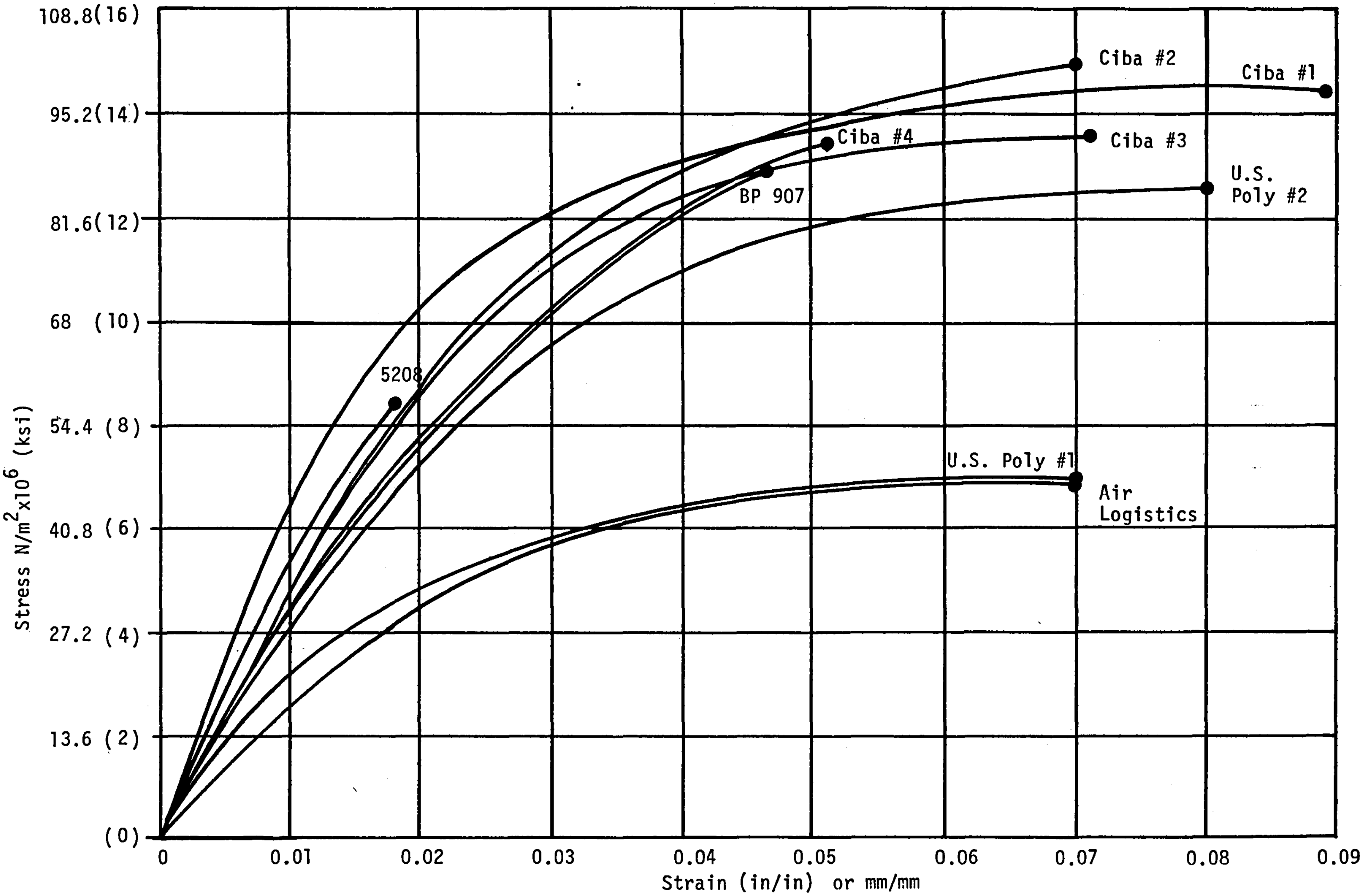
TABLE 1

NEAT RESIN PROPERTIES

NO.	NAME OF SUPPLIER	MATERIAL IDENTIFICATION	RESIN TOUGHENING MECHANISM	RESIN PROPERTIES		
				NEAT TENSILE ULTIMATE N/M^2 X 10^7 (PSI)	TENSILE MODULUS N/M^2 X 10^7(PSI)	% ELONGATION AT FAILURE
1	Narmco	5208	MY-720 Aromatic Amine	5.72 (8,300)	399.6 (580,000)	1.5
2	Narmco	95995	Epoxy Aromatic Amine	7.44 (10,800)	373.4 (542,000)	2.4
3	Narmco	X1114	Bis-Phenol A Nonaromatic Amine + Elastomers	3.15 (4,500)	165.3 (240,000)	6.0
4	Narmco	X108/34A	Bis-Phenol A Aromatic Amine + Elastomers	-	-	-
5	Narmco	107	Bis-Phenol A Nonaromatic Amine + Elastomers	-	-	-
6	Narmco	109	Bis-Phenol A Nonaromatic Amine + Elastomers	-	-	-
7	American Cyanamid	BP-907	Bis-Phenol A Latent Aliphatic Amine Vinyl Resin	8.92 (13,000)	310.1 (450,000)	4.8
8	American Cyanamid	919	Bis-Phenol A/Epoxy Novalac Latent Aliphatic Amine + Elastomers	-	-	-
9	American Cyanamid	937	Bis-Phenol A + Specialty Latent Aromatic Plus Aliphatic Amine + Elastomers	-	-	-
10	American Cyanamid	982	Bis-Phenol A/Epoxy Novalac Latent Aromatic and Aliphatic Amines	-	-	-

TABLE 1 (Cont'd)

NO.	NAME OF SUPPLIER	MATERIAL IDENTIFICATION	RESIN TOUGHENING MECHANISM	RESIN PROPERTIES		
				NEAT TENSILE ULTIMATE N/M^2 X 10^7 (PSI)	TENSILE MODULUS N/M^2 X 10^7 (PSI)	% ELONGATION AT FAILURE
11	Air Logistics	#1	Amine-Cured Elastomer Modified Bis-Phenol Epoxy	4.75 (6,900)	172.2 (250,000)	8.0
12	Ciba Geigy	#1	Hydantoin Aromatic Amine	9.92 (14,400)	443.7 (644,000)	8.7
13	Ciba Geigy	#1M	Hydantoin Aromatic Amine + Thermoplastic	-	-	-
14	Ciba Geigy	#2	Hydantoin Aromatic Amine	10.33 (15,000)	330.7 (480,000)	7.0
15	Ciba Geigy	#3	Hydantoin Aromatic Amine	9.43 (13,700)	333.5 (484,000)	7.0
16	Ciba Geigy	#4	Bis-Phenol A Aliphatic Amine + Thermoplastic	8.92 (13,000)	332.1 (482,000)	4.6
17	Ciba Geigy	Fiberdux 920	Bis-Phenol A Aliphatic Amine + Thermoplastic	7.51 (10,900)	312.1 (453,000)	4.1
18	Ciba Geigy	Fiberdux 914	Multifunctional Epoxy + Thermoplastic	4.96 (7,200)	399.6 (580,000)	1.4
19	Hexcel	#1	Bis-Phenol A High Functionality Epoxy Di-Cy + Elastomer	5.30 (7,700)	220.5 (320,000)	7.0
20	Hexcel	#2	Bis-Phenol A and F Di-Cy + Elastomer	4.47 (6,500)	254.9 (370,000)	1.9
21	Fiberite	HY-E 976	High Functionality Epoxy Aromatic Amine	6.20 (9,000)	257.6 (400,000)	5.0
22	U.S.Polymeric	#1	Bis-Phenol A + Specialty Aromatic Amine + Elastomers	4.82 (7,000)	234.3 (340,000)	19
23	U.S. Polymeric	#2	Bis-Phenol A + Specialty	9.37 (13,600)	-	8



NOTE: Curves are averaged results as recorded by various testing agencies and are intended to show general relationships.

FIGURE 1. TOUGH RESIN STRESS-STRAIN CURVES

5208 material and the resultant across the board improvement in all mechanical properties and impact properties (at least when tested at room temperature). We do not know the difference that the modified cure cycle makes in the basic neat resin properties. This optimization was considered beyond the scope of this program.

Table 2 summarizes the supplier recommended curing cycle for each individual material.

2.2.1 Impact Tests

All panels for the thin laminate impact tests contained an eight-layer balanced 0,+45,-45,90 fiber pattern. Quality control tests for each panel included a thickness measurement, resin and void content obtained by using the hot nitric acid digestion process, and a nondestructive test (NDT) C-scan print.

Impact tests were conducted on all materials using the Garnder Impact Tester and a portion of the materials using the Rheometric Constant Speed Impact Tester.

2.2.2 Gardner Impact Test

The Gardner Impact Tester, see Figure 2, used a free fall, .9 kilograms (two-pounds) weight, in the form of a 15.9 mm (5/8 inch) diameter rod with a rounded 15.9 mm (5/8 inch) diameter impact nose or a flat blunt 15.9 mm (5/8 inch) diameter impact nose. (See Figure 3.) The rod was lifted to a measured height, in Millimeters (inches), and was released for free fall down a guide tube to impact the specimen in a single impact.

All materials were impacted on the Gardner Impact Tester with a 31.8 mm (1.25 inch) diameter simple support, a 15.9 mm (5/8 inch) diameter impact head, and 1.13 (10), 2.26 (20) and 3.39 joules (30 inch pounds) free fall energy. All materials were also impacted on the Gardner Impact Tester with a 95.3 mm (3.75 inch) diameter simple support, a 15.9 mm (5/8 inch) diameter flat impact head, and at various levels between 1.13 joules (10) and 11.3 joules (100 inch pounds) free fall impact energy. (See Figure 2.)

The evidence and extent of visible back side damage from all Gardner Impact Tests in the 0^o and 90^o to surface fiber orientation are recorded in Table 3. A tabulation of all impact tests is presented for all materials in Appendix I that includes visual observations of both front and back side surfaces, a C-scan record, the square inch area of damage as shown by C-scan, and a general comment on failure apprearance.

Appendix II shows the damage to aluminum of equal weight and of equal thickness when impacted at the same levels.

TABLE 2

RECOMMENDED CURE CYCLES

NO.	NAME OF SUPPLIER	MATERIAL IDENTIFICATION	CURING SPECIFICATIONS
1	Narmco	5208	Room temp. to 135°C (275°F) 1.6 to 4.4°C/min (3 to 8°F) vacuum pressure then 6.9 x 10^5 N/m^2 (100 psi)/vent vacuum then 176°C(350°F)/6.9 X 10^5 N/M^2 (100 psi) 2 hours.
2	Narmco	95995	6.9 X 10^5N/M^2 (100 psi) from room temperature to 176°C (350°F) and hold 2 hours.
3	Narmco	X-1114	6.9 X 10^5N/M^2 (100 psi) from room temperature to 121°C (250°F) and hold for 1 hour.
4	Narmco	X-108/34A	6.9 X 10^5N/M^2 (100 psi) from room temperature to 176°C (350°F) and hold for 1 1/2 hours.
5	Narmco	107	Room temp. to 176°C (350°F) at 2.7°C/min (5°F) unde vacuum then 6.9 X 10^5N/M^2 (100 psi) to 176°C (350°F) for 90 minutes.
6	Narmco	109	Vacuum pressure from room temperature to 176°C (350°F) at 2.7°C/min (5°F) then 6.9 X 10^5 N/M^2 (100 psi) and 176°C (350°F) for 90 minutes.
7	American Cyanamid	BP-907	Apply vacuum and heat to 121°C (250°F) and hold for 1 hour. Apply 6.9 X 10^5N/M^2 and heat to 176°C (350°F) and hold for 1 hours (100 psi).
8	American Cyanamid	919	Apply vacuum and heat to 65°C (150°F) and hold for 1 hour. Then apply 6.9 X 10^5 N/M^2 (100 psi) and heat to 121°C (250°F) and hold for 1 hour.
9	American Cyanamid	937	Apply vacuum and heat to 121°C (250°F) and hold for 1 hour. Then apply 6.9 N/M^2 10^5 (100 psi) and heat to 176°C (350°F) and hold for 1 hour.
10	American Cyanamid	982	Apply vacuum and heat to 121°C (250°F) and hold for 1 hour. Then apply 6.9 x 10^5 N/M^2 (100 psi) and heat to 176°C (350°F) and hold for 1 hour.
11	Air Logistics	#1	6.9 X 10^5 N/M^2 (100 psi) from room temperature to 149°C (300°F) and hold for 2 hours.
12	Ciba Geigy	#1	30 min./room temp./vacuum. Raise pressure to 2 X 10^5 N/M^2 (30 psi) then temperature to 100°C (212°F) for 90 minutes then 176°C (350°F) for 3 hours at 5.5x10^5 N/m^2 (80 psi).
13	Ciba Geigy	#1M	30 min/room temp/vacuum. Raise temp. to 100°C (212°F) under vacuum then apply 6.9 X 10^5N/M^2 (100 psi). Raise temperature to 176°C (350°F) and hold for 3 hours.

TABLE 2 (Cont'd)

NO.	NAME OF SUPPLIER	MATERIAL IDENTIFICATION	CURING SPECIFICATIONS
14	Ciba Geigy	#2	30 min./R.T./vacuum. Raise pressure to 6.7 X 10^5N/M^2 (95 psi) then temperature to 79°C (174°F) and hold 90 minutes. Cool. Then post cure 2 hours at 300°F.
15	Ciba Geigy	#3	Raise pressure to 5.5 X 10^5N/M^2 and temperature to 100°C (210°F) and hold for 90 mintues. Temp. to 176°C (350°F) and hold 5.5 X 10^5N/M^2 (80 psi) for 3 hours.
16	Ciba Geigy	#4	Apply vacuum for 1 hour and then heat to 100°C (210°F) and apply 6.9 X 10^5N/M^2 (100 psi) then heat to 121°C (250°F) and hold for 1 hour.
17	Ciba Geigy	Fiberdux 920	Apply vacuum and heat to 82°C (180°F), then apply 6.9 X 10^5N/M^2 (100 psi) and heat to 121°C (250°F) and hold for 1 hour.
18	Ciba Geigy	Fiberdux 914	Apply vacuum pressure and heat to 121°C (250°F). Then apply 6.9 X 10^5N/M^2 (100 psi), vent vacuum and heat to 176°C (350°F) and hold for 1 hour. Post cure 4 hours at 204°C (400°F).
19	Hexcel	#1	Apply 3.5 X 10^5N/M^2 (50 psi) and heat to 121°C (250°F) hold for 1 hour.
20	Hexcel	#2	Apply 5.6x10^5N/M^2 (80 psi) and heat to 176°C (350°F) hold for 1 hour.
21	Fiberite	HY-E 976	Apply vacuum and heat to 121°C (250°F) and hold for 20 min. Apply 6.9 X 10^5N/M^2 (100 psi), Hold 45 minutes at 121°C (250°F) then increase temp. to 176°C (350°F) and hold for 2 hours.
22	U.S. Polymeric	#1	R.T. to 135°C (275°F) - Vacuum and hold for 30 minutes. Then apply 6.9 X 10^5N/M^2 (100 psi) and 176°C (350°F) and hold for 4 hours.
23	U.S. Polymeric	#2	Apply 6.9 X 10^5N/M^2 (100 psi) and heat to 149°C (300°F) hold for 2 hours.

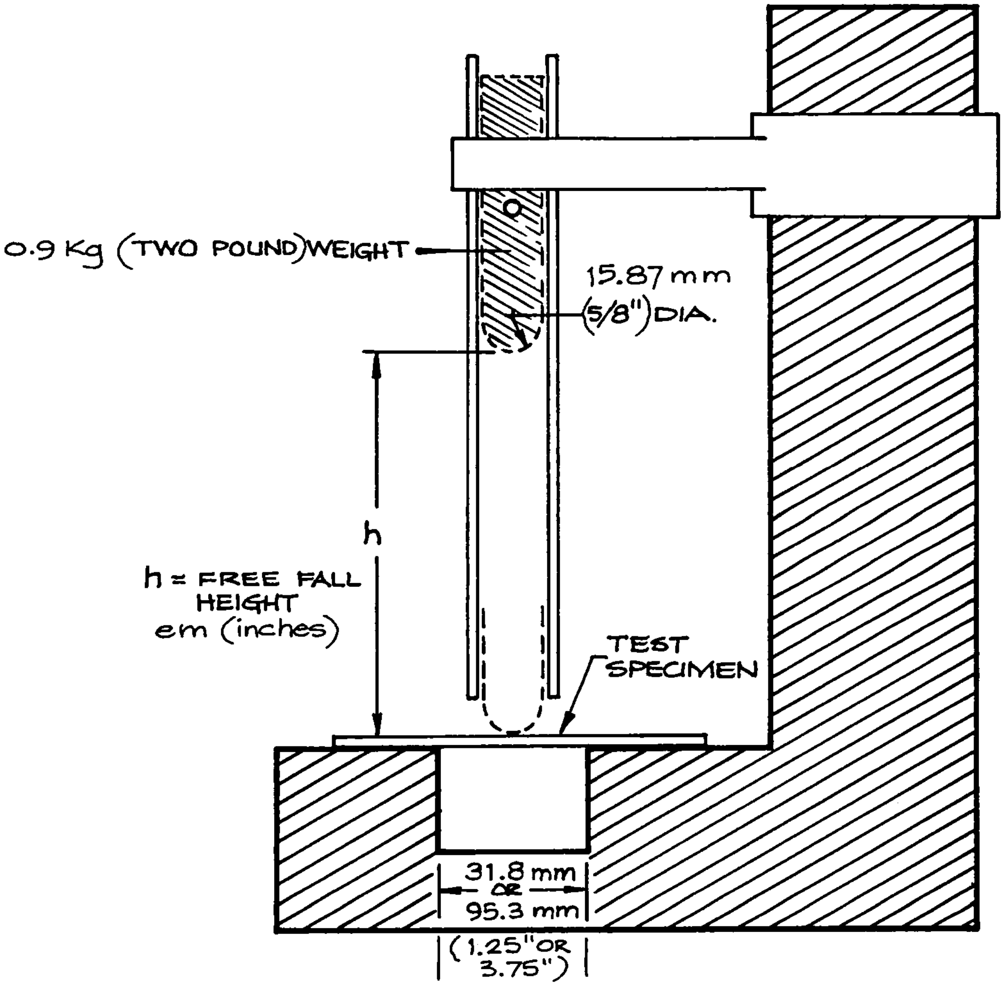


FIGURE 2. GARDNER IMPACT TESTER

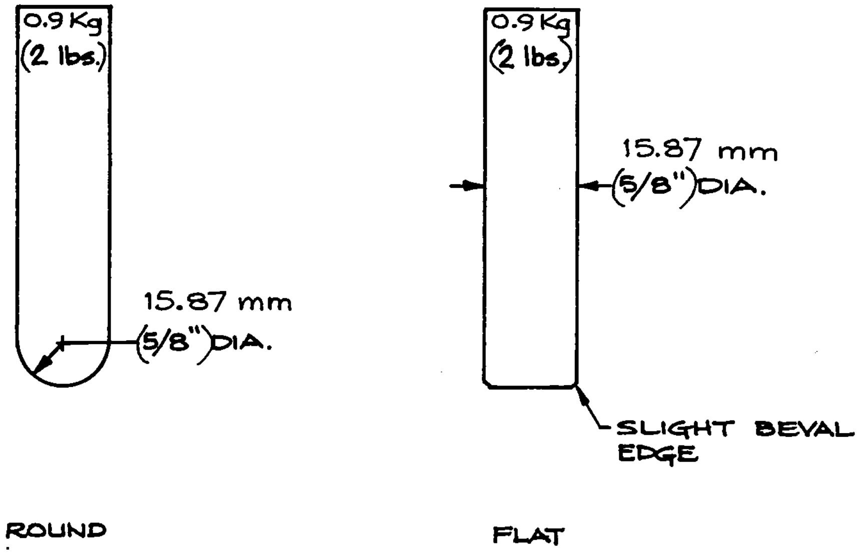


FIGURE 3. GARDNER ROUND AND FLAT IMPACT HEADS

TABLE 3

VISIBLE IMPACT DAMAGE ON THIN LAMINATES 8 PLY $(, \pm 45, 90)_s$

			FIBREDUX 920	HEXCEL #2	CIBA GEIGY #4	NARMCO X1114	NARMCO X108/34A	U.S. POLY #2	5208 SLOW CURE	FIBREDUX 920 LOW RESIN	CIBA GEIGY #1M	A. M. CYAN BP907 LOW RESIN	CYCOM 937	CIBA GEIGY 1M 2nd	NARMCO 107	CYCOM 982	NARMCO 109	CYCOM 919	FIBERDUX 914
		RESIN CONTENT	31.7	29.9	27.5	30.0	25.4	24.6	26.4	29.2	26.5	29.6	30.7	31.8	31.0	27.0	30.8	30.0	23.5
		TOTAL THICKNESS (IN) mm PLY THICKNESS (IN) mm	(.044) 1.12 (.0055) .142	(.042) 1.07 (.0052) .132	(.047) 1.19 (.0059) .149	(.050) 1.27 (.0061) .155	(.042) 1.07 (.0052) .132	(.043) 1.09 (.0051) .132	(.043) 1.09 (.0054) .137	(.043) 1.09 (.0054) .137	(.043) 1.09 (.0054) .137	(.043) 1.09 (.0054) .137	(.043) 1.09 (.0054) .137	(.045) 1.14 (.0056) .142	(.046) 1.17 (.0058) .147	(.041) 1.04 (.0051) .132	(.044) 1.12 (.0055) .142	(.027) .685 (.039) .991	(.042) 1.07 (.0052) .157
(1.25") 31.7 mm SUPPORT 5/8" ROUND IMPACT HEAD		(10" LB) X 1.13 Joules Y	(0) 0 * (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(.1) 2.54 (1.0) 25.4	(0) 0 (0) 0	(0) 0 (0) 0	(.2) 5.1 (.1) 2.54	(0) 0 (0) 0	(.2) 5.1 (.2) 5.1	(.2) 5.1 (.1) 2.54	(0) 0 (0) 0	(.1) 2.54 (.5) 12.7	(.1) 2.54 (.7) 17.8	(.2) 5.1 (.2) 5.1	(.2) 5.1 (1.0) 25.4	(0) 0 (0) 0
		(20" LB) X 2.26 Joules Y	(.4) 10.16 (.3) 7.62		(.1) 2.54 (1.2) 30.5	(.2) 5.1 (.1) 2.54	(.3) 7.62 (1.5) 38	(.2) 5.1 (1.0) 25.4	(.2) 5.1 (1.0) 25.4	(.4) 10.16 (.3) 7.62	(.2) 5.1 (1.5) 38	(.2) 5.1 (.4) 10.16	(.5) 12.7 (1.2) 30.5	(.2) 5.1) (.7) 17.8	(.3) 7.62 (.5) 12.7	(.5) 12.7 (1.0) 25.4	(.3) 7.62 (.6) 15.24	(.3) 7.62 (1.2) 30.5	(.2) 5.1 (.4) 10.16
		(30" LB) X 3.39 Joules Y	(.5) 12.7 (.5) 12.7	(.1) 2.54 (1.0) 2.54	(.3) 7.62 (1.2) 30.5	(.2) 5.1 (.3) 7.62	(.4) 10.16 (1.5) 38	(.4) 10.2 (1.2) 30.5	(.3) 7.62 (1.2) 30.5	(.5) 12.7 (.5) 12.7	(.4) 10.16 (1.3) 33.02	(.7) 17.8 (.8) 20.32	(.7) 17.8 (1.3) 33.02	(.3) 7.62 (1.4) 35.56	(.5) 12.7 (1.0) 25.4	(.7) 17.8 (1.3) 33.02	(.5) 12.7 (.6) 15.24	(.4) 10.16 (1.2) 30.5	(.3) 7.62 (.5) 12.7
(3.75") 92.2 mm SUPPORT	(5/8") 15.8 mm ROUND IMPACT HEAD	(10" LB) X 1.13 Joules Y	(0) 0 (0) 0	(0) 0 (0) 0				(0) 0 (0) 0		(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0
		(20" LB) X 2.26 Joules Y	(0) 0 (0) 0					(0) 0 (0) 0	(.1) 2.54 (1.0) 25.4	(.2) 5.1 (.4) 10.2	(0) 0 (.7) 17.8	(0) 0 (0) 0	(.3) 7.62 (.2) 5.08	(0) 0 (0) 0	(.1) 2.54 (1.0) 25.4	(.1) 2.54 (1.2) 30.5	(.3) 7.62 (.1) 2.54	(.3) 7.62 (.7) 17.8	(0) 0 (0) 0
		(30" LB) X 3.39 Joules Y	(.5) 12.7 (.3) 7.62	(.2) 5.08 (1.2) 30.5				(0) 0 (0) 0	(.3) 7.62 (2.5) 63.5	(.4) 10.2 (.4) 10.2	(.3) 7.62 (2.4) 61	(0) 0 (0) 0	(.6) 15.24 (.4) 10.16	(0) 0 (0) 0	(.1) 2.54 (.8) 20.32	(.3) 7.62 (3.0) 76.2	(.1) 2.54 (1.0) 25.4	(.1) 2.54 (1.2) 30.5	(.3) 7.62 (.7) 17.8
	(5/8") 15.8 mm FLAT IMPACT HEAD	(40" LB) X 4.52 Joules Y									(0) 0 (0) 0	(0) 0 (0) 0							
		(50" LB) X 5.65 Joules Y										(0) 0 (0) 0	(0) 0 (0) 0		(0) 0 (0) 0	(0) 0		(0)	
		(60" LB) X 6.78 Joules Y			(0) 0 (0) 0	(1.2) 30.5 (.2) 5.1	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(.8) 20.32 (1.5) 38.1	(.5) 12.7 (2.0) 50.4		(.8) 20.32 (.5) 12.7	(.8) 20.32 (1.2) 30.5	(0) 0 * (0) 0	(1.0) 38.1 (.5) 12.7	(.1) 2.54 (.4) 10.16
		(70" LB) X 7.91 Joules Y	(1.4) 35.56 (.5) 12.7			(1.0) 25.4 (.5) 12.7	(0) 0 (0) 0	(.1) 2.54 (.1) 2.54		(1.5) 38.1 (1.0) 25.4								(1.0) (1.5) 38.1	
		(80" LB) X 9.04 Joules) Y	(2.7) 68.6 (.6) 15.24	(0) 0 (0) 0	(1.3) 33.02 (1.3) 33.02		(1.0) 25.4 (1.2) 30.5	(.9) 22.9 (1.1) 27.9	(.1) 2.54 (.8) 20.32	(1.5) 38.1 (1.7) 43.2	(0) 0 (0) 0	(.8) 20.32 (2.0) 50.8	(1.3) 33.02 (1.5) 38.1	(0) 0 (0) 0	(1.2) 30.5 (1.0) 25.4		(1.5) 38.1 (.8) 20.32		(.6) 15.24 (.8) 20.32
		(90" LB) X 10.17 Joules Y		(1.0) 2.54 (1.5) 38.1	(.7) 17.8 (3.2)									(0) 0 (0) 0					
		(100" LB) X 11.3 Joules Y									(1.0) 25.4 (3.7) 94			(0) 0 * (0) 0					(.9) 22.9 (.9) 22.9
		(120" LB) X 13.56 Joules Y												(1.2) 30.5 (1.7) 43.2					

* NOTE: UNITS ARE (INCHES) MILLIMETERS IN THE X AND Y DIRECTION OF AREA OF DAMAGE

TABLE 3 (Cont'd)

				NARMCO 5208 REFERENCE	5208 RESIN RICH	5208 RESIN POOR	A. M. CYAN BP907	U. S. POLY #1	NARMCO 95995	AIR LOG #1	HEXCEL #1	CIBA GEIGY #2	CIBA GEIGY #3	CIBA GEIGY #1 (RERUN)	FIBERITE 976
		RESIN CONTENT		27.7	29.9	24.6	29.8	29.2	32.7	28.0	28.3	28.0	24.6	28.9	29.6
		TOTAL THICKNESS (IN) mm PLY THICKNESS (IN) mm		(.042) 1.07 (.0052) .13	(.044) 1.12 (.0055) .14	(.040) 1.02 (.0050) .127	(.040) 1.02 (0.061) .15	(.040) 1.02 (.0050) .127	(.041) 1.04 (.0051) .132	(.048) 1.22 (.0060) .152	(.043) 1.09 (.0054) .137	(.042) 1.07 (.0052) .132	(.042) 1.07 (.0052) .132	(.042) 1.07 (.0052) .132	(.046) 1.17 (.0058) .147
(1.25") 31.7 mm SUPPORT	5/8" ROUND IMPACT HEAD	(10" LB) 1.13 Joules	X Y	(.2) 5.1 * (.7) 17.8	(.1) 2.54 (1.0) 25.4	(0) 0 (0) 0	(0) 0 (0) 0	(.2) 5.1 (.1) 2.54	(.2) 5.1 (.8) 20.32	(0) 0 (0) 0	(0) 0 (0) 0		(0) 0 (0) 0		(0) 0 (0) 0
		(20" LB) 2.26 Joules	X Y	(.3) 7.62 (1.2) 30.5	(.3) 7.62 (1.5) 38	(.2) 5.1 (1.2) 30.5	(.3) 7.62 (1.0) 25.4	(.3) 7.62 (.2) 5.1	(.3) 7.62 (2.0) 50.8		(.3) 7.62 (.2) 5.1		(.2) 5.1 (1.0) 25.4		(.2) 5.1 (1.2) 30.5
		(30" LB) 3.39 Joules	X Y	(.4) 10.2 (1.2) 30.5	(.5) 12.7 (1.5) 25.4	(.6) 15.24 (1.5) 38.1	(.6) 15.24 (.8) 20.32	(.4) 10.16 (.7) 17.8	(.7) 17.8 (2.0) 50.8		(.3) 7.62 (.3) 7.62		(.3) 7.62 (1.5) 38.1		(.4) 10.2 (1.2) 30.5
(3.75") 92.2 mm SUPPORT	(5/8") 15.8 mm ROUND IMPACT HEAD	(10" LB) 1.13 Joules	X Y	(0) 0 (0) 0	(.1) 2.54 (.5) 12.7	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0			(0) 0 (0) 0
		(20" LB) 2.26 Joules	X Y	(.2) 5.1 (1.5) 38	(.1) 2.54 (1.0) 25.4	(.1) 2.54 (1.0) 25.4	(.1) 2.54 (.1) 2.54	(.2) 5.08 (.1) 2.54	(0) 0 (0) 0	(.1) 2.54 (.2) 5.1	(.4) 10.16 (.4) 10.16				(.2) 5.1 (.8) 20.32
		(30" LB) 3.39 Joules	X Y	(.3) 7.62 (3.0) 76.2	(.5) 12.7 (3.5) 88.9	(.3) 7.62 (3.0) 76.2	(.3) 7.62 (.3) 7.62	(.4) 10.16 (.6) 15.24	(.4) 10.2 (1.7) 43.2	(.4) 10.2 (.5) 12.7	(.4) 10.16 (1.0) 25.4				(.2) 5.1 (2.0) 50.4
	(5/8") 15.8 mm FLAT IMPACT HEAD	(40" LB) 4.52 Joules	X Y	(0) 0 (0) 0	(0) 0 (0) 0										(0) 0 (0) 0
		(50" LB) 5.65 Joules	X Y	(0) 0 (0) 0	(1.0) 25.4 (2.5) 63.5	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0		(0) 0 (0) 0				(0) 0 (0) 0
		(60" LB) 6.78 Joules	X Y	(1.1) 27.9 (1.1) 27.9	(1.0) 25.4 (2.5) 63.5	(.6) 15.24 (.5) 12.7	(1.3) 33.02 (.7) 17.8	(0) 0 (0) 0	(1.5) 38.1 (1.3) 33.02	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0		(0) 0 (0) 0	(0) 0 (0) 0
		(70" LB) 7.91 Joules	X Y										(0) 0 (0) 0	(0) 0 (0) 0	(.2) 5.1 (.3) 7.62
		(80" LB) 9.04 Joules	X Y	(1.2) 30.5 (3.7) 93.9	(1.7) 43.2 (2.2) 55.9	(.7) 17.8 (2.0) 50.8	(1.5) 38.1 (.5) 12.7	(1.5) 38.1 (.5) 12.7	(1.4) 35.56 (1.5) 38.1	(.7) 17.8 (.4) 10.16	(1.1) 27.94 (.7) 17.78	(.4) 10.16	(0) 0 (0) 0	(0) 0 (0) 0	(.1) 2.54 (.3) 7.62
		(90" LB) 10.17 Joules	X Y										(0) 0 (0))	(0) 0 (0))	(.8) 20.32 (2.0) 5.08
		(100" LB) 11.3 Joules	X Y												
		(120" LB) 13.56 Joules)	X Y												

* NOTE: UNITS ARE (INCHES) MILLIMETERS IN THE X AND Y DIRECTION OF AREA OF DAMAGE

2.2.3 Reheometric Constant Speed Impact Test

The Rheometric Impact Tester gave another useful means of evaluation of the impact characteristics of the materials. The test machine gathered data during the test event, recorded a printed record of a load deflection curve, and calculated and printed the calculation of initial slope of the stress strain curve (which is a measure of the material modulus of elasticity), energy in joules (inch pounds), absorbed at first sign of failure, and the total energy absorbed, in joules (inch pounds), during the total test event.

The Rheometric Impact Tester (see Figure 4) used a constant speed overwhelming force impact ram with a 15.9 mm (5/8 inch) round impact nose that penetrated the specimen. The specimens were securely clamped to the machine across a 50.8 mm (2-inch) diameter support hole that was centered to the path of the impact head. The tests were all conducted at a constant speed of 76.2 m (3000 inches) per minute. A load and deflection curve was plotted for each material during the penetration impact. The events recorded and calculated by the Rheometric Impact Tester are shown in Figure 5 and are described below:

(1). This is the time that the impact head first makes contact with the specimen.

(2). This is a low point on the approximate straight line portion of the stress/strain curve as selected by the machine operator after completion of the test.

(3). This is the high point on the approximate straight line portion of the stress/strain curve as selected by the machine operator. The data is not reduced to account for the 50.8 mm (2 inch) diameter rigid support and, thus, is not recorded as a true modulus calculation.

(4). Yield is the time that the stress/strain deviates from an approximate straight line and is considered the point of initial impact damage to the specimen. The area, in joules (inch pounds), under the curve from point 1 to 4, is calculated as the energy absorbed at first sign of panel damage or failure.

(5). Ultimate is the deflection where maximum load is achieved during the impact penetration event. Major fiber breakage has probably occurred by this time.

(6). Total is the deflection where the load has reduced to a near constant level and impact penetration is complete. It probably represents the drag on the edge of the plunger as the penetration continued to full depth of the impact stroke. The area, in joules (inch pounds), under the curve point 1 to 6 is calculated as the total energy absorbed by the panel for this impact test.

RHEOMETRICS, INC.

High Rate
Impact Tester

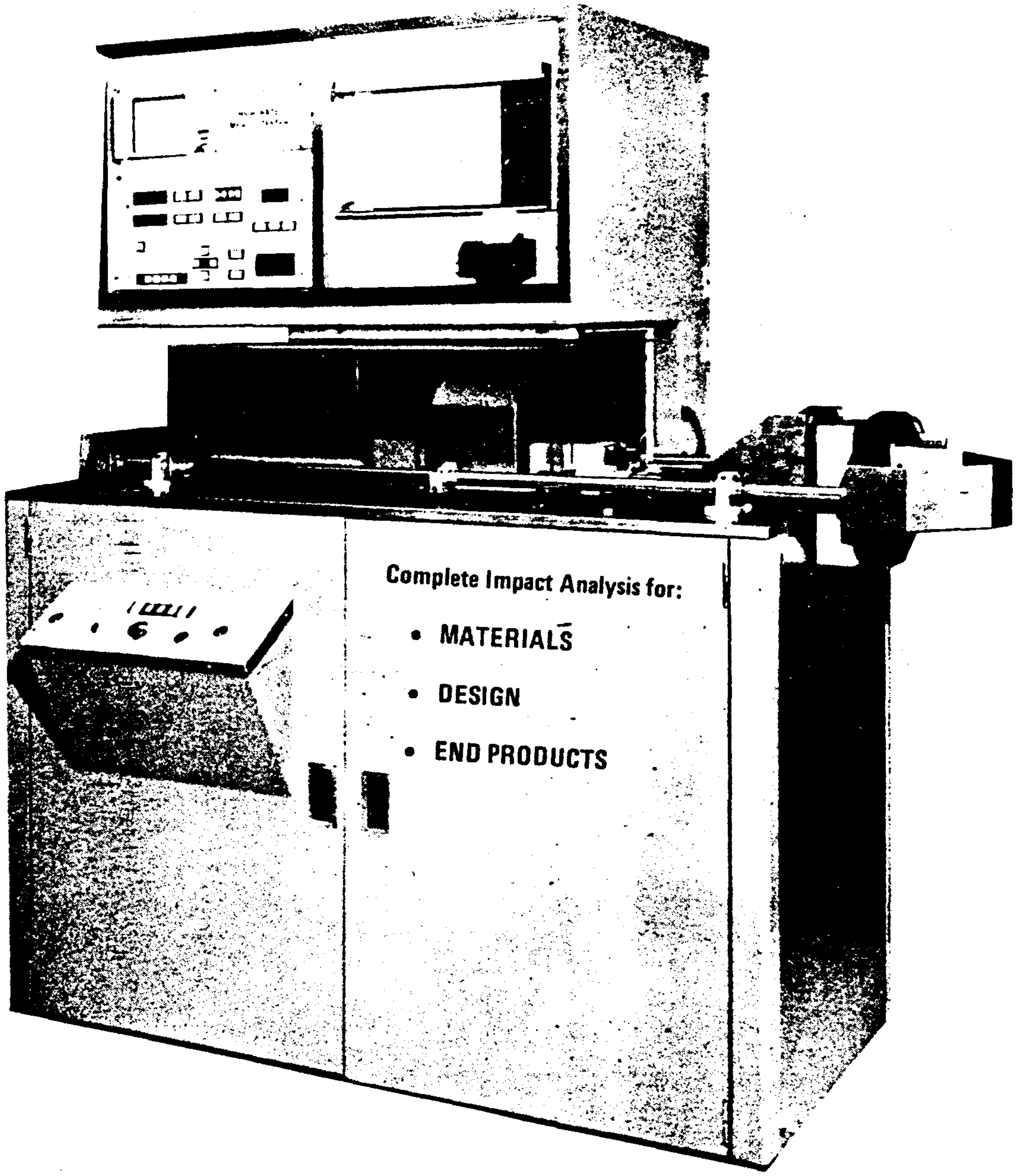


FIGURE 4. RHEOMETRIC CONSTANT SPEED IMPACT TESTER

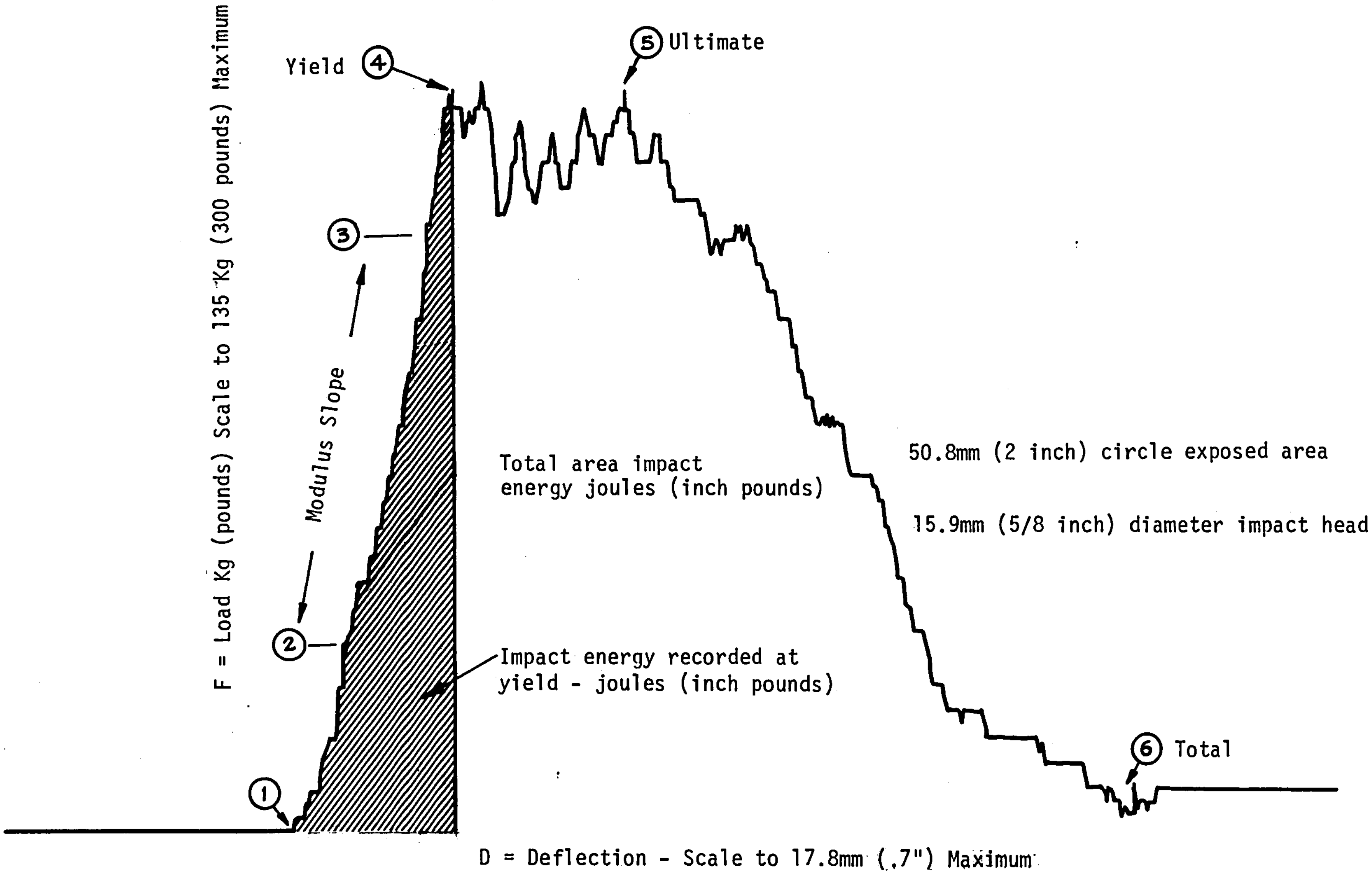


FIGURE 5. RHEOMETRICS CONSTANT SPEED IMPACT CHART

A summary of the Rheometric calculations of slope of the stress-strain curve, energy absorbed at initial impact failure and total energy absorbed by impact penetration is shown in Table 4. Individual traces for the ten materials, studied are presented in Appendix 3.

2.3. TASK 3 - LAMINATE MECHANICAL PROPERTIES

Each material received from each of the suppliers was processed into laminate form for both impact and mechanical property tests, as presented in Task 2, during a single curing cycle. All flexural and all short beam shear coupons were cut from 16 ply 0^o fiber orientation panels. Flexural coupon size and formula for calculation of maximum stress and modulus of elasticity are shown in Figure 6.

Short beam shear coupon size and formula for calculation of shear stress is shown in Figure 7.

All tensile and compression coupons were cut from 6 ply 0^o fiber orientation panels. The composite coupons were autoclave bonded to 3.8 cm (1 1/2") thick 368 Kg/M^3 (23 $pound/ft^3$) 3.2 mm (1/8 inch) cell aluminum honeycomb using a 121^oC (250^oF) curing FM73 adhesive film from American Cyanamid Corp. Steel skins were bonded to the opposite surface of the honeycomb and sized to force failure, whether tension or compression loading, into the composite skin. Tension and compression coupon configuration, test procedure, and formula for calculation of stress at failure and modulus of elasticity are shown in Figure 8.

Quality control tests for each panel used for flexural, shear, tensile, and compression tests include a thickness measurement and resin and void content obtained by using the hot nitric acid digestion process.

All mechanical property tests were conducted at room temperature on an Instron test machine. A summary of all mechanical property tests is presented in Table 5.

2.4 TASK 4 - THICK LAMINATE IMPACT RESISTANCE

Each material received from each of the suppliers was processed into a thick 48 ply impact panel by procedures detailed in Task 2 and in a single curing cycle along with the thin impact panels of Task 2 and the mechanical property panels of Task 3. The laminate 48 ply pattern was the same for all panels.

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

Each panel was cut to one 12.5cm x 12.5cm (5" x 5") and one 12.5cm x 25cm (5" x 10") coupon and delivered to NASA for thick laminate impact studies.

TABLE 4

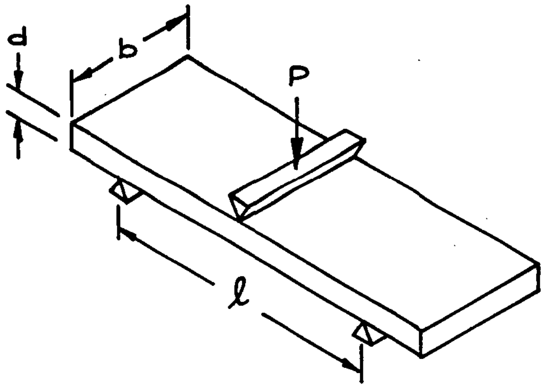
RHEOMETRIC IMPACT PENETRATION TEST RESULTS

76.2 M/Min

(3000 Inches/Minute)

8 Ply (0, ± 45°, 90°)$_s$ Thornel Fiber Pattern

MATERIAL	SLOPE OF STRESS/STRAIN CURVE (IN LBS/IN) JOULES/mm	YIELD			TOTAL		
		LOAD (POUNDS) kg	DEFLECTION, (IN) mm	ENERGY ABSORBED, (IN LBS) JOULES	LOAD, (POUNDS) Kg	DEFLECTION, (IN) mm	ENERGY ABSORBED, (IN LBS) JOULES
Narmco 5208	(3205) 14.1	(191) 86	(0.12) 3.05	(9.4) 1.06	(8) 3.6	(0.56) 14.22	(41.0) 4.63
Ciba Geigy #4	(4000) 17.60	(347) 157	(0.16) 4.06	(23.9) 2.70	(37) 16.7	(0.55) 13.97	(83.3) 9.42
Ciba Geigy Fiberdux 920	(2809) 12.36	(218) 99.1	(0.11) 2.79	(9.05) 1.02	(37) 16.7	(0.55) 13.97	(60.0) 6.79
American Cyanamid BP/907	(2889) 12.71	(224) 101	(0.12) 3.05	(19.8) 1.22	(11) 5	(0.56) 14.22	(64.7) 7.31
U.S. Polymeric #2	(3205) 14.10	(253) 114	(0.12) 3.05	(13.9) 1.57	(11) 4.9	(0.55) 13.97	(67.7) 7.09
Narmco X1114	(3399) 14.95	(316) 143	(0.21) 5.33	(36.2) 4.09	(0) 0	(0.57) 14.48	(88.9) 10.0
American Cyanamid BP-982	(3121) 13.73	(199) 90.1	(0.14) 3.56	(14.2) 1.61	(27) 12.2	(0.50) 12.7	(53.3) 6.02
Ciba Geigy #1M	(3852) 16.95	(243) 110	(0.12) 3.05	(11.9) 1.35	(19) 8.6	(0.57) 14.48	(70.4) 7.96
Narmco X-107	(3553) 15.63	(246) 111	(0.15) 3.81	(18.5) 2.89	(27) 12.2	(0.56) 14.22	(67.6) 6.73
American Cyanamid BP-919	(3131) 13.78	(248) 112	(0.13) 3.30	(13.1) 1.48	(3) 1.3	(0.52) 13.21	(56.6) 6.39



Flexural strength and modulus was calculated as the arithmetic mean for a minimum of three specimens.

$$\text{Flexural Strength} = \frac{3PL}{2bd^2}$$

$$\text{Flexural Modulus of Elasticity} = \frac{L^3M}{4bd^3}$$

Where: P = The ultimate failure load in Kg (pounds to the nearest Kg (pound).

L = The span length in cm (inches) to the nearest .13 mm (0.005 inch).

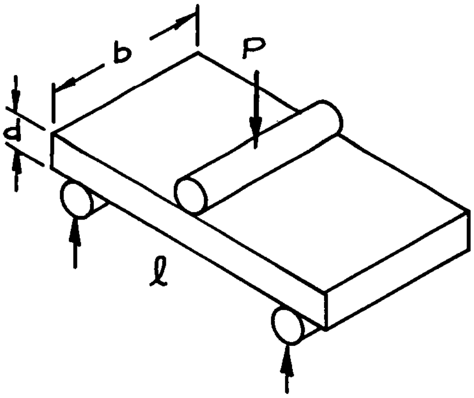
b = The specimen width in mm (inches) to the nearest .025mm (0.001 inch).

d = The specimen thickness in mm (inches) to the nearest .013mm (0.0005 inch).

M = The initial slope of the load-deflection curve in Kg/meter (pounds per inch) to three significant figures.

The span to thickness ratio was 32 ± 2 to 1.

FIGURE 6. FLEXURAL SPECIMEN



Short beam shear strength was calculated as the arithmetic mean of a minimum of three specimens.

$$\text{Horizontal Shear Strength} = \frac{3P}{4bd}$$

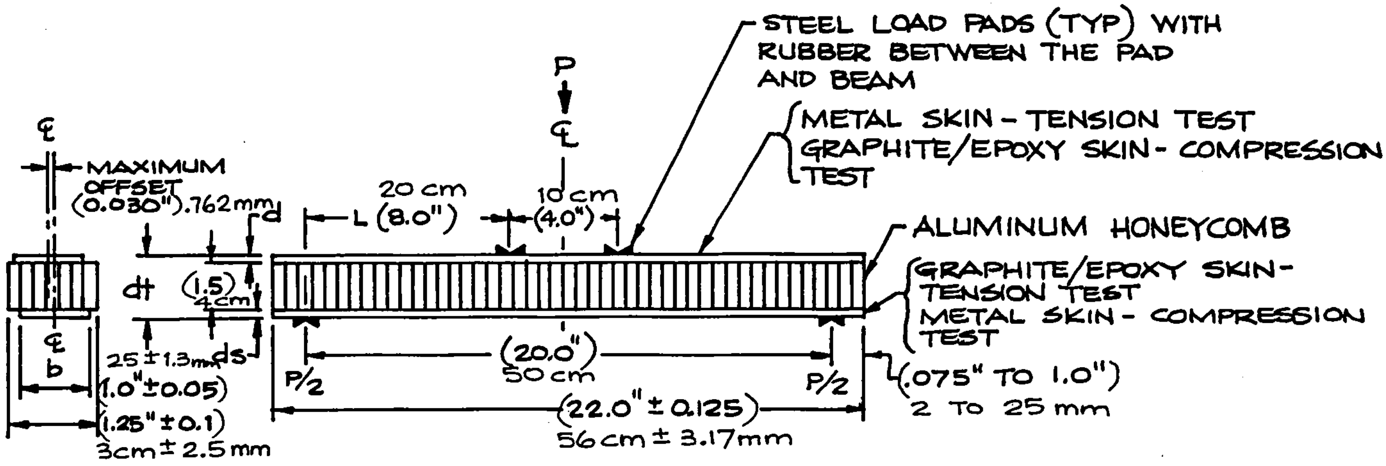
Where: P = The shear failure load in Kg (pounds) to the nearest Kg (pound).

b = The speicmen width in mm (inches) to the nearest .0254mm (0.001 inch).

d = The specimen thickness in mm (inches) to the nearest .127 mm (0.005 inch).

The span to thickness ratio was between 3 1/2 and 4 to 1.

FIGURE 7. SHORT BEAM SHEAR SPECIMEN



NOTES: (1) Metal skins were 25.4mm (1.00 inch) wide, 3.17mm (.125 inch) thick and 55.9cm (22.0 inches) length and made of 4130 steel hardened to a minimum of $9.64 \times 10^8 N/m^2$ (140,000 psi).

(2) The honeycomb core was 38mm (1.5 inch) thick 5052-H39 nonperforated 3.17mm (1/8 inch) cell, .152 mm (0.006 inch) foil gage aluminum.

(3) Composite skins were 25.4mm (1.00 inch) wide, .76mm (.03 inch) thick and 55.9cm (22 inches) long.

Longitudinal tensile and compression strength and modulus of elasticity were calculated as the arithmetic mean of a minimum of three specimens.

St and Sc - Tensile Strength and Compressive Strength $= \dfrac{PL}{bd(2dt-d-ds)}$

Et or Ec - Tensile Modulus and Compressive Modulus $= \dfrac{(St \text{ or } Sc)\ M}{P}$

Where: St = Ultimate tensile strength.

Sc = Ultimate compressive strength.

P = Ultimate failure load in Kg (pounds) to the nearest Kg (pound).

L = Moment arm between applied load and reaction support.

d = Specimen thickness in mm (inches) to the nearest .0127mm (0.0005 inch).

b = Specimen width in mm (inches) to the nearest .0254mm (0.001 inch).

dt = Overall thickness of sandwich in mm (inches) to the nearest .254mm (0.01 inch), measure at the center.

ds = Thickness of the steel facing in mm (inches) to the nearest .254mm (0.01 inch).

Et = Initial tensile modulus.

Ec = Initial compressive modulus.

M = The slope of the load/strain curve at the straight line portion nearest the origin in Kg per meter per meter (pounds per inch per inch) to three significant digits.

FIGURE 8. SANDWICH BEAM TENSILE AND COMPRESSION SPECIMENS

TABLE 5

MATERIAL PROPERTY TESTS

	Narmco 5208/T300	Am. Cyan. BP907	U. S. Poly #1	Narmco 95995	Air Log. #1	Ciba Geigy #1	Hexcel #1	Ciba Geigy #2	Ciba Geigy #3	Fiberite 976 HY-E	Fibredux 920	Hexcel #2	Ciba Geigy #4	Narmco X1114	Narmco X108/34A	U.S. Poly #2	5208 Slow Cure	Fibredux 920 Low Resin	Ciba Geigy #1M	Am. Cyan BP-907 Low Resin	Am. Cyan 919	Am. Cyan 937	Ciba Geigy 1M 2nd	Narmco 107	Narmco 109	Am Cyan. 982	Fibredux 914
CURED PROP.																											
Flex. Str.(ksi) N/M^2 X 10^8	(310) 21.35	(334) 23.01	(223) 15.36	(284) 19.57	(126) 8.68	(333) 22.94	(269) 18.53	(239) 16.47	(262) 18.06	(307) 21.15	(321) 22.12	(191) 13.16	(298.) 20.53	(183) 12.61	(318) 21.91	(322.0) 22.18	(337) 23.22	(305) 21.01	(310) 21.36	(327) 22.53	(368) 25.35	(397) 27.35	(413) 28.45	(324) 22.32	(279) 19.22	(284) 19.57	(344) 23.70
Flex. Mod.,(msi) N/M^2 X 10^9	(19.0) 130.91	(20.7) 142.62	(21.0) 144.69	(20.0) 137.80	(16.7) 115.06	(21.0) 144.69	(17.9) 123.33	(18.5) 127.46	(20.0) 137.80	(20.5) 141.24	(20.5) 141.24	(21.2) 146.07	(21.5) 148.13	(17.5) 120.57	(25.3) 174.32	(23.5) 161.91	(23.5) 161.91	(19.7) 135.73	(20.5) 141.24	(18.6) 128.15	(23.3) 160.54	(26.2) 180.52	(23.0) 158.47	(17.8) 122.64	(17.8) 122.64	(20.8) 143.31	(20.6) 141.93
Shear Str.(ksi) N/M^2 X 10^6	(19.0) 130.91	(15.0) 103.35	(12.2) 84.06	(18.1) 124.71	(8.3) 57.19	(13.1) 90.26	(12.9) 88.88	(9.2) 63.39	(12.3) 84.75	(17.6) 121.26	(14.1) 97.15	(13.5) 93.01	(16.2) 111.62	(7.9) 54.43	(19.6) 135.04	(15.8) 108.86	(19.8) 136.42	(15.6) 107.48	(10.5) 72.34	(14.7) 101.28	(14.9) 102.66	(15.7) 108.17	(9.3) 64.08	(13.5) 93.01	(12.2) 84.06	(16.7) 115.06	(18.0) 124.02
Resin Cont. %	28.0	28.1	27.6	31.4	32.9	24.3	28.3	24.4	24.8	26.5	37.2	27.1	25.0	36.7	23.1	24.0	25.1	31.9	26.1	29.8	30.3	29.5	26.6	36.3	34.5	26.8	23.5
Void Cont. %	1.0	1.3	0.5	.3	4.9	.5	-0-	1.1	1.5	1.0	.7	1.7	1.7	3.5*	1.1*	1.5*	1.0	0.5	-0.41	0.7	-2.7	-0.8	-0.2	1.9*	2.4*	0.5	1.2
Tens. Str.(ksi) N/M^2 X 10^8	(218) 15.02	(247) 17.02	(267) 18.39	(206) 14.19	(238) 16.39	(326) 22.46	(273) 18.81	(277) 19.08	(311) 21.43	(230) 15.85	(281) 19.36	(246) 16.95	(278) 19.15	(251) 17.29	(257) 17.71	(307) 21.15	(276) 19.02	(252) 17.36	(281) 19.36	(248) 17.09	(259) 17.84	(248) 17.09	(276) 19.02	(232) 15.98	(243) 16.74	(243) 16.74	(270) 18.60
Tens. Mod.(msi) N/M^2 X 10^9	(19.0) 130.91	(18.9) 130.22	(19.5) 134.35	(16.6) 114.37	(16.7) 115.06	(22.5) 155.02	(20.4) 140.55	(21.5) 148.13	(22.0) 151.58	(18.5) 127.46	(20.6) 141.93	(19.0) 130.91	(18.0) 124.02	(21.2) 146.07	(21.0) 144.69	(23.9) 164.67	(21.7) 149.51	(21.1) 145.38	(22.8) 157.09	(20.0) 137.80	(20.6) 141.93	(20.9) 144.00	(19.2) 132.29	(19.7) 135.73	(19.2) 132.29	(20.7) 142.62	(20.7) 142.62
Comp. Str.(ksi) N/M^2 X 10^8	(210) 14.47	(178) 12.26	(93) 6.40	(190) 13.09	(88) 6.06	(226) 15.57	(116) 7.99	(148) 10.19	(214) 14.74	(159) 10.95	(167) 11.51	(153) 10.54	(165) 11.37	(69) 4.75	(155) 10.68	(237) 16.33	(281) 19.36	(176) 12.13	(236) 16.26	(203) 13.99	(194) 13.37	(220) 15.16	(181) 12.47	(109) 7.51	(94) 6.48	(258) 17.78	(232) 15.98
Comp. Mod.(msi) N/M^2 X 10^9	(18.0) 124.02	(16.3) 112.31	(19.7) 135.73	(15.0) 103.35	(15.7) 108.17	(21.0) 144.69	(17.5) 120.57	(19.2) 132.29	(20.0) 137.80	(17.0) 117.13	(17.9) 123.33	(17.4) 119.89	(20.0) 137.80	(15.5) 106.79	(19.5) 134.35	(19.4) 135.67	(19.5) 134.35	(16.4) 112.99	(17.7) 121.95	(17.6) 121.95	(18.6) 128.15	(17.9) 123.33	(17.6) 121.26	(17.5) 120.57	(16.7) 115.06	(17.2) 118.51	(17.6) 121.26
Resin Cont. %	28.0	31.7	24.6	33.0	27.0	25.7	28.8	25.0	23.4		33.6	28.9	28.7	30.8	24.0	24.8	25.2	33.8	27.6	31.4	31.7	31.7	32.8	29.8	33.5	27.0	
Void Cont. %	1.	.6	1.3	.3	3.1	.9	-1.0	.6	1.3		1.3	1.5	0.9	4.7*	1.3*	0.9*	1.3	0.5	-0.45	0.3	-2.8	-1.4	-1.0	1.5*	1.1*	0.7	
SUPPLIER DATA MATRIX PROP.																											
Tens. Str.(ksi) N/M^2 X 10^6	(8.3) 57.2	(13) 89.47	(7.0) 48.23	(10.8) 74.41	(6.9) 47.54	(14.4) 99.22	(7.7) 53.05	(15.) 103.35	(13.7) 94.39	(9.0) 62.01	(10.9) 75.10	(6.5) 44.78	(13.0) 89.57	(4.5) 31.00		(13.6) 93.70	(6.3) 43.41	(10.9) 75.10		(13) 89.57							(7.2) 49.61
Tens. Mod.(ksi) N/M^2 X 10^8	(580) 39.96	(450) 31.00	(340) 23.43	(542) 37.34	(250) 17.22	(644) 44.37	(320) 22.05	(480) 33.07	(484) 33.35	(400) 27.56	(453) 31.21	(370) 25.49	(482) 33.21	(240) 16.54			(580) 39.96	(453) 31.21		(450) 31.00							(580) 39.96
Elong. Yield %	1.5	4.8	7.0					5.5					---			---		---		4.8							
Elong. Failure %	1.		19.	2.4	8.0	8.7	7.0	7.0	7.0	5.	4.1	1.9	4.7	6.0		8.0		4.1									1.4
Density	1.267	1.22	1.23	*	*	1.270	*	1.219	1.234	1.28	1.239		1.221	*	*		1.267	1.215	1.27	1.22	1.33	1.26	1.27			1.25	---

Quality control tests for each panel include resin content determination by using the hot nitric acid digestion process and calculation of % void and % fiber volume.

A summary of all thick laminate quality control tests is presented in Table 6.

2.5 TASK 5 - DISCUSSION OF TEST RESULTS

Discussion of results for tests conducted on candidate tough resin systems are presented below. Twenty-three different resin systems supplied by seven different manufacturers were tested. Three material systems were tested at high and low resin content and one material had a second batch tested to verify the first batch test results. In all, a total of thirty different panels were evaluated during the course of the program.

2.5.1 Thin Laminate Impact Vs. Resin Matrix Properties

The thin laminate impact study is based on the Gardner Impact Test results reported in Table 3 and in Appendix 1 and the Rheometric constant speed impact penetration test results reported in Table 4 and Appendix 3.

2.5.1.1 Gardner Impact Specimens

The criteria for evaluation of the Gardner impact results are:

a. Level of impact - (inch pounds) joules
b. Visual evidence and extent of front surface damage.
c. Visual evidence and extent of back surface damage.
d. Area of internal damage recorded by C-scan NDT.

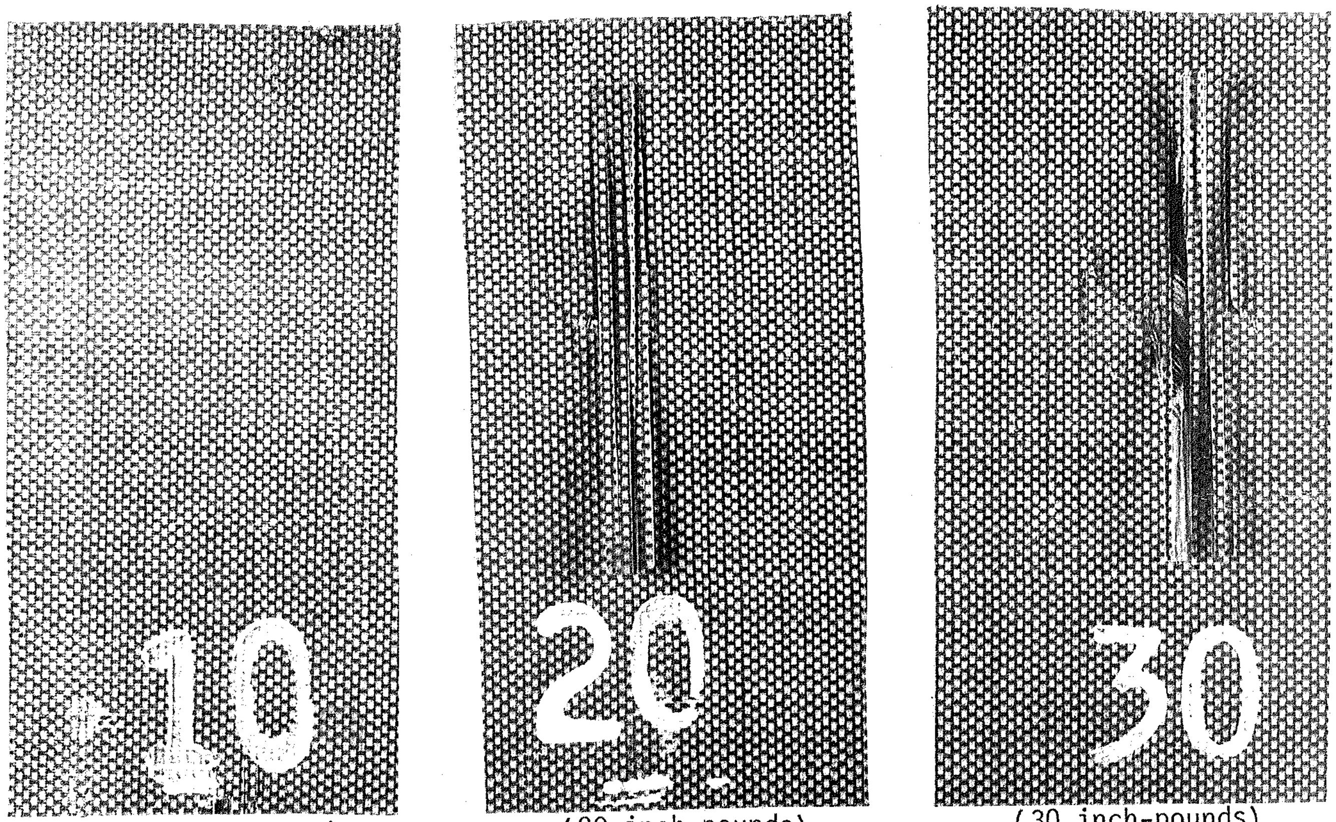
Almost all of the materials evaluated proved to have superior thin laminate impact resistance compared to the baseline Narmco 5208/T-300 material. This was an encouraging result and verified that the material suppliers do have the technical knowledge and capability to improve the toughness of current composite materials. The amount of visible damage from the Gardner Impact Tester is recorded for both the impact side and the back side of each impact panel in Appendix 1. Appendix 1 also includes a record of the C-scan recordings of internal damage and other detail information on resin and laminate properties. Figures 9, 10, 11 12 and 13 show the visual evidence at 2x magnification of damage on the back side of the Narmco 5208/T-300 material and four "toughened" materials. Note that all of the toughened systems exhibit much less visible impact damage. In every case the visible damage is more extensive on the back side than the impact side of the panel as recorded in Appendix 1.

TABLE 6

48 PLY IMPACT PANEL QUALITY CONTROL TESTS

MATERIAL	RESIN CONTENT-%	VOID CONTENT-%	FIBER VOLUME-%
American Cyanamid BP-907	30.2	1.2	61
U.S. Polymeric #1	27.6	0.6	64.5
Narmco 95995	37.6	0.6	54.4
Air Logistics #1	33.9	3.1*	56.8
Ciba Geigy #1	28.7	0.8	63.8
Hexcel #1	32.6	-0.7*	60.5
Ciba Geigy #2	27.6	-1.3	65.6
Ciba Geigy #3	33.9	2.2	57.2
Fiberite HY-E 976	29.5	1.7	62.6
Fiberdux 920	39.8	3.0*	50.9
Hexcel #2	34.1	2.4*	57.0
Ciba Geigy #4	38.5	0.7	52.5
Narmco X1114	38.1	4.4*	51.8
Narmco X-108/34A	26.6	1.o*	67.2
U.S. Polymeric #2	27.4	1.0*	65.2
Narmco 5208 Slow Cure	28.2	0.1	64.9
Fiberdux 920 Low Resin	33.9	0.8	57.9
Ciba Geigy #1M	31.0	-1.8*	62.1
American Cyanamid BP-907 Low Resin	37.2	2.0	54.0
American Cyanamid 919	34.4	-3.3*	60.1
American Cyanamid 937	37.2	-1.6	56.0
Ciba Geigy #1M 2nd	43.2	1.0*	49.5
Narmco 107	39.3	2.3	51.8
Narmco 109	37.0	2.4	54.0
American Cyanamid 982	32.2	2.1	59.3
Fiberdux 914	23.2	2.1	68.6

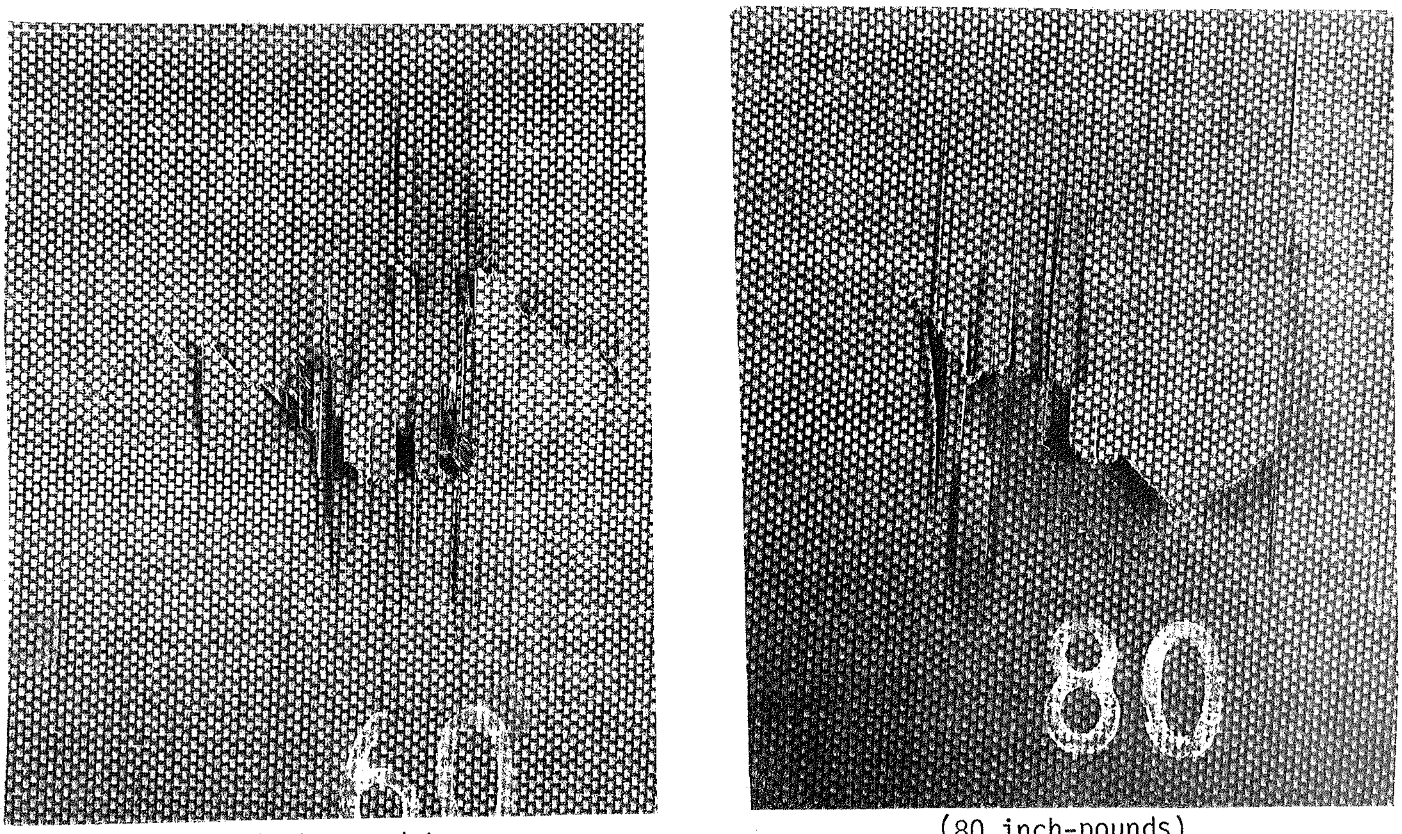
* Assumed resin density of 1.267 gm/cc



(10 inch-pounds)
1.13 Joules

(20 inch-pounds)
2.26 Joules

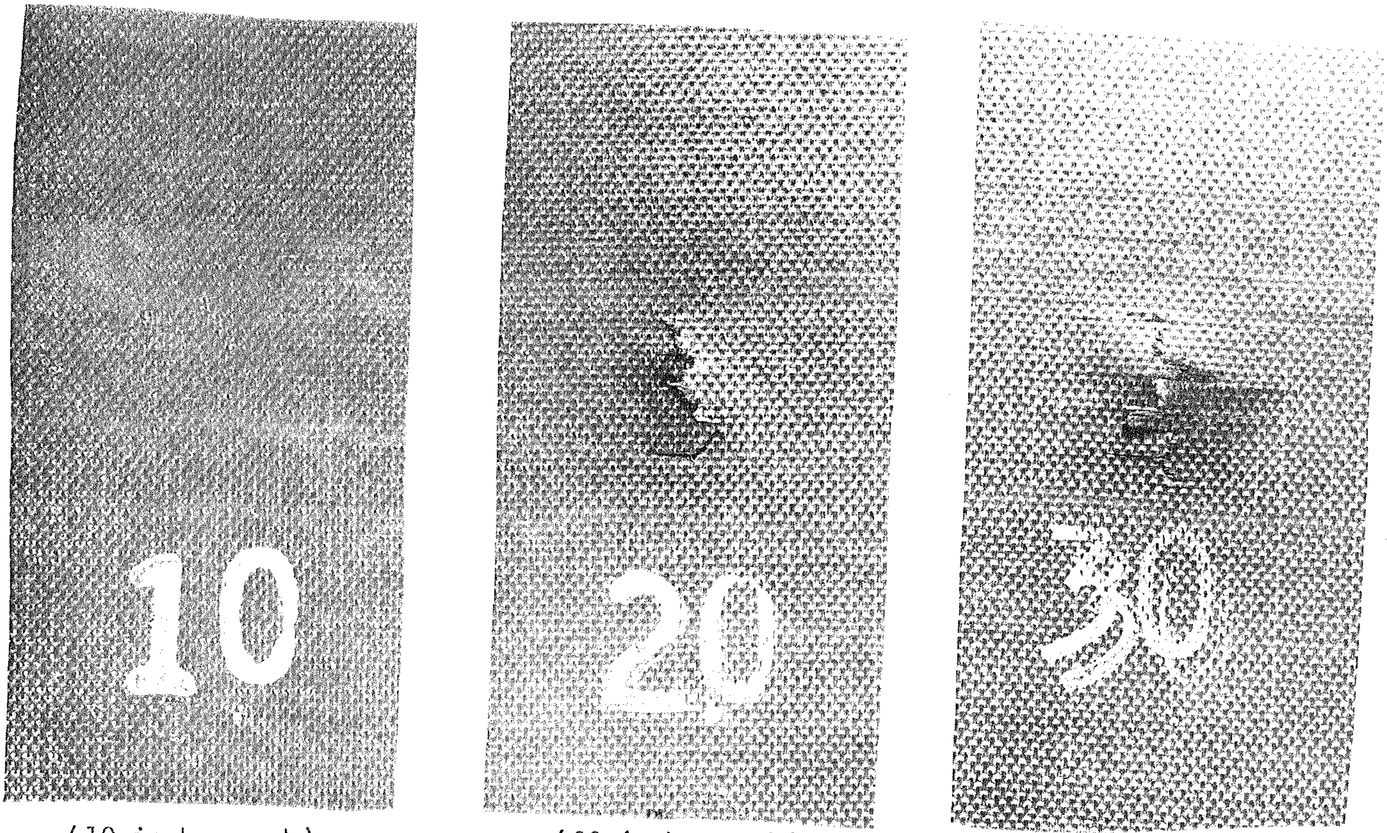
(30 inch-pounds)
3.39 Joules



(60 inch-pounds)
6.78 Joules

(80 inch-pounds)
9.04 Joules

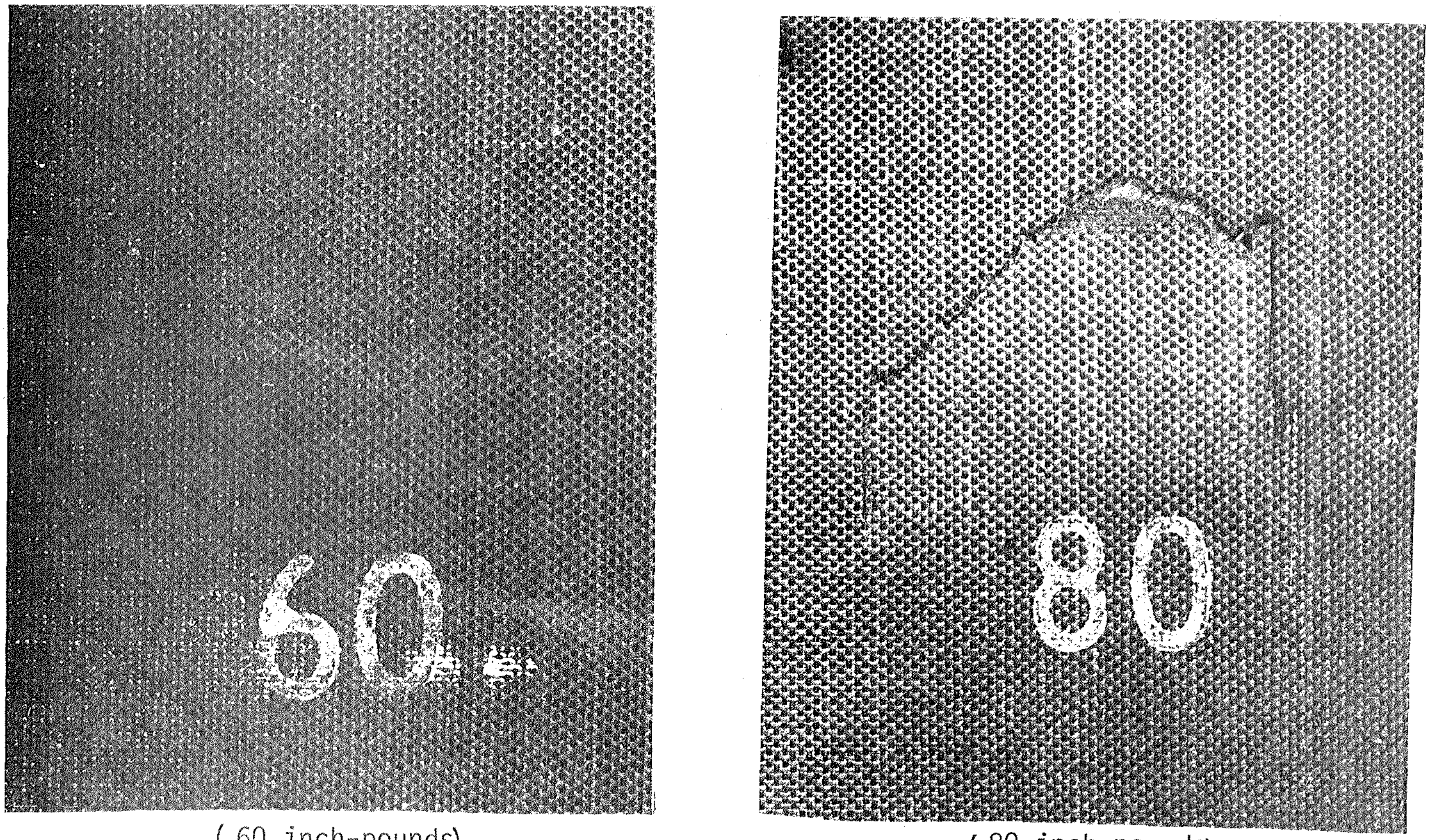
FIGURE 9. VISIBLE IMPACT DAMAGE ON BACK SIDE $(0, \pm 45, 90)_s$
5208 REFERENCE LAMINATE



(10 inch-pounds)
1.13 Joules

(20 inch-pounds)
2.26 Joules

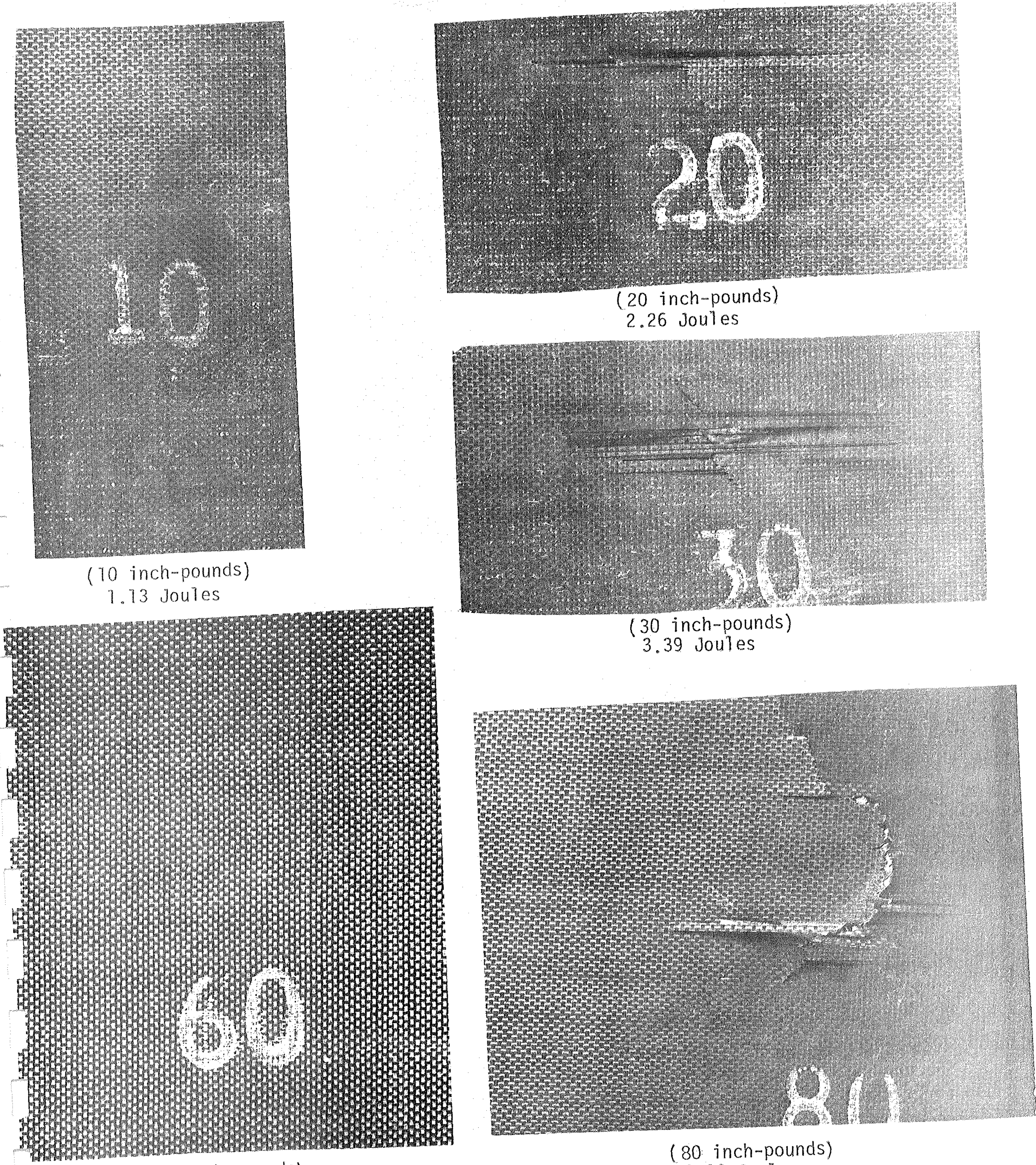
(30 inch-pounds)
3.39 Joules



(60 inch-pounds)
6.78 Joules

(80 inch-pounds)
9.04 Joules

FIGURE 10. VISIBLE IMPACT DAMAGE ON BACK SIDE $(0, \pm 45, 90)_s$ HEXCEL #1 LAMINATE



(10 inch-pounds)
1.13 Joules

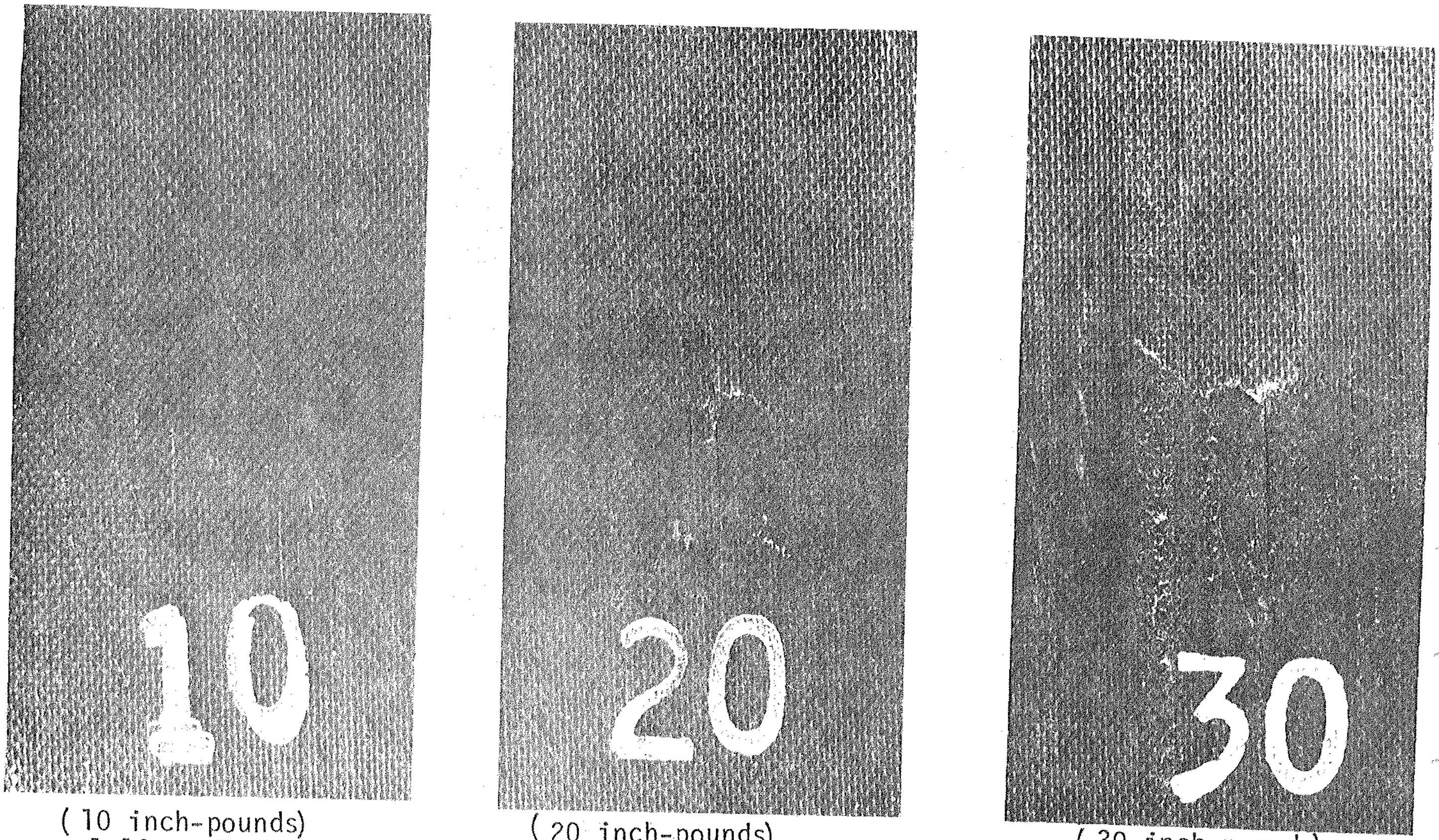
(20 inch-pounds)
2.26 Joules

(30 inch-pounds)
3.39 Joules

(60 inch-pounds)
6.78 Joules

(80 inch-pounds)
9.04 Joules

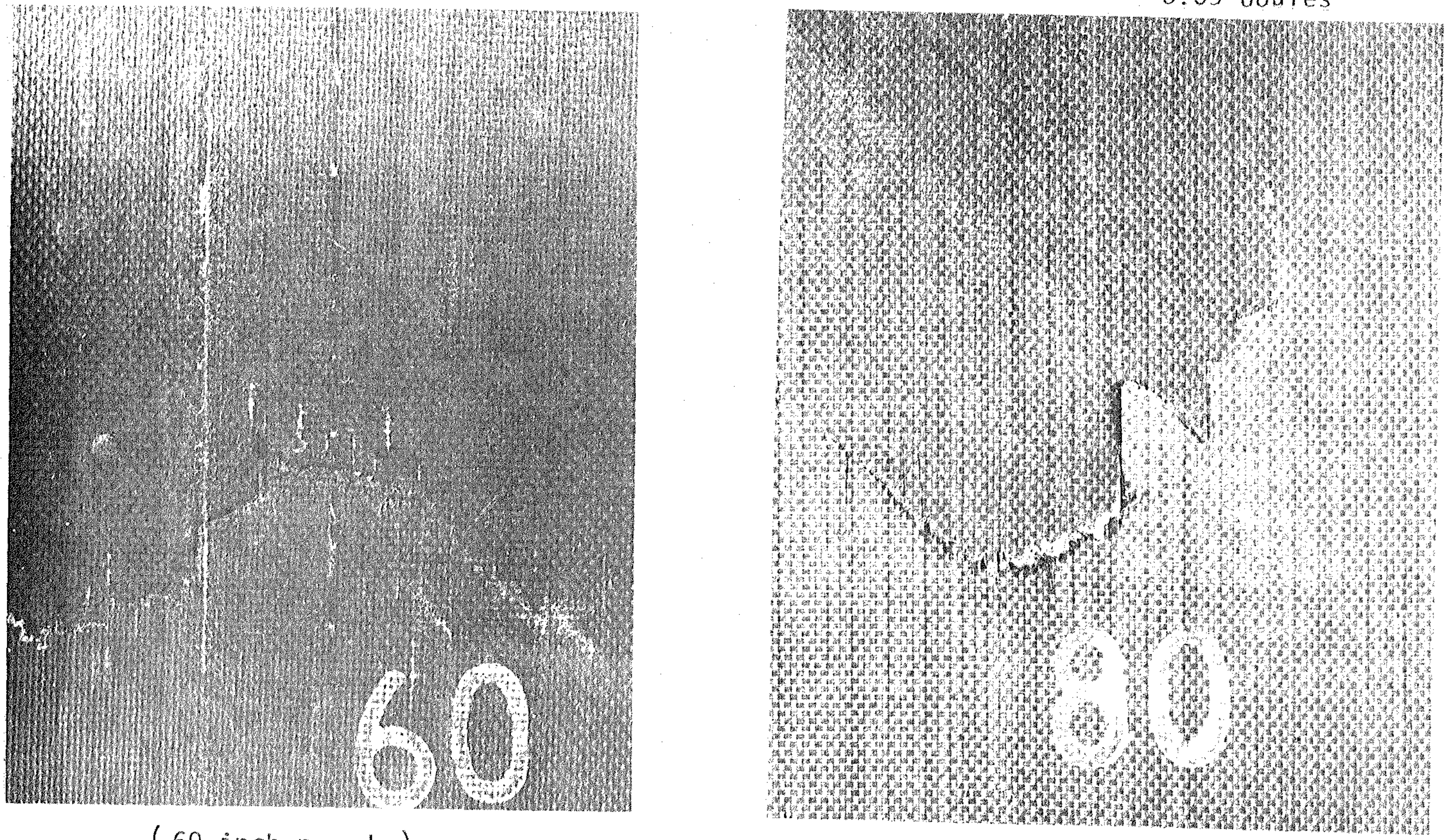
FIGURE 11. VISIBLE IMPACT DAMAGE ON BACK SIDE $(0, \pm 45, 90)_s$ CIBA GEIGY #4 LAMINATE



(10 inch-pounds)
1.13 Joules

(20 inch-pounds)
2.26 Joules

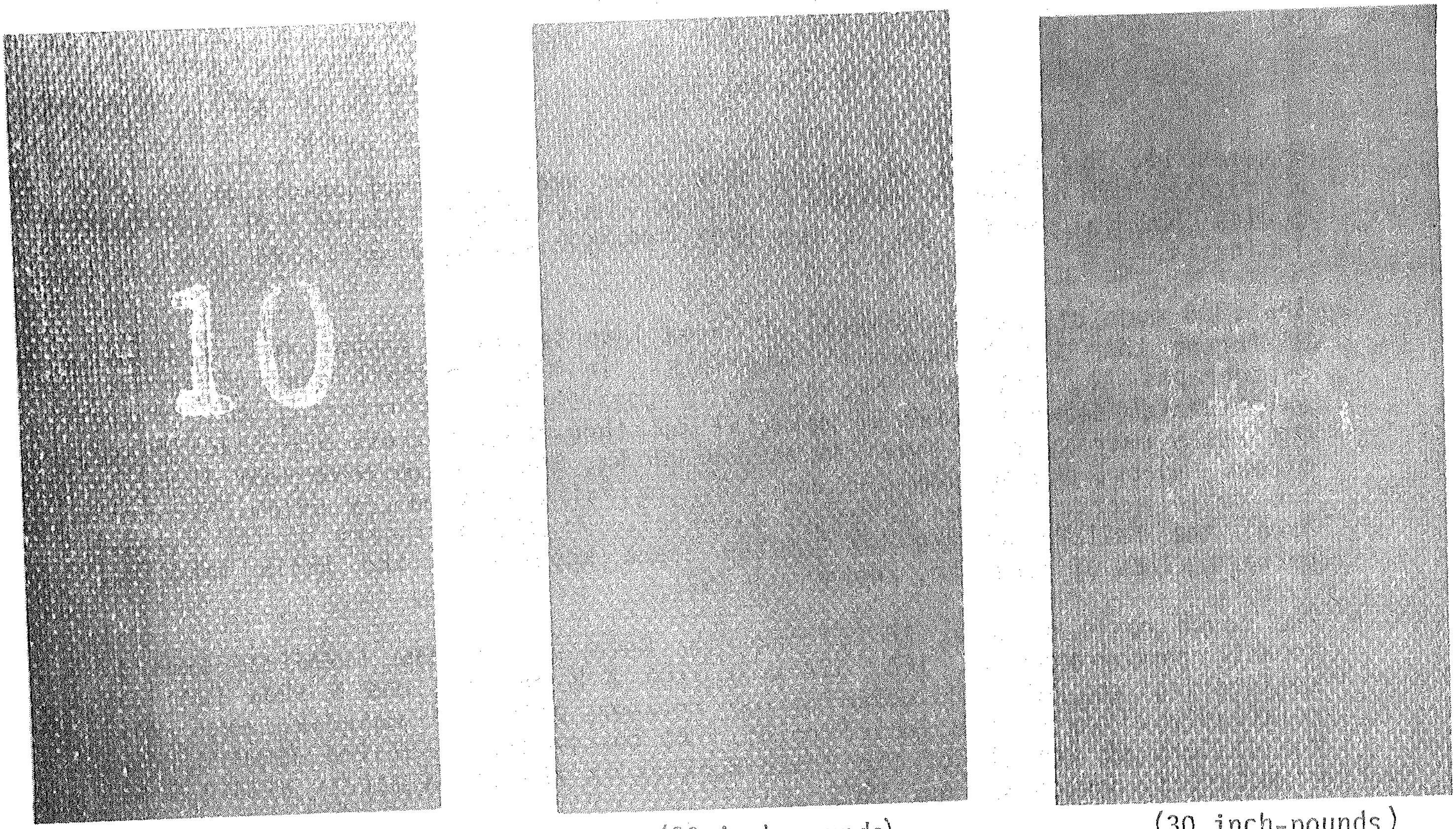
(30 inch-pounds)
3.39 Joules



(60 inch-pounds)
6.78 Joules

(80 inch-pounds)
9.04 Joules

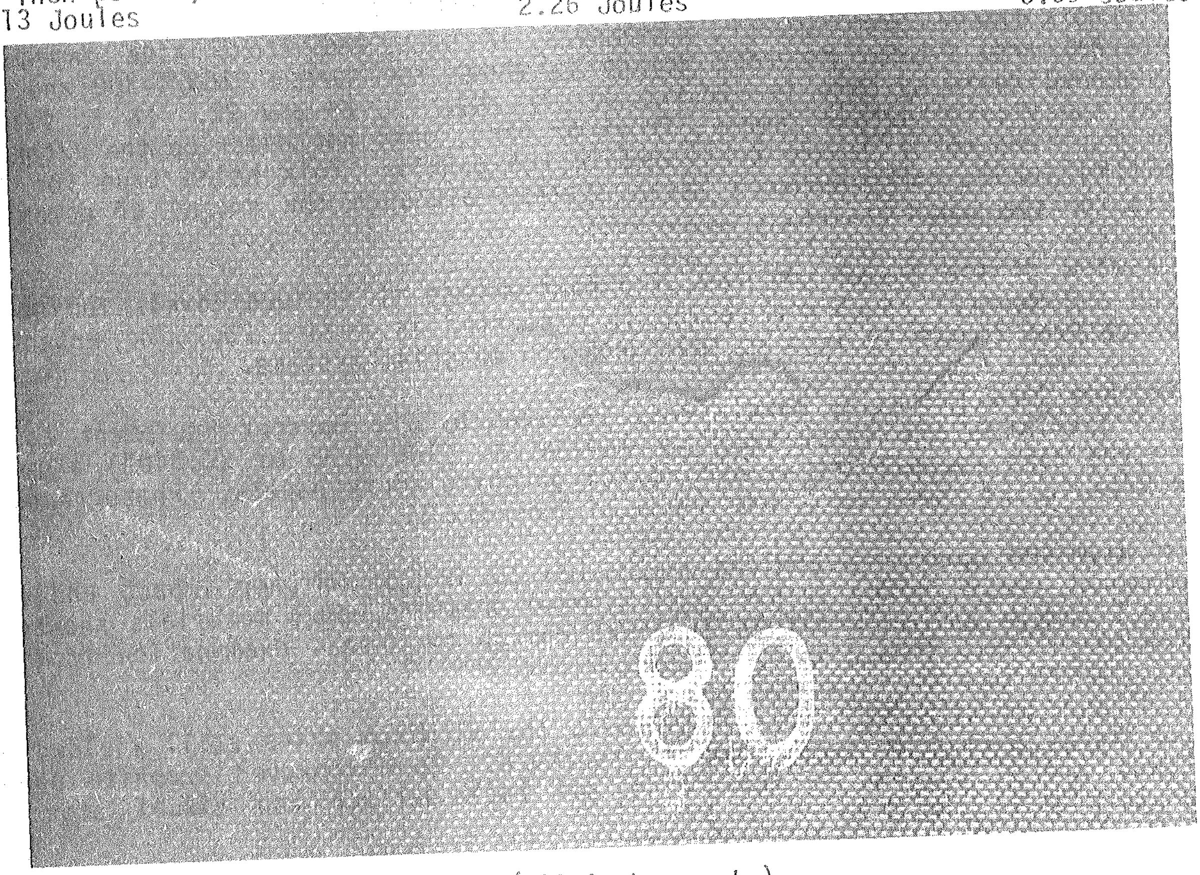
FIGURE 12. VISIBLE IMPACT DAMAGE ON BACK SIDE (0, ± 45, 90)s BP907 LAMINATE



(10 inch-pounds)
1.13 Joules

(20 inch-pounds)
2.26 Joules

(30 inch-pounds)
3.39 Joules



(80 inch-pounds)
9.04 Joules

FIGURE 13. VISIBLE IMPACT DAMAGE ON BACK SIDE (0, ± 45, 90)s FIBERDUX 920 LAMINATE

Figures 14, 15, 16, 17, 18 and 19 show cross sectional photographs at varying magnifications of damage caused by impact blows of 3.39 joules (30) and 9.04 joules (80 in pounds) to Narmco 5208, BP-907 and Ciba Geigy #4 eight ply laminates.

The 5208 mode of impact failure, at these load levels of impact, is noticeably different than the "toughened" materials. In the immediate area at impact, photographs No. 14A and 15A, there is considerable splintering and severe delamination between plies of material and thru-the-thickness ply cracking of the resin matrix, best shown in photograph No. 14C. As we move away from the direct impact, photographs 14B and 15B, the failure is mainly delamination in the resin matrix between plies of material. At the periphery of the damaged area, the failure at the tip of the crack appears in the resin interface between plies of laminate, photograph 15C.

The tough resin systems, BP-907 and Ciba Geigy #4, in the immediate area of impact, photographs No. 16A, 17A & B, 18A & B and 19A and B show far less splintering and minimal delamination between plies of material even when relatively close to the impact point. At the periphery of the damaged area, the failure at the tip of the crack appears in the resin matrix within a ply of material, photograph No. 19C.

The C-scan NDT process has proven very beneficial in determining the extent of internal damage from impact. Examples of back and front side damage vs internal area C-scan recorded damage is shown for Narmco 5208/T-300 and five toughened resin systems in Figures 20, 21, 22, 23, 24 and 25. It is evident that the visual surface damage, front or back, does not describe the extent of the real amount of damage contained in the panels. This holds true for both brittle (5208) and toughened resin systems although the extent of damage is less for the tough resins.

A review of the C-scan records of impact damage at various levels for Narmco 5208 and several toughened resins is presented in Figure 26. The extent of damage from impact is less in the toughened material systems.

Aluminum 2024 T-3 alloy panels were impacted by the Gardner Equipment at the same levels as the graphite/epoxy laminates. The 0.98 mm (0.040") aluminum was the same approximate weight as the graphite/epoxy panels. Photographs of the results of these tests are shown in Appendix II.

The aluminum specimens yielded under low 10 in lb. Gardner impact and made permanent dents in the skin. The improved graphite/epoxy materials showed no visual damage and only slight internal damage by C-scan examination from the same 10 in. lbs. impact load.

At higher impact loads, to 100 in lbs., the aluminum skins still yielded and took large permanent dents, but no puncture. Most improved graphite panels showed broken fibers on the front and back surface and visual signs of puncture of the surface.

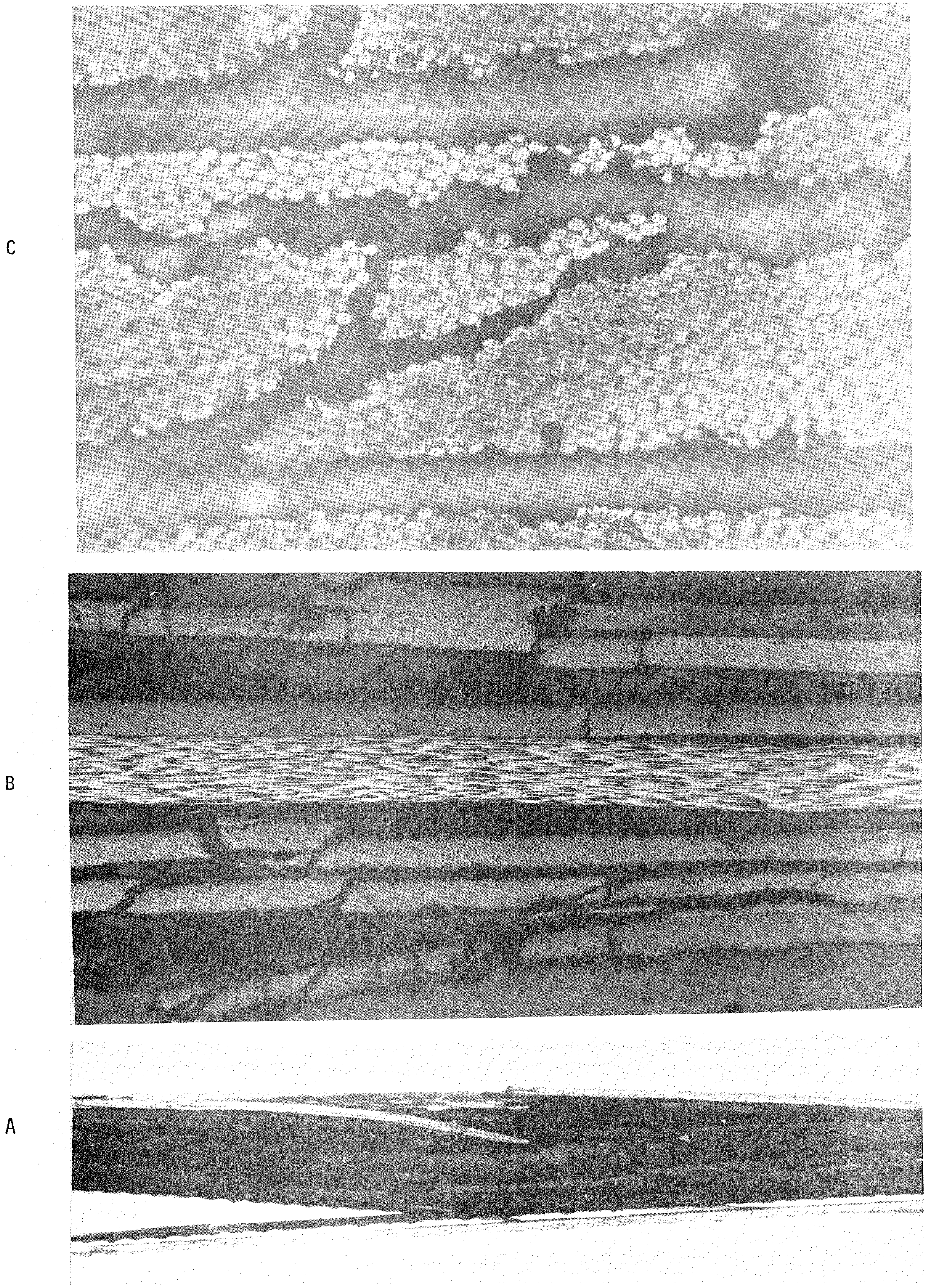


FIGURE 14. NARMCO 5208 3.39 JOULES (30 INCH POUNDS) GARDNER IMPACT

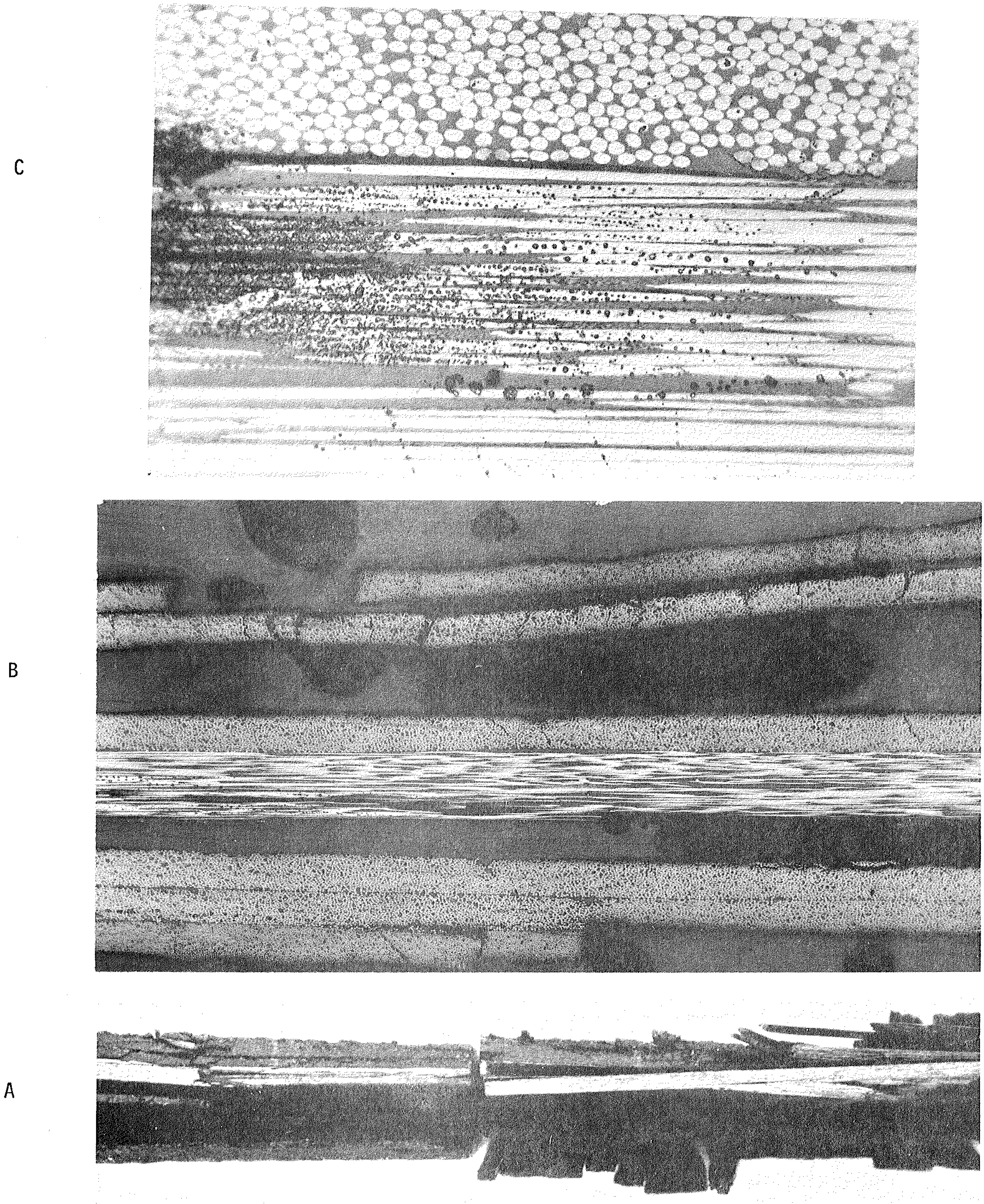


FIGURE 15. NARMCO 5208 9.04 JOULES (80 INCH POUNDS) GARDNER IMPACT

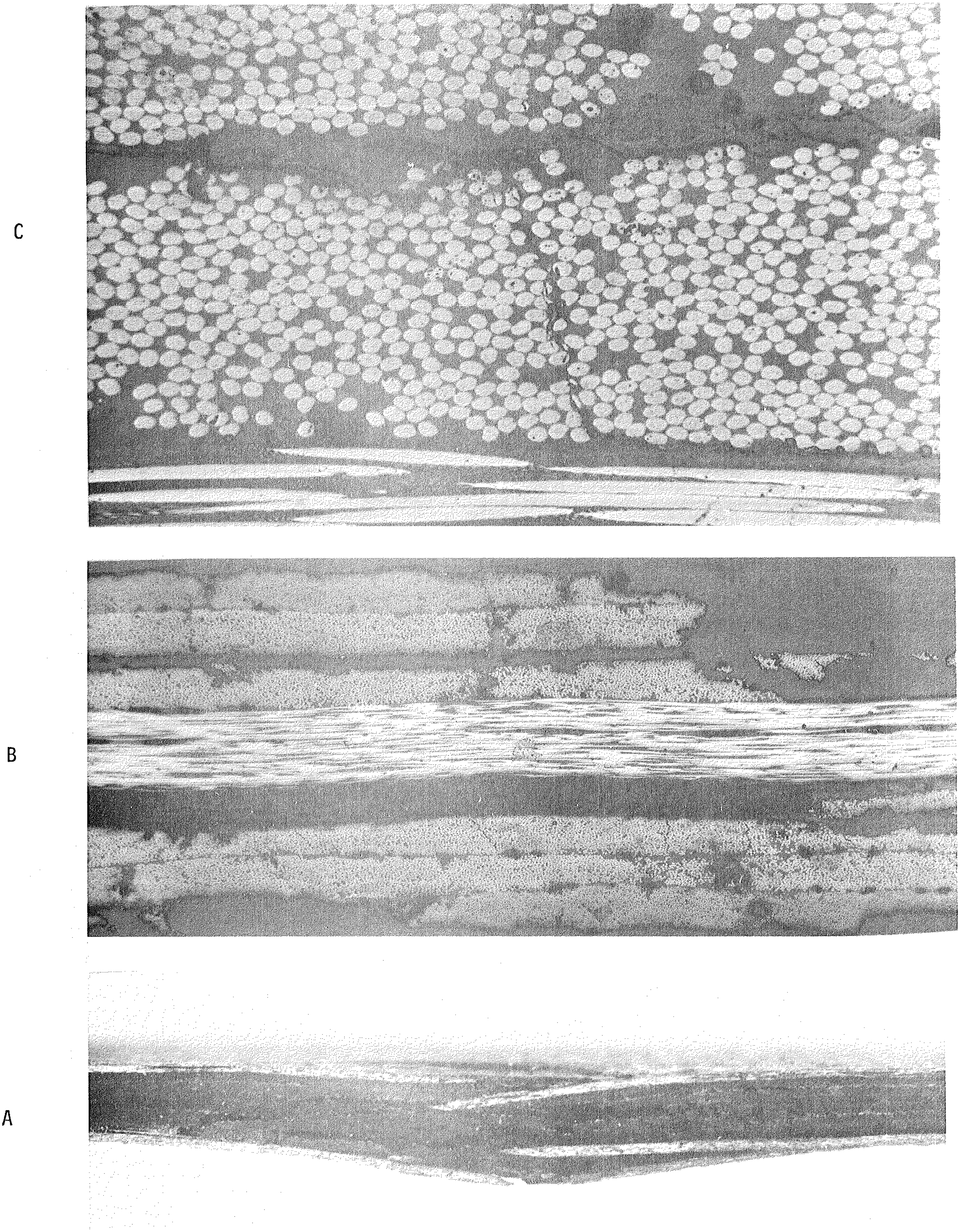


FIGURE 16. BP-907 3.39 JOULES (30 INCH POUNDS) GARDNER IMPACT

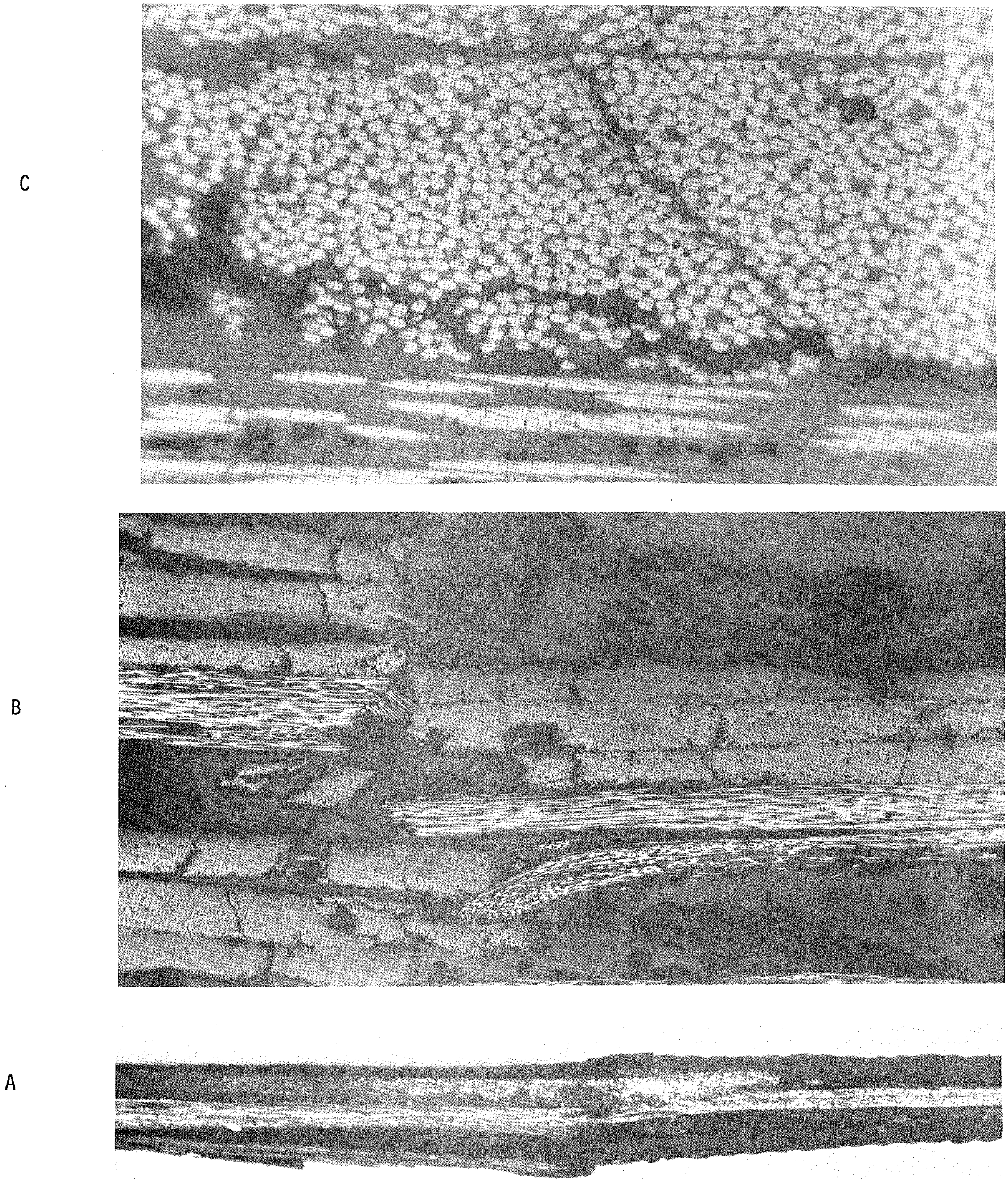


FIGURE 17. BP-907 9.04 JOULES (80 INCH POUNDS) GARDNER IMPACT

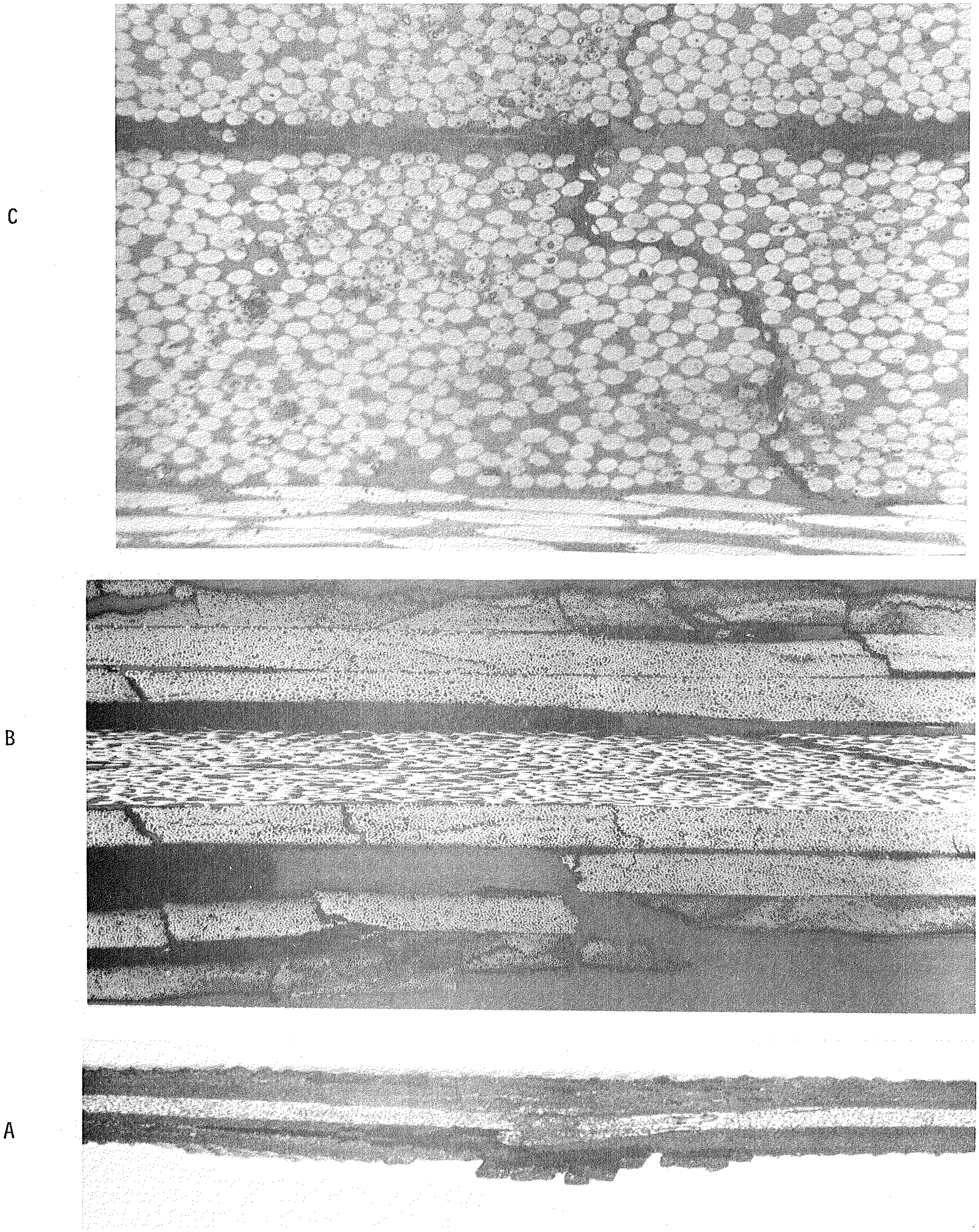


FIGURE 18. CIBA GEIGY #4 3.39 JOULES (30 INCH POUNDS) GARDNER IMPACT

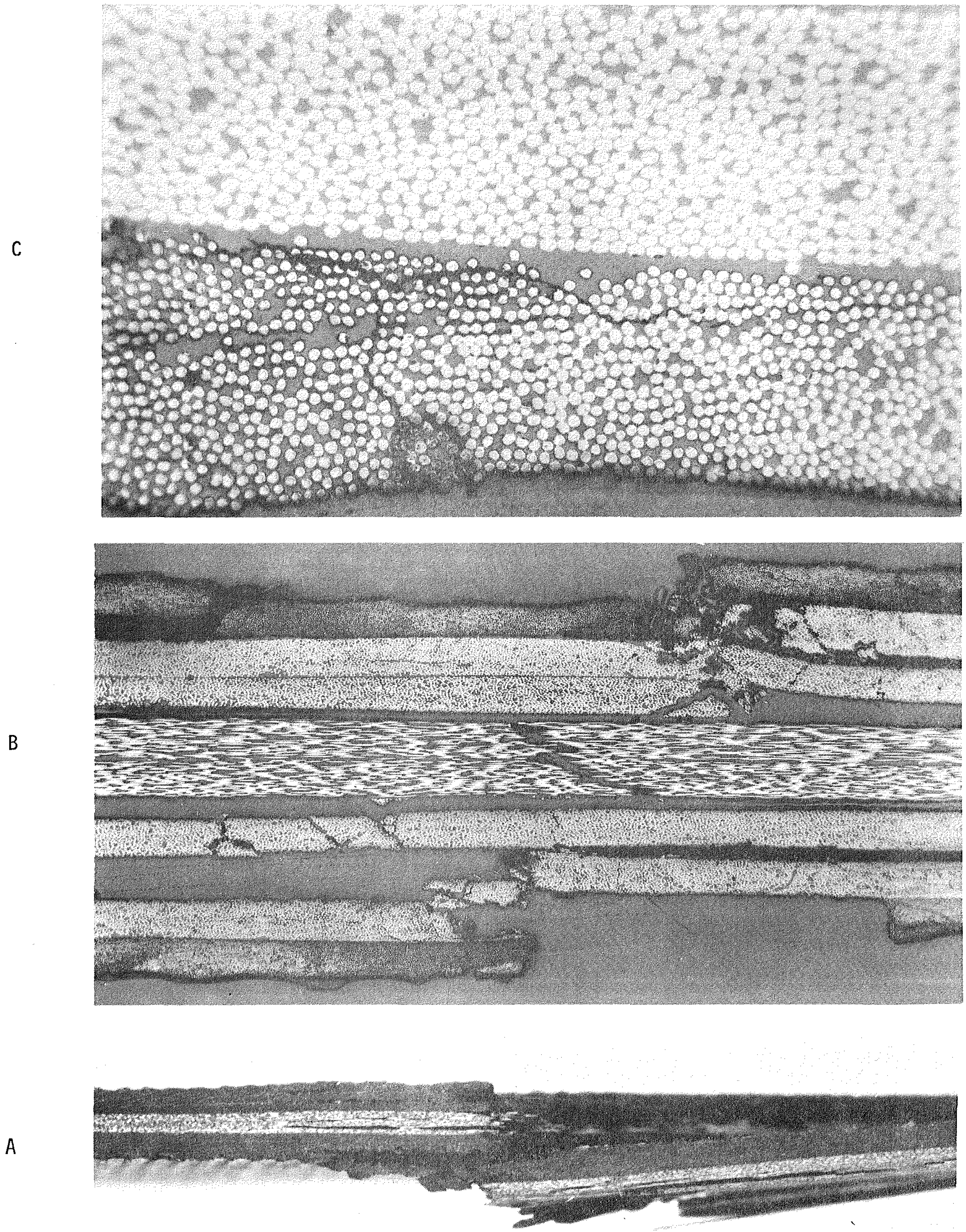
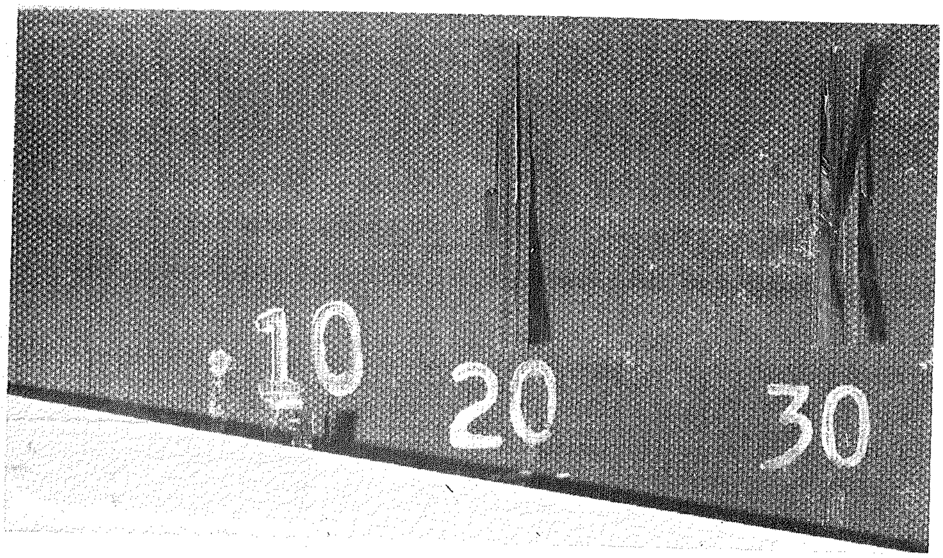


FIGURE 19. CIBA GEIGY #4 9.04 JOULES (80 INCH POUNDS) GARDNER IMPACT

Visible Damage Back side



NARMCO 5208/T300
REFERENCE

Visible Damage Front side	None	None	3.17 mm (1/8 inch)hole + broken fibers

Total Damage by C-scan

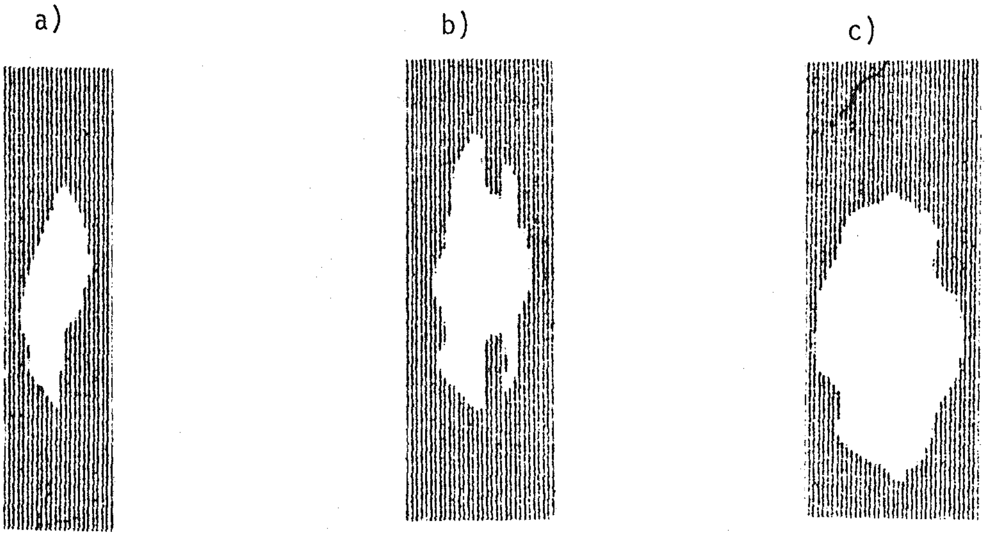
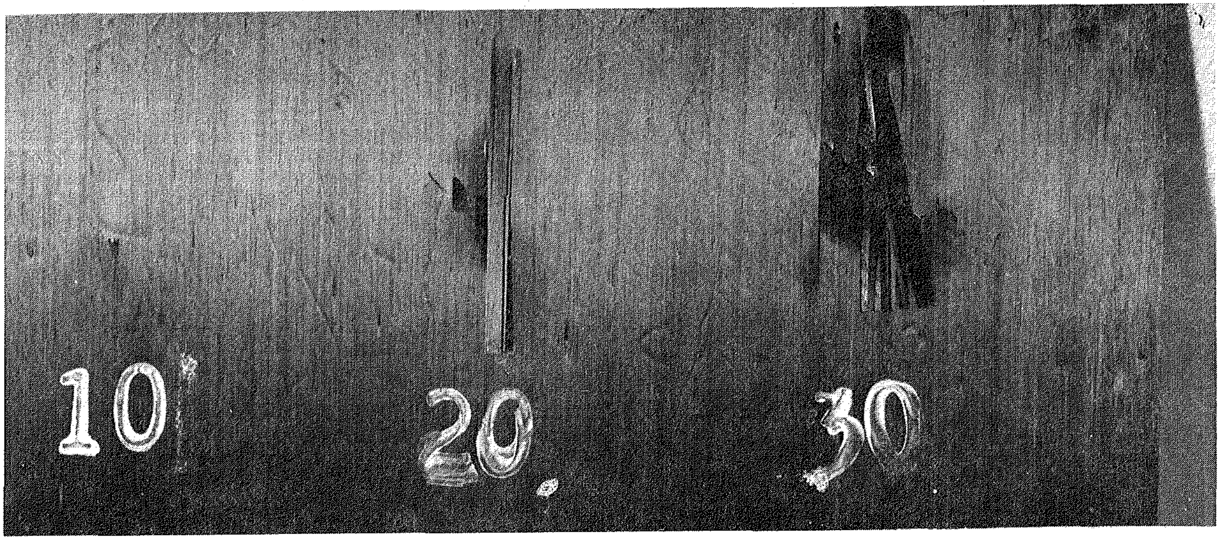


FIGURE 20. COMPARISON OF VISUAL IMPACT DAMAGE VS. NDT INSPECTION FOR NARMCO 5208/T300 FOR 3.17 cm (1.25 INCH) SUPPORT AT a. 1.13 JOULES (10 INCH-POUNDS), b. 2.26 JOULES (20 INCH-POUNDS) AND c. 3.39 JOULES (30 INCH-POUNDS)

Visible
Damage
Back side



NARMCO 95995/T300

Visible Damage Front side	None	None	Broken Fibers
	a)	b)	c)

Total Damage
by C-scan

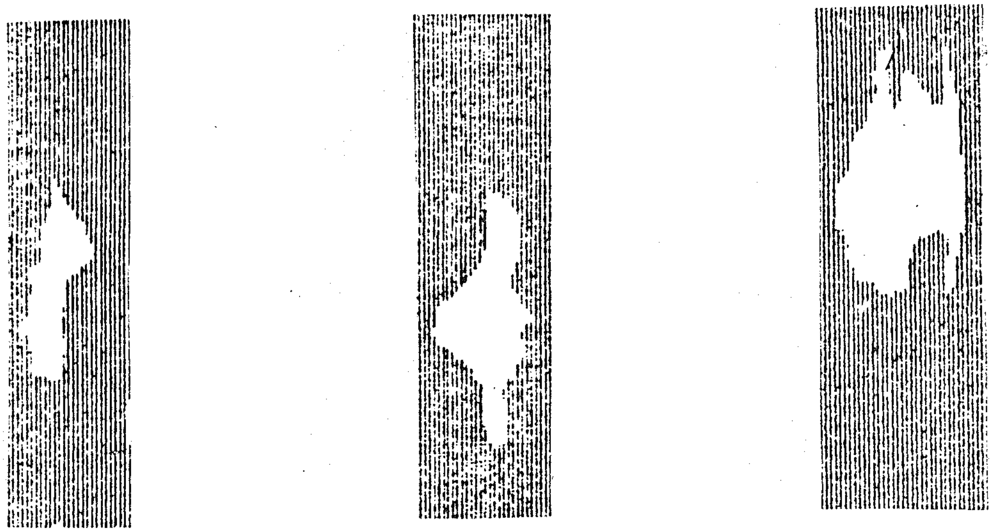
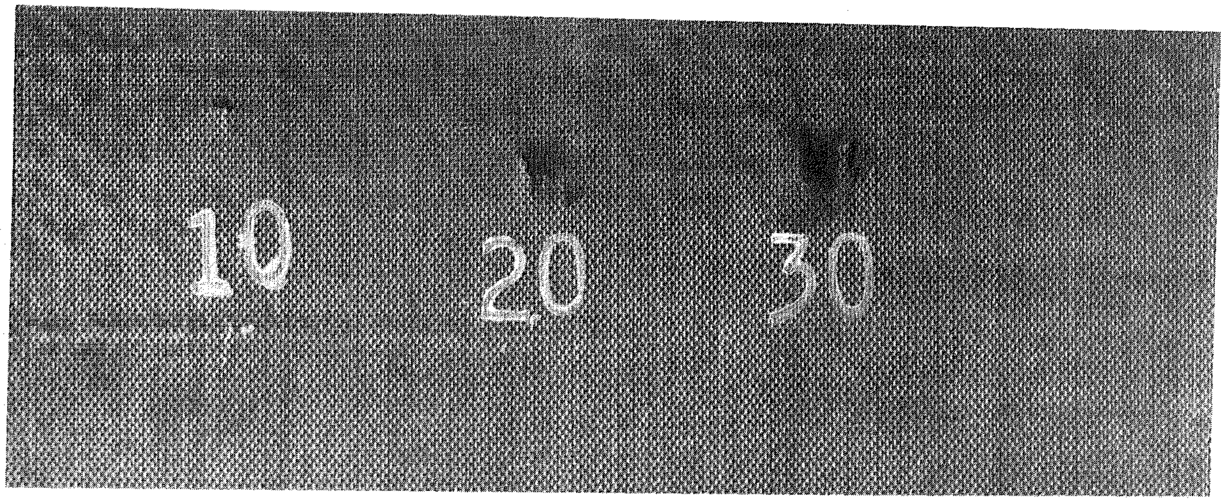


FIGURE 21. COMPARISON OF VISUAL IMPACT DAMAGE VS. NDT INSPECTION FOR NARMCO 95995/T300 FOR 3.17 cm (1.25 INCH) SUPPORT AT a. 1.13 JOULES (10 INCH-POUNDS), b. 2.26 JOULES (20 INCH-POUNDS) AND c. 3.39 JOULES (30 INCH-POUNDS)

Visible
Damage
Back side



U.S. POLYMERIC TOUGH RESIN #1/T300

Visible
Damage
Front side

None

a)

3.17 mm
(1/8 inch)
dent

b)

6.35 mm
(1/4 inch) dent +
broken fibers

c)

Total Damage
by C-scan

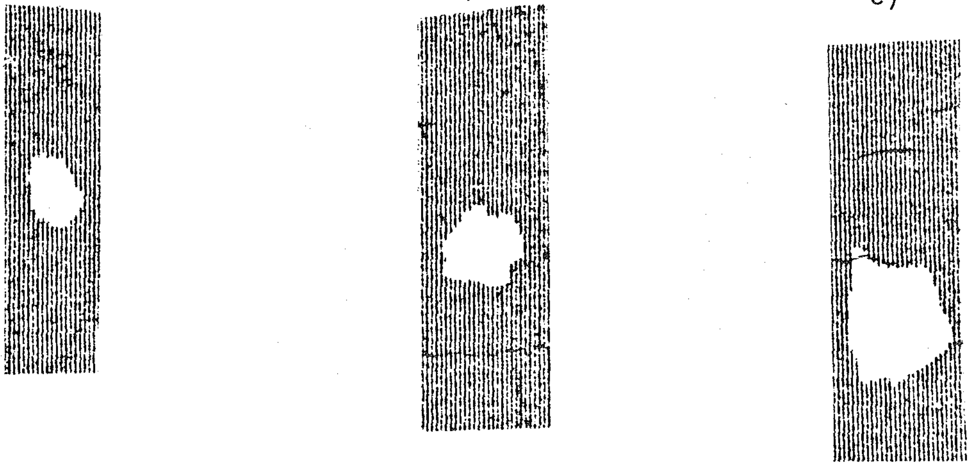
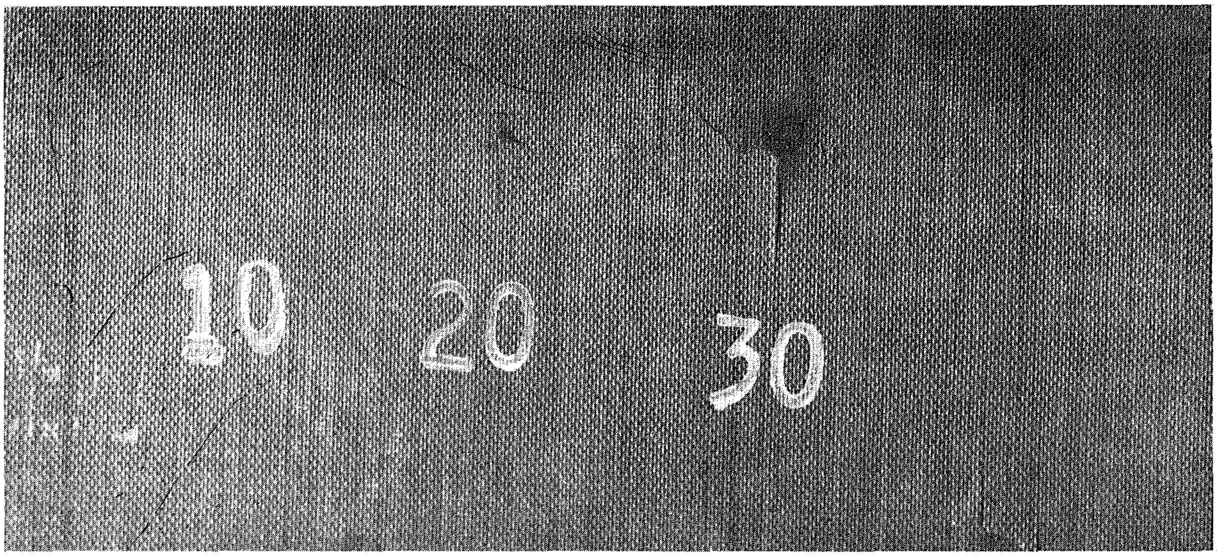


FIGURE 22. COMPARISON OF VISUAL IMPACT DAMAGE VS. NDT INSPECTION FOR U.S. POLYMERIC TOUGH RESIN #1 FOR 3.17 cm (1.25 INCH) SUPPORT AT a. 1.13 JOULES (10 INCH-POUNDS), b. 2.26 JOULES (20 INCH-POUNDS) AND c. 3.39 JOULES (30 INCH-POUNDS)

Visible
Damage
Back side



AMERICAN CYANAMIDE BP-907/T300

Visible Damage Front side	None a)	3.17 mm (1/8 inch) dent b)	6.35 mm (1/4 inch)dent + broken fibers c)

Total Damage
by C-scan

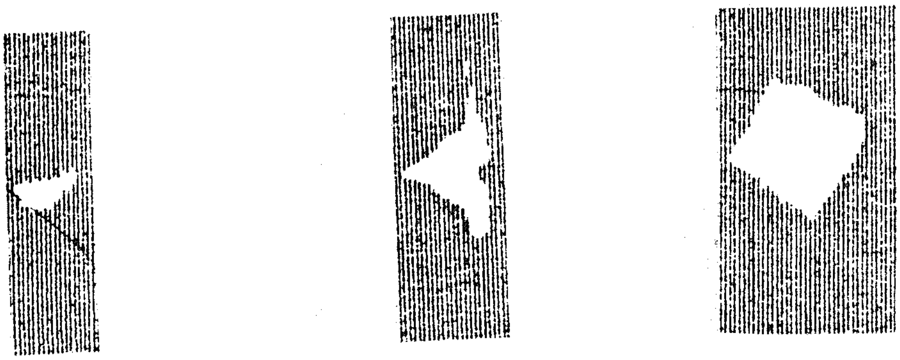
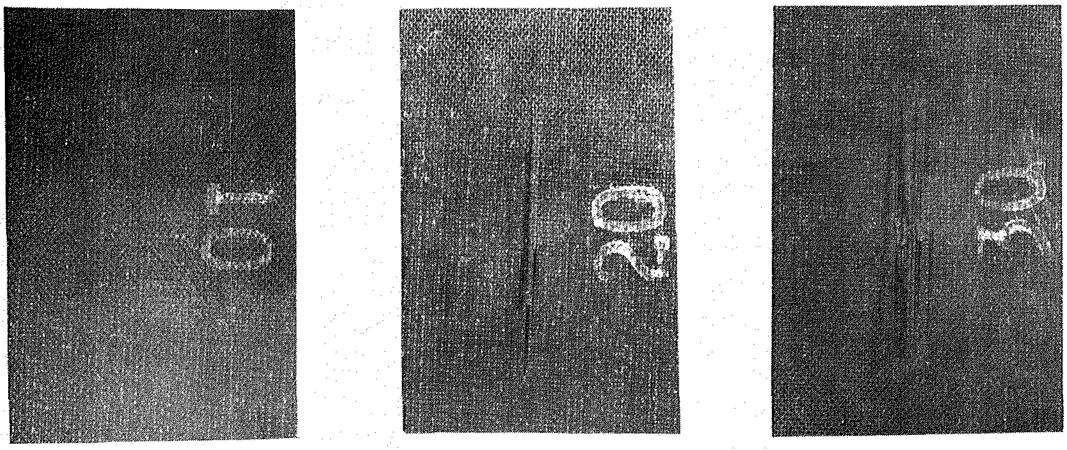


FIGURE 23. COMPARISON OF VISUAL IMPACT DAMAGE VS NDT INSPECTION FOR AMERICAN CYANAMID BP-907 FOR 3.17 cm (1.25 INCH) SUPPORT AT a. 1.13 JOULES (10 INCH-POUNDS), b. 2.26 JOULES (20 INCH-POUNDS) AND c. 3.39 JOULES (30 INCH-POUNDS)

Visible
Damage
Back side



Visible
Damage
Front side

None

None

5.1 mm
(.2 inch) dent
some broken
fibers

(a)

(b)

(c)

Total Damage
by C-scan

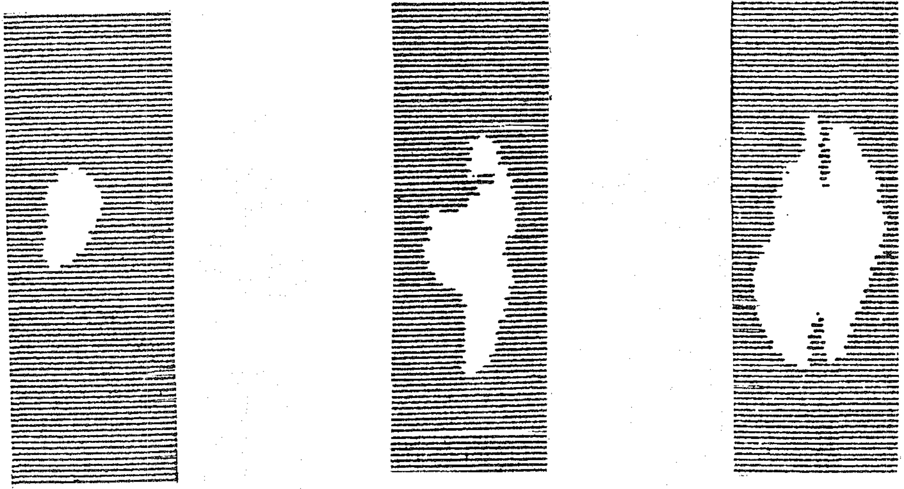


FIGURE 24. COMPARISON OF VISUAL IMPACT DAMAGE VS NDT INSPECTION FOR CIBA GEIGY #4 FOR 3.17 cm (1.25 INCH) SUPPORT AT a. 1.13 JOULES (10 INCH POUNDS), b. 2.26 JOULES (20 INCH POUNDS) AND c. 3.39 JOULES (30 INCH POUNDS)

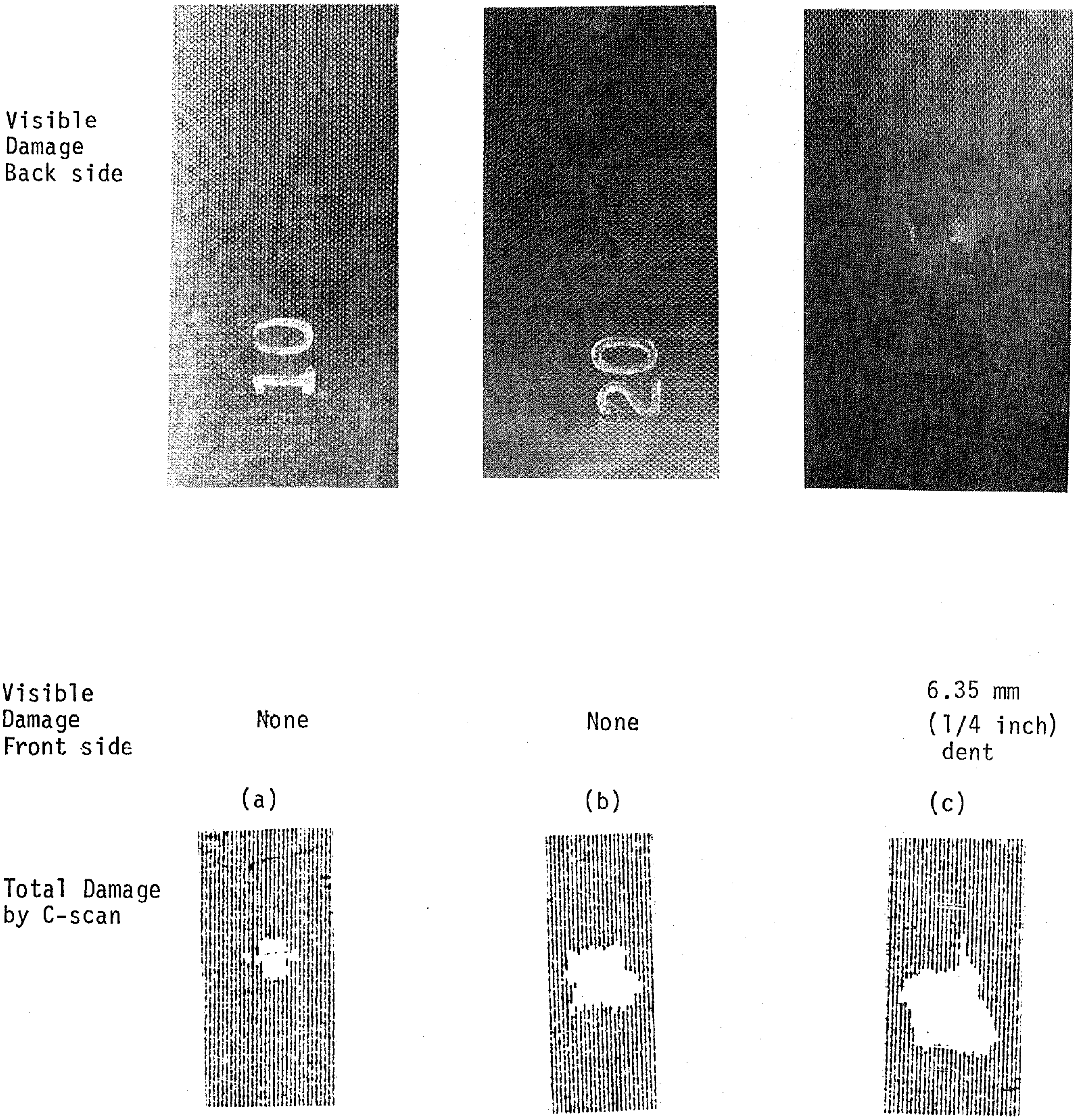


FIGURE 25. COMPARISON OF VISUAL IMPACT DAMAGE VS NDT INSPECTION FOR FIBERDUX 920 FOR 3.17 cm (1.25 INCH) SUPPORT AT a. 1.13 JOULES (10 INCH POUND), b. 2.26 JOULES (20 INCH POUND) AND c. 3.39 JOULES (30 INCH POUND)

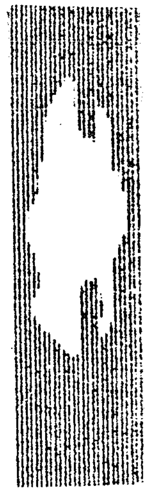
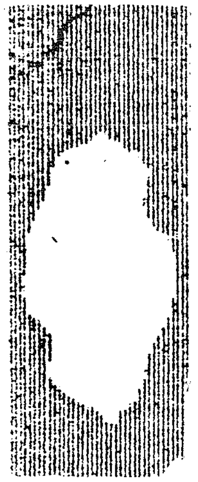
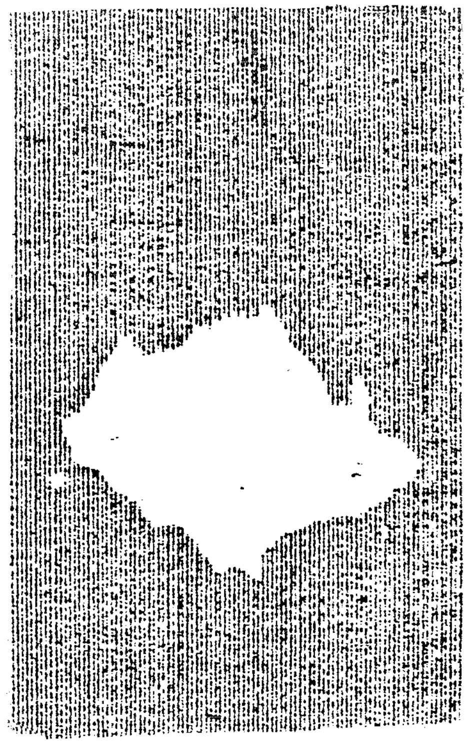
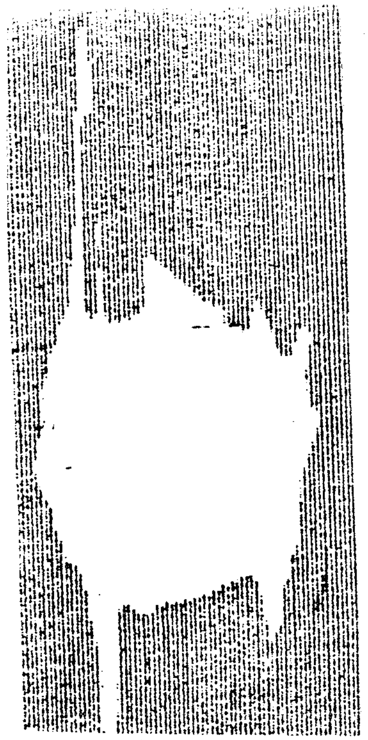
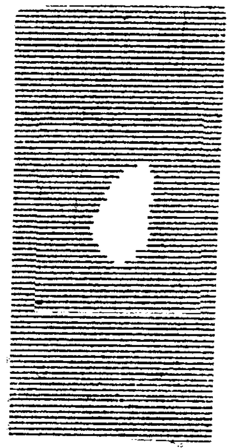
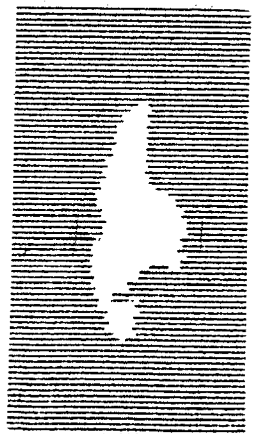
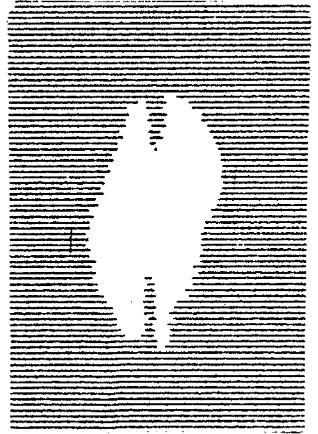
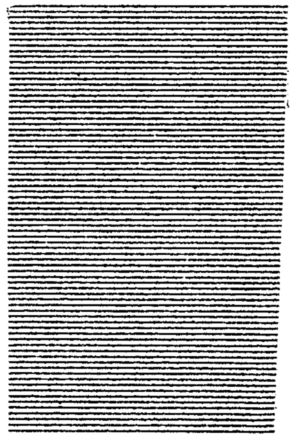
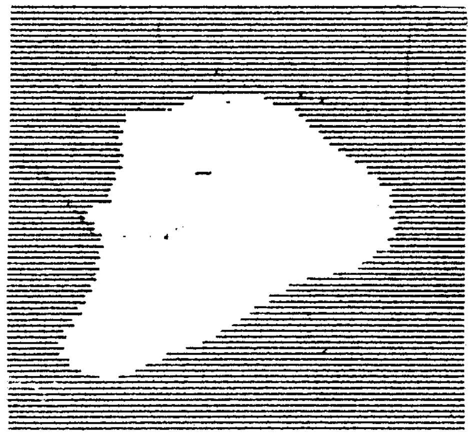
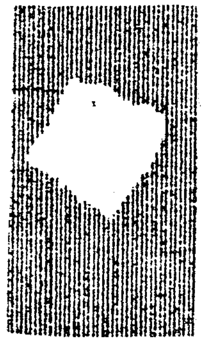
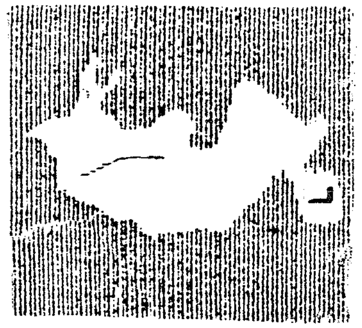
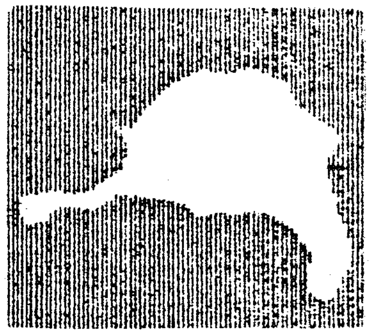
JOULES IMPACT - (INCH - POUND)	1.13 (10) Round	2.26 (20) Round	3.39 (30) Round	6.78 (60) Flat	9.04 (80) Flat
Narmco 5208					
C-scan damage area (in^2) cm^2	(.26) 1.69	(.56) 3.64	(.82) 5.33	(1.56) 10.14	(2.22) 14.43
Ciba Geigy #4					
C-scan damage area (in^2) cm^2	(.10) .65	(.32) 2.08	(.59) 3.83	(0) 0	(1.60) 10.40
American Cyanamide BP 907					
C-scan damage area (in^2) cm^2	(.04) .26	(.16) 1.04	(.30) 1.95	(.76) 4.94	(.86) 5.59

FIGURE 26. THIN LAMINATE GARDNER IMPACT $(0°,\pm45°,90°)_s$

2.5.1.2 Rheometric Impact Specimens

The criteria for evaluation of the Rheometric impact results are:

a. Load at apparent yield
b. Deflection at apparent yield
c. Area under the stress/strain curve to yield
d. Total area under the stress/strain curve at total penetration

The Rheometric Constant Speed Penetration Impact machine, located at NASA-Langley Field, was used for these tests. The load vs deflection curve was plotted by the machine as the impact head penetrated the specimen at a constant velocity of 76.2 meters per minute (3000 inches per minute). The operator selected the yield point and the total penetration point to allow the machine to calculate the areas under the stress/strain curves at these points.

The load and deflection at the operator selected yield point for all toughened material systems were, as expected, greater than the 5208 yield point. (Table 4 and Appendix 3.)

A study of Figure 27 data shows the superior laminate impact resistance properties of toughened resin matrix systems, with BP-907 as a typical example, compared to the standard Narmco 5208 material, by both Rheometric and Gardner impact tests.

The energy absorbed at "yield" for the Gardner Impact, or area under the stress-strain curve to yield, is greater for the BP-907 (1.22 Joules) than for the Narmco 5208 (1.06 Joules) material. At total penatration, the energy absorbed is also greater for the BP-907 (7.31 Joules) than the Narmco 5208 (4.63 Joules) material.

The Gardner impact data also supports the conclusion that the BP-907 graphite/epoxy laminate has superior damage tolerance or impact resistance than Narmco 5208 laminates. The area of damage, shown by C-scan examination, of Gardner impact damaged panels was less for BP-907 (0.26 cm^2) than for Narmco 5208 (1.69 cm^2) material at low 1.13 joules (10 inch pounds) impact. At high load impact of 9.04 joules (80 inch pounds), the BP-907 area of damage, 5.59 cm^2 is much less than the 14.43 cm^2 damage for the Narmco 5208 material.

At total penetration, the Rheometric total "energy absorbed" values for all toughened materials recorded in Table 4 were, as expected from the Gardner Impact Tests, superior to the Narmco 5208. An additional example of this correlation is shown in Figure 28 for Narmco 5208 and Ciba Geigy #4 materials. Note that the higher Rheometric energy absorbed value by Ciba Geigy #4 indicated improved impact resistance. At the same time smaller area damage of the Gardner Impact Test, shown by C-scan also indicates improved impact strength for the Ciba Geigy material.

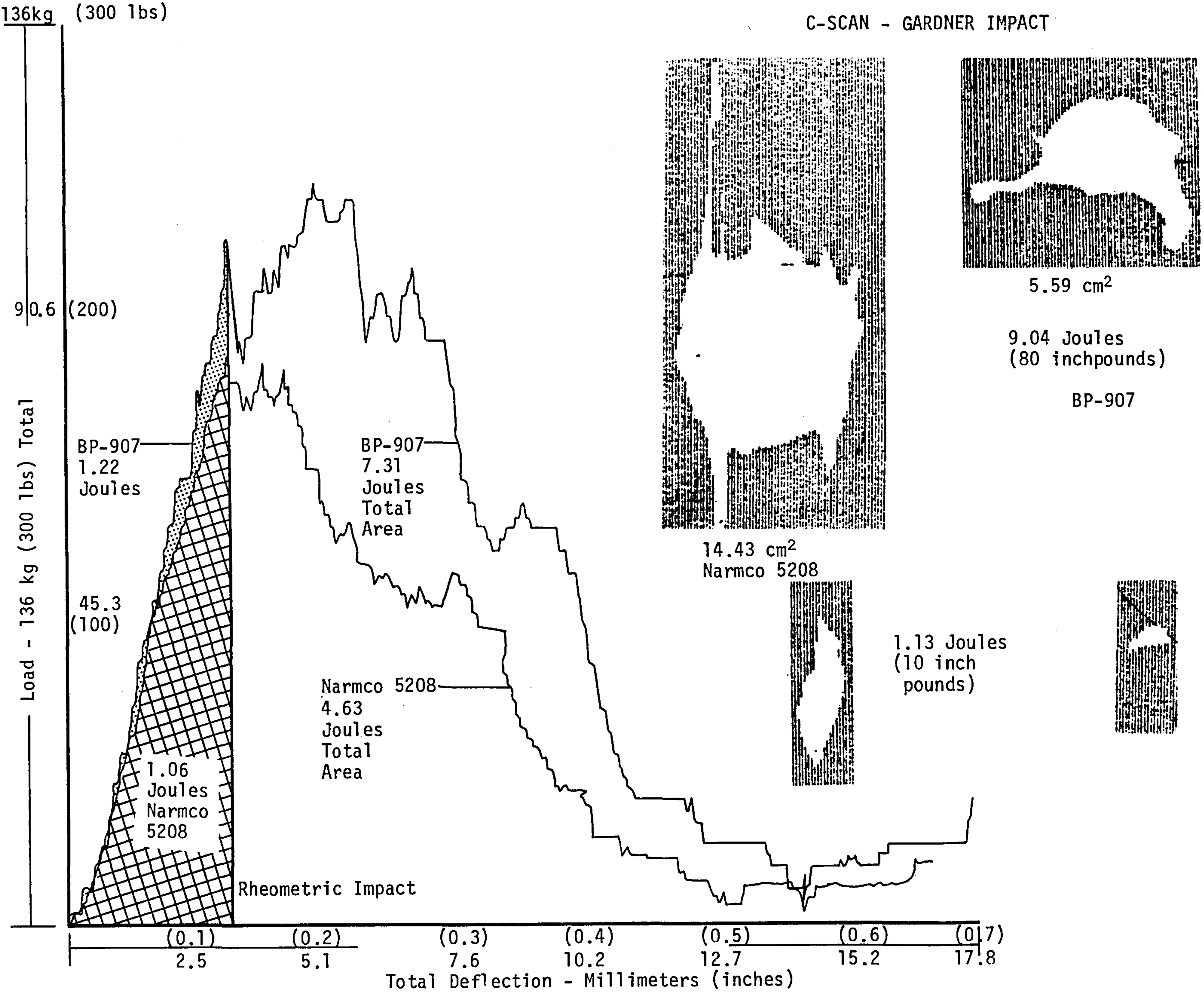


FIGURE 27. BP-907 VS NARMCO 5208 FOR RHEOMETRIC IMPACT AND GARDNER IMPACT AREA OF DAMAGE

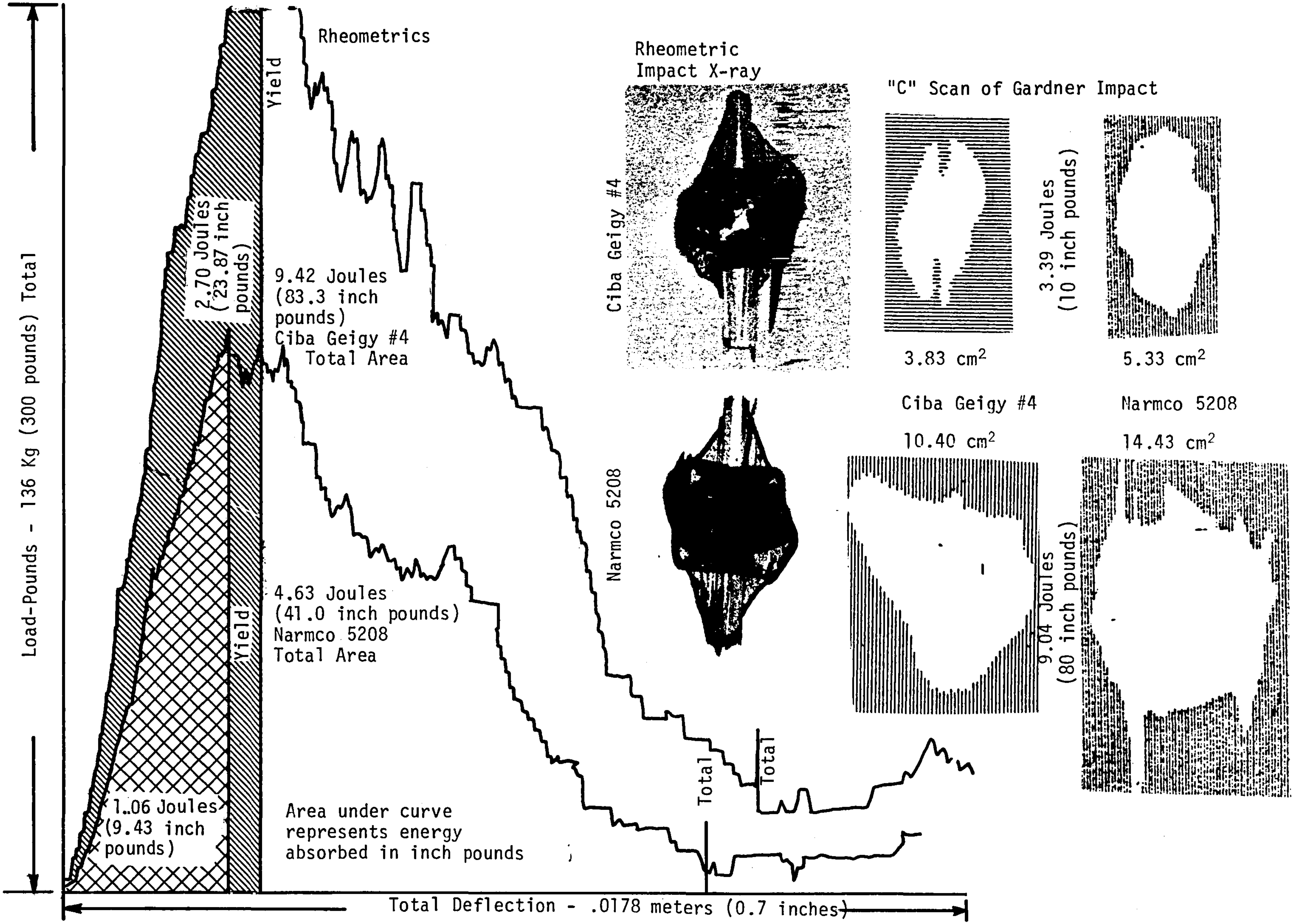


FIGURE 28. CIBA GEIGY #4 VS NARMCO 5208 FOR RHEOMETRIC IMPACT AND GARDNER IMPACT AREA OF DAMAGE

An interesting observation of the Rheometric impact penetration specimens is that the impact penetration hole was closed with broken fibers for the Narmco 5208 specimens but every toughened material contained a visible hole, with broken fiber edges, where the impact plunger penetrated. The X-rays of the impacted speciments in Figure 28 show this characteristic.

The use of the Rheometric Impact Tester has been limited to a few specimens for this program and the means of selecting the critical yield and total failure points are still in development. The equipment, with further testing and understanding, should become a valuable tool for the study of low velocity impact phenomenon.

2.5.1.3 Potential Rheometric Impact Tester Use

The Rheometric Impact tester can reduce the data in the plastic deformation area of the stress strain curve (before yield) to a kiligrams per meter (pounds per inch) slope - a measurement of modulus of elasticity. If the machine were adjusted to a slow velocity (impact) and stopped before yield or internal damage occurred, the data might prove useful as a Quality Control measure. The proper slope or modulus of elasticity function from reduced data would indicate certain qualities of the part such as:

1. Proper fiber patter
2. Proper thickness
3. Proper processing cure cycle.

The equipment seems to have the potential to offer a quick low cost NDT procedure for production Quality Control evaluation.

2.5.2 Correlation of Resin Properties to Laminate Impact Damage Area

Neat resin tensile ultimate, modulus and % elongation were obtained on as many of the resin systems as possible. These resin properties were compared to the area of damage at various levels of impact damage (Gardner impact) for laminates made for each of the resin systems and Thornel 300 fiber reinforcement. The data was plotted and the curves were obtained from a general least square best line of fit program using an HP 9825A calculator plotter.

2.5.2.1 Neat Resin Tensile Strength Vs Impact Resistance

The resin tensile strength is not an important resin variables for developing laminate impact resistance as shown in Figure 29. Toughened resins with both higher and lower tensile strength than Narmco 5208 resin produced higher impact resistant laminates.

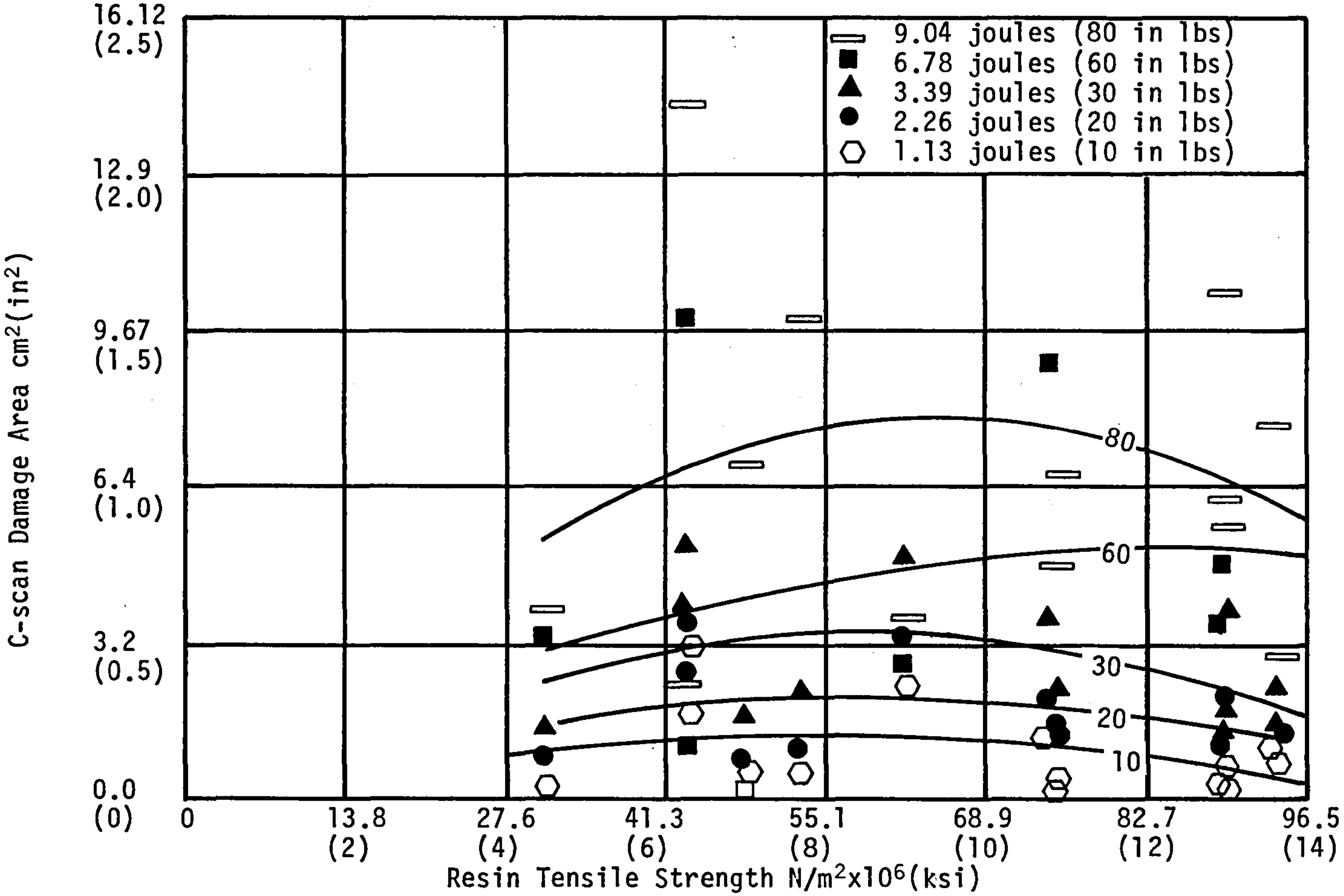


FIGURE 29. NEAT RESIN TENSILE STRENGTH VS IMPACT DAMAGE AREA

2.5.2.2 Neat Resin Tensile Modulus Vs Impact Resistance

The resin tensile modulus is an important variable in the development of laminate impact resistance as shown in Figure 30. As the resin tensile modulus increases, the extent of the impact damage area increases and therefore the impact damage tolerance decreases. However, once the resin tensile modulus drops below 3.1 x 10^9 N/m^2 (450,000 psi) there is no significant improvement in impact resistance.

2.5.2.3 Neat Resin Tensile % Elongation Vs Impact

It was observed that all of the tough resin systems evaluated had an elongation to failure greater than 5208. Figure 31 shows how the area of damage for five levels of impact as recorded on the C-scan varied with the % tensile elongation of the resin. There was a noticeable improvement in impact resistance with increased tensile elongation of the resin. However, once the % elongation reaches 5 or 6% there was only a small gain in impact resistance. Resin elongation appears to be a major variable in controlling laminate properties.

2.5.3 Correlation of Resin Properties and Laminate Mechanical Properties

Mechanical property tests (tensile, compression, interlaminar shear and flexural strength) were conducted on laminate panels made with all toughened resin systems and compared to the baseline Narmco 5208. The purpose of the work was to improve impact characteristics with a minimum or no los of laminate mechanical properties.

2.5.3.1 Tensile Strength of Resin Vs Laminate Mechanical Properties

The neat resin tensile strength does not have significant effect on the tensile strength of the cured laminate as shown in Figure 32. There is minimal effect on laminate compression and flexural strength until the resin tensile strength drops below 5.5 x 10^7N/M^2 (8000 psi). Interlaminer shear strength appears to drop as resin tensile strength falls below 4.8 x 10^7N/M^2 (7000 psi) and raises above 9 x 10^7N/M^2 (13,000 psi).

2.5.3.2 Tensile Modulus of Resin vs Laminate Mechanical Properties

The neat resin tensile modulus appears to be more important than resin tensile strength in controlling laminate mechanical properties. There is a rapid decline in flexural, interlaminar shear and compression strength in laminates when the resin tensile modulus falls much below 344 x10^7N/M^2 (500,000 psi) as shown in Figure 33. The laminate tensile strength is less affected with change in resin tensile modulus, but does show a gradual reduction in laminate tensile properties as the resin modulus declines.

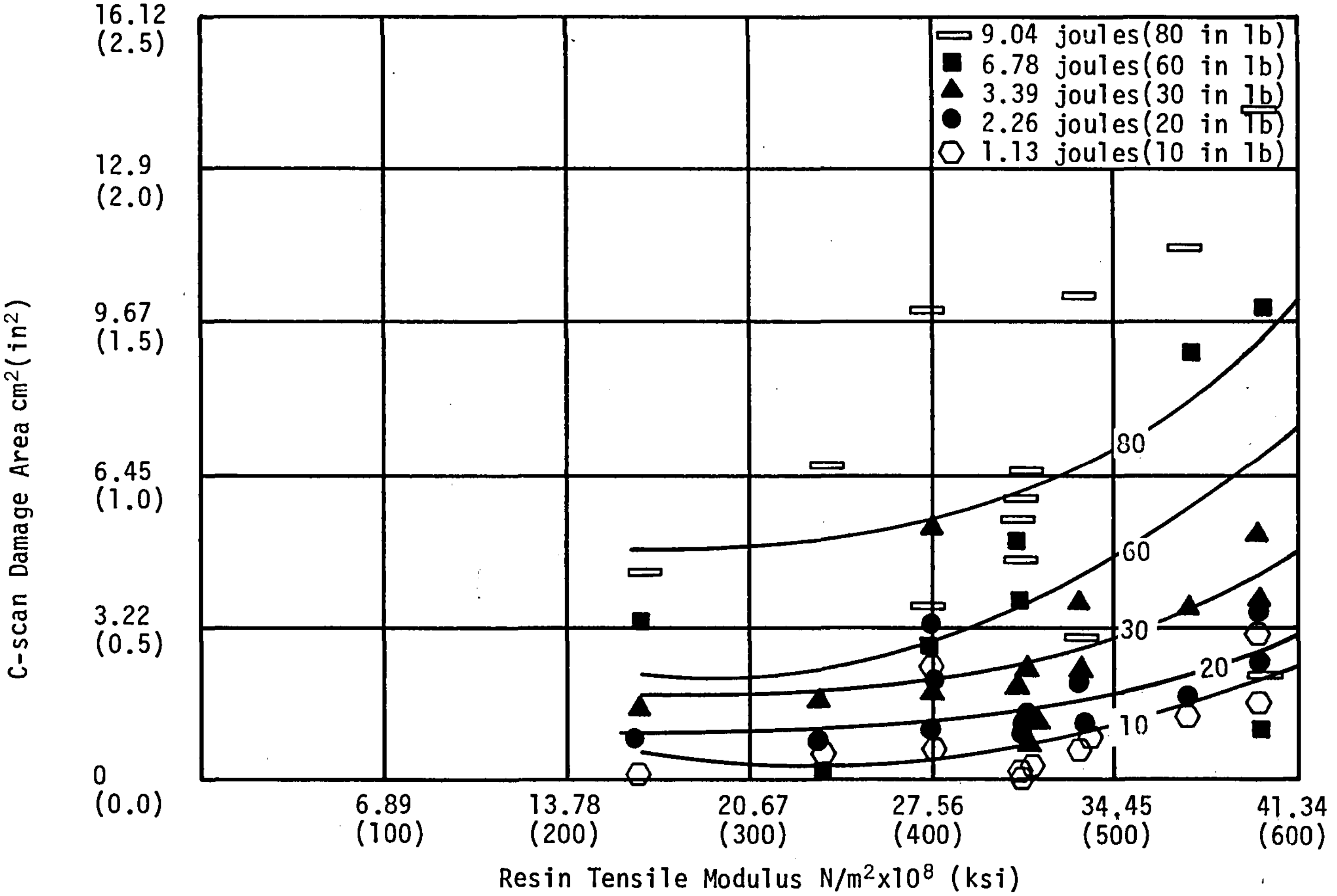


FIGURE 30. NEAT RESIN TENSILE MODULUS VS IMPACT DAMAGE AREA

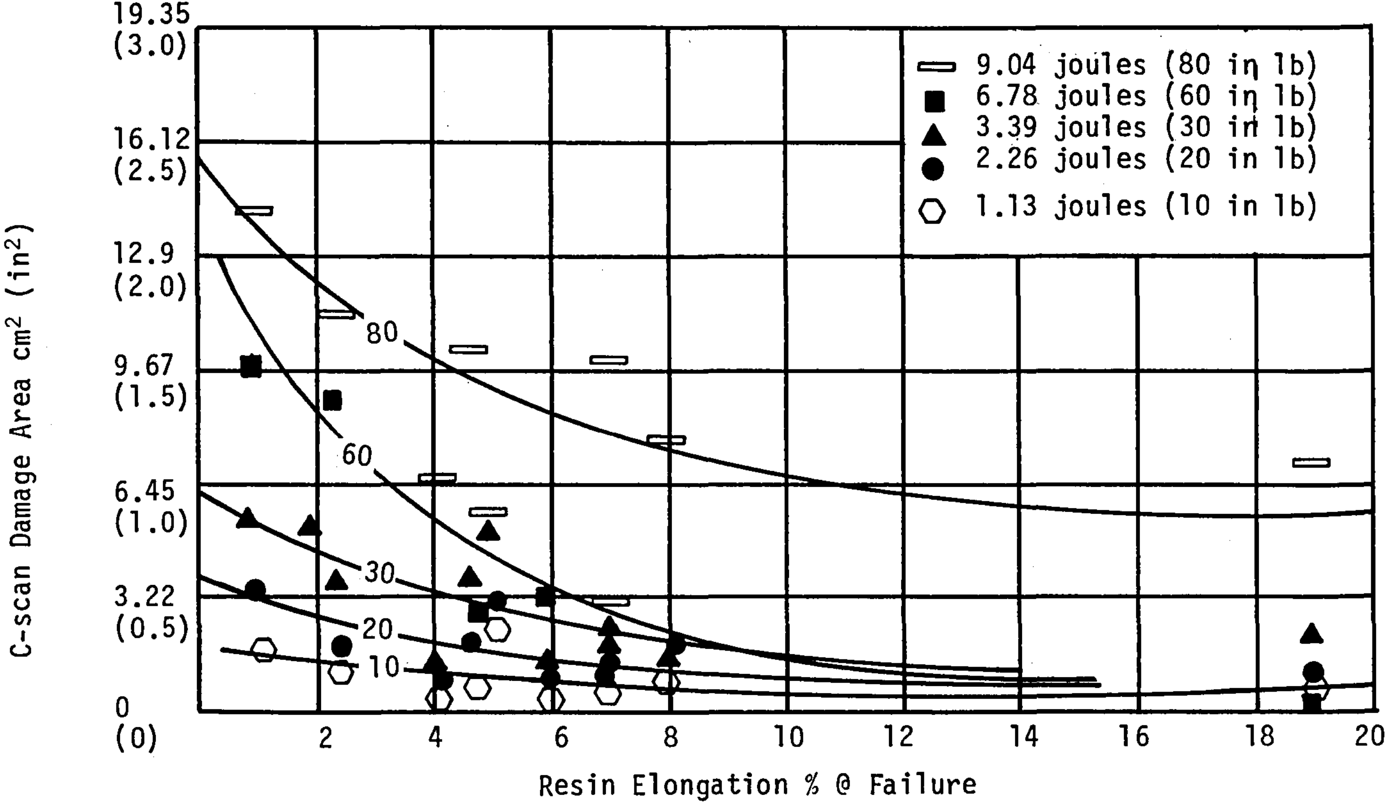


FIGURE 31. NEAT RESIN % ELONGATION AT FAILURE VS. IMPACT DAMAGE AREA

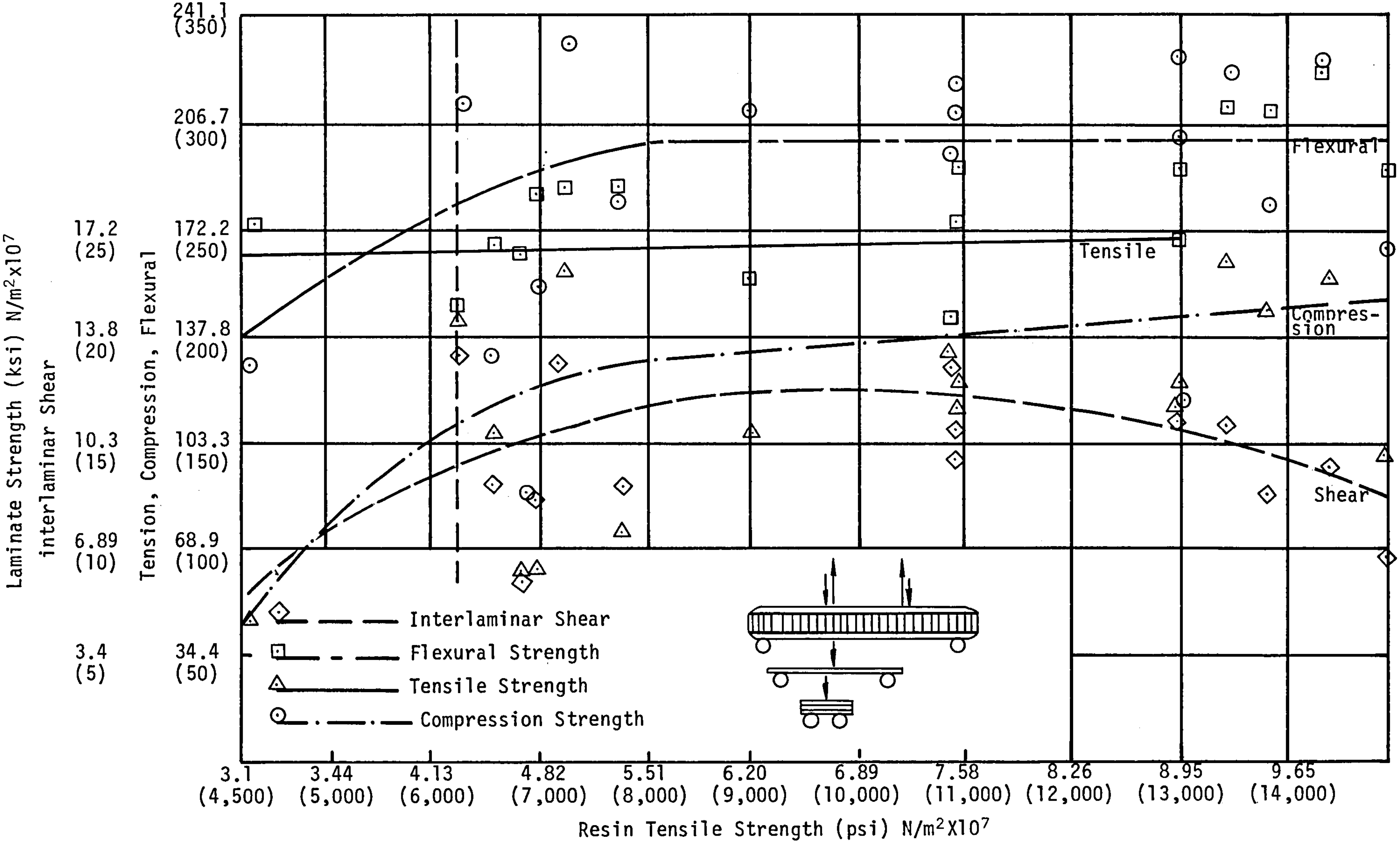


FIGURE 32. RESIN TENSILE STRENGTH VS LAMINATE MECHANICAL PROPERTIES

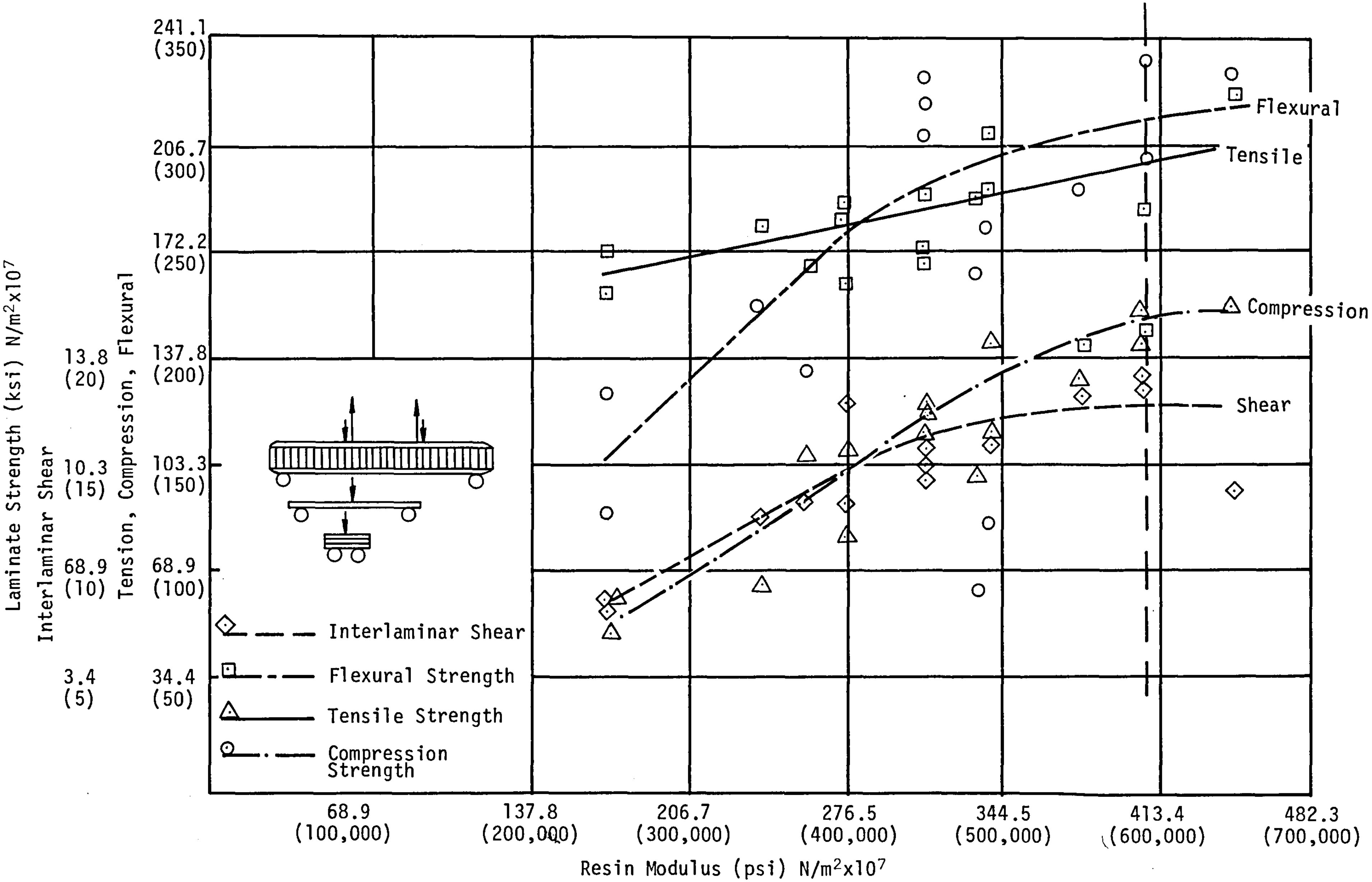


FIGURE 33. RESIN TENSILE MODULUS VS LAMINATE MECHANICAL PROPERTIES

2.5.3.3 Tensile Elongation of Resin Vs Laminate Mechanical Properties

The resin tensile elongation has a varied effect on laminate properties as shown in Figure 34. The flexural strength remains nearly constant until the resin tensile elongation increases above 6%. Above this level there was a rapid loss of flexural strength. Laminate tensile strength increased with resin tensile elongation until about 5% elongation and remained unaffected at higher resin elongation. Laminate compression and interlaminar shear strength gradually reduced as the resin elongation increased.

2.5.4 Threshold of Impact Damage

Figures 35, 36 and 37 show cross sectional photomacrographs at 20x magnification for composite plates constructed using Narmco 5208, BP 907, Ciba Geigy #4 and Fiberdux 920 resins and impacted by the Gardner Tester at several levels near the threshold of damage. (The arrow shows the point of impact.) C-scans of the same area are shown. The three toughened systems exhibit significantly less damage at all levels compared to 5208 as previously discussed. The majority of the damage occurred on the side opposite the impact.

The 5208 laminate was damaged at very low impact levels. Cracks and delaminations are present at .45 joules (4 inch pounds) (see Figure 37), well below the damage threshold of approximately 1.13 joules (10 inch pounds) for the other three materials. The 5208 laminate had one interesting failure characteristic; the resin cracks through the plies all point toward the point of impact. Thick laminates exhibit the same type of failure at comparative low impact levels. the toughened materials did not show this type of failure. In general, they failed by delamination with the exception of Fiberdux 920, which randomly shattered at 2.26 joules (20 inch pounds).

2.6 VAIDITY OF LAMINATE MECHANICAL AND NEAT RESIN DATA

The results of this program must be considered only as a starting guideline for desirable neat resin properties. Each material system evaluated, was based on a single batch of material. The cure cycles used to cure the test panels were carefully monitored to assure exact processing as specified by the material supplier. However, many of these development systems have not had even a start at a process optimization study. Note that even in the case of Narmco 5208/T-300, that a modified slow curing cycle (see Figure 38) produced a panel with higher mechanical properties and greater resistance to impact than the panel with the standard cure cycle. (See Figure 39). Thus, it could be expected that altering the curing cycles of other materials could also revise their properties. Note that in Figure 39 that 1.13 (10), 2.26 (20) and 3.39 joules (30 inch pounds) Gardner Impact Tests were conducted using a 15.9 mm (5/8 inch) impact head. The 6.78 (60) and 9.03 joules (80 inch pound) panel impact tests used a 5/8" flat impact head. The flat head spread the load over a greater area than the round head and caused the threshold of

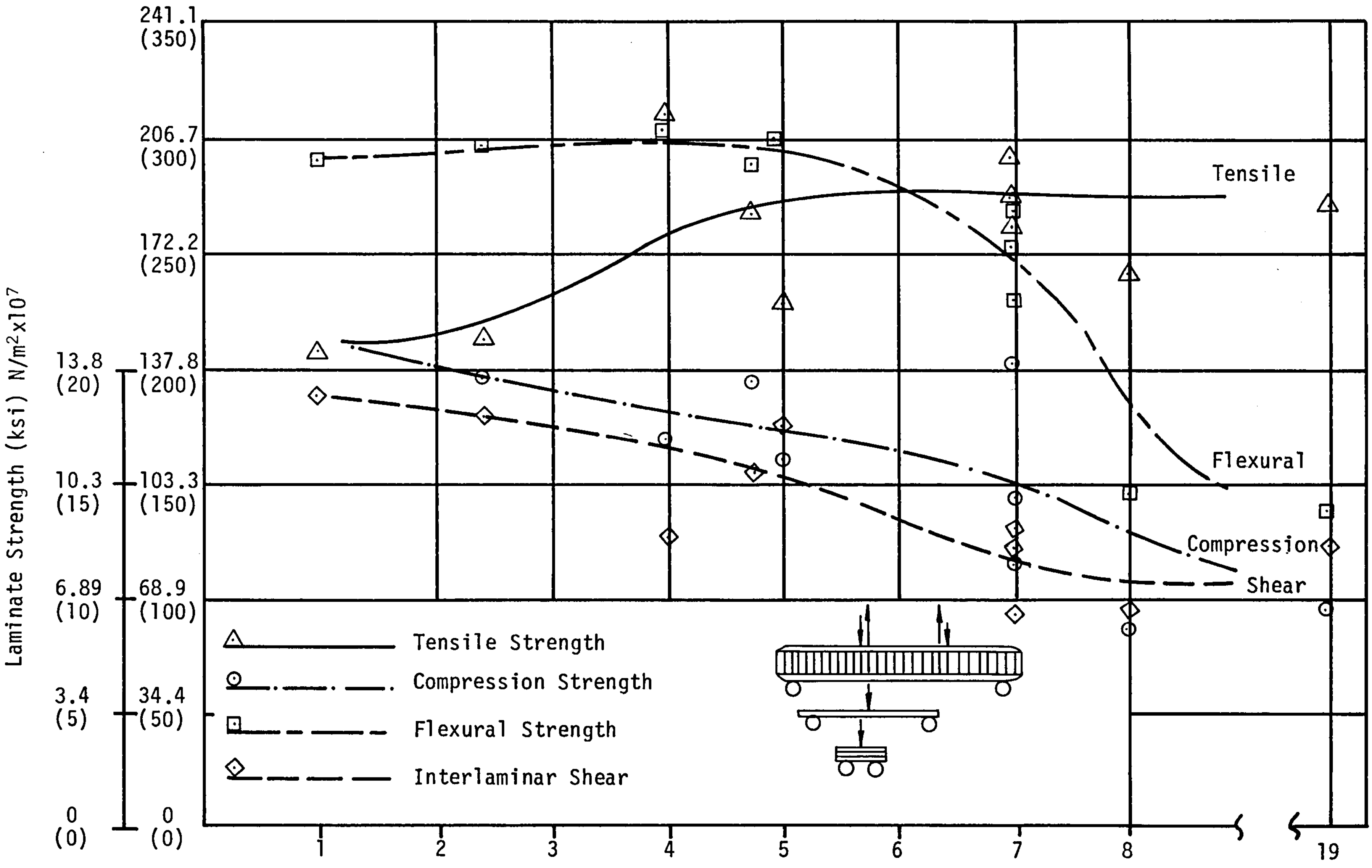
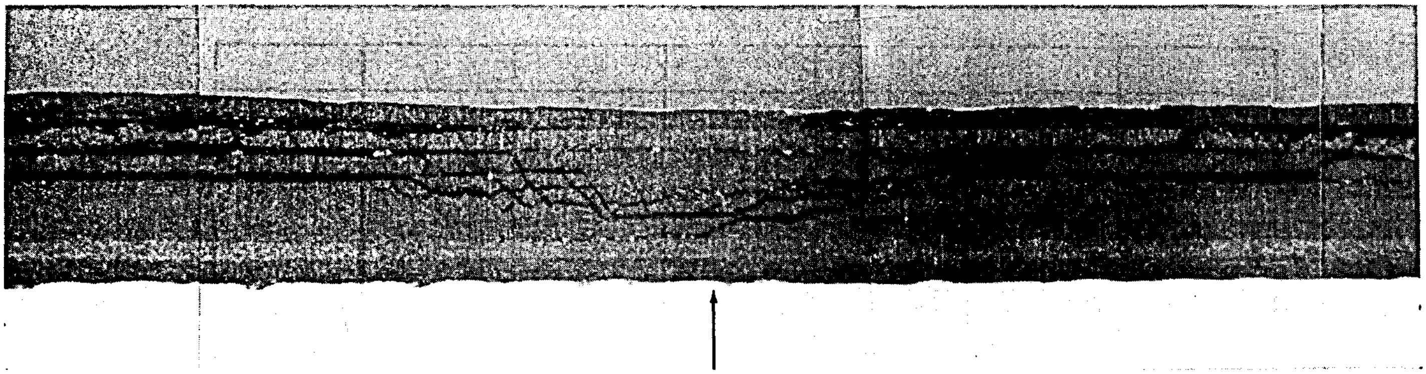
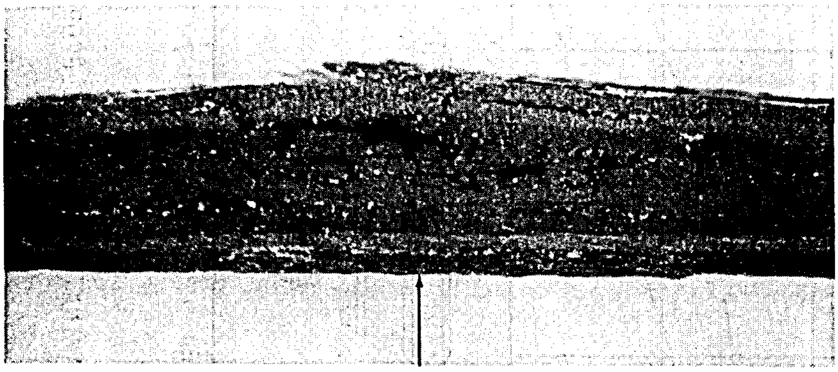


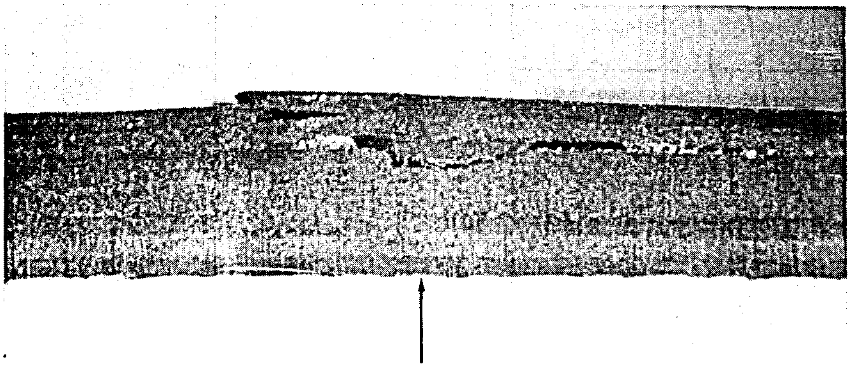
FIGURE 34. RESIN TENSILE ELONGATION VS LAMINATE MECHANICAL PROPERTIES



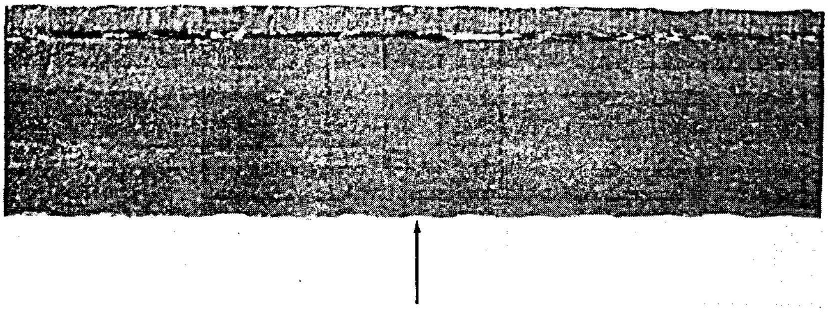
a. Narmco 5208/T-300



b. Fiberdux 920



c. BP 907



d. Ciba Geigy #4

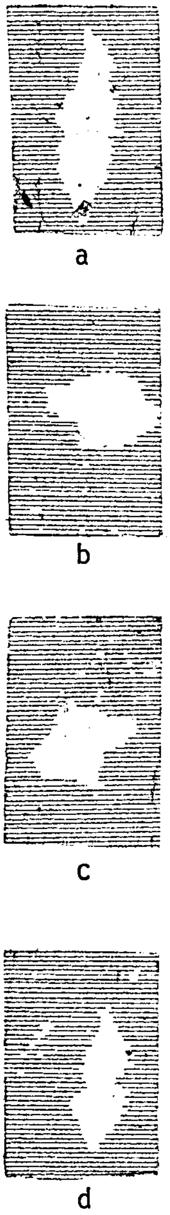
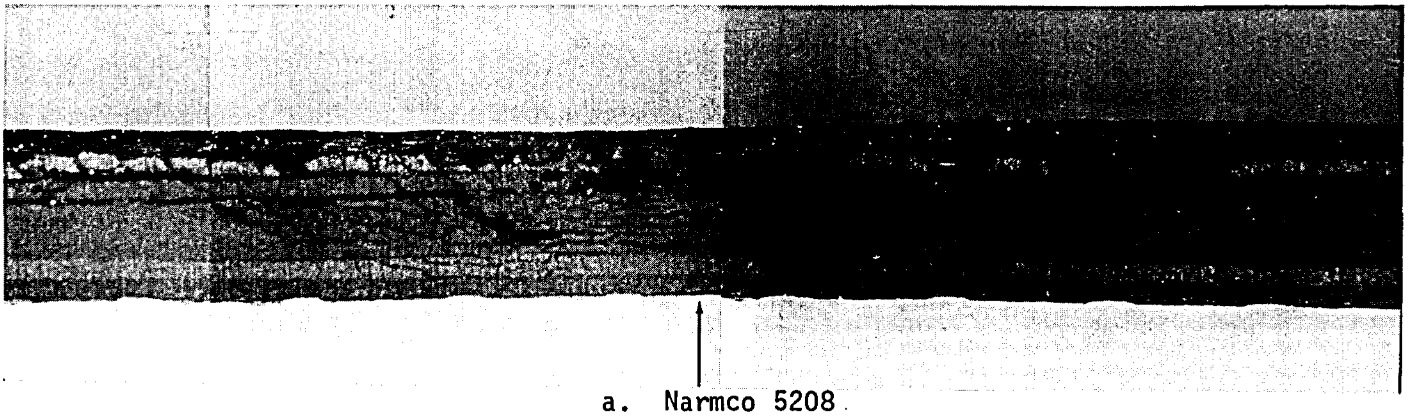
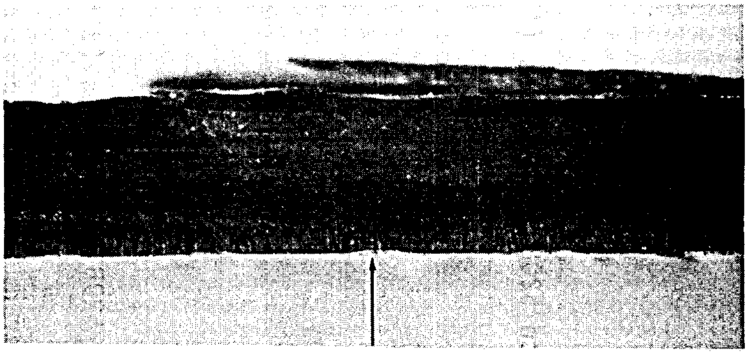


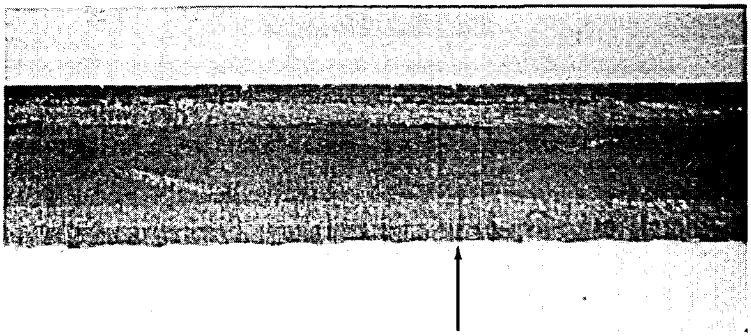
FIGURE 35. PHOTOMACROGRAPHS AT 20x & C-SCAN OF 2.26 JOULES (20 INCH POUNDS) IMPACT



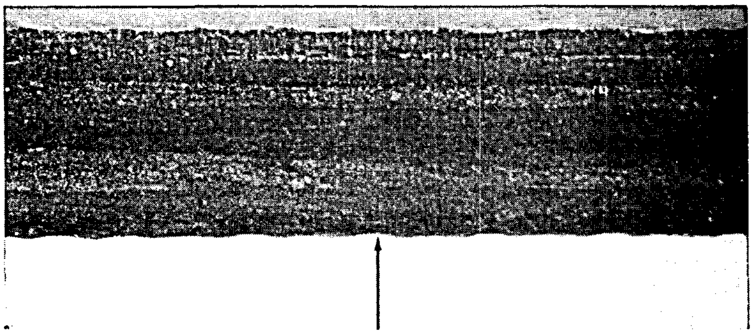
a. Narmco 5208



b. Fiberdux 920



c. BP-907



d. Ciba Geigy #4

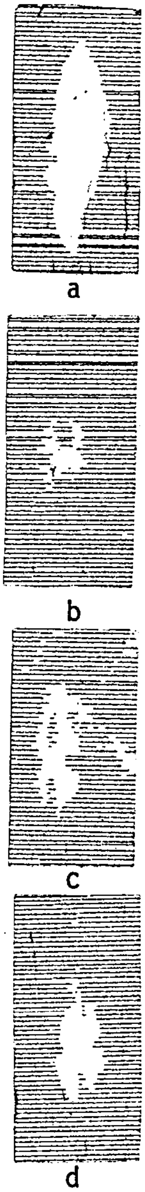
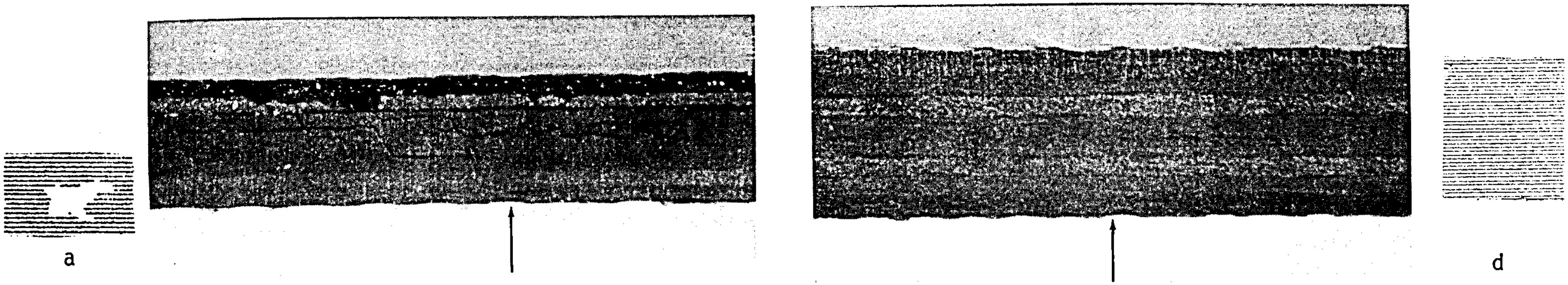
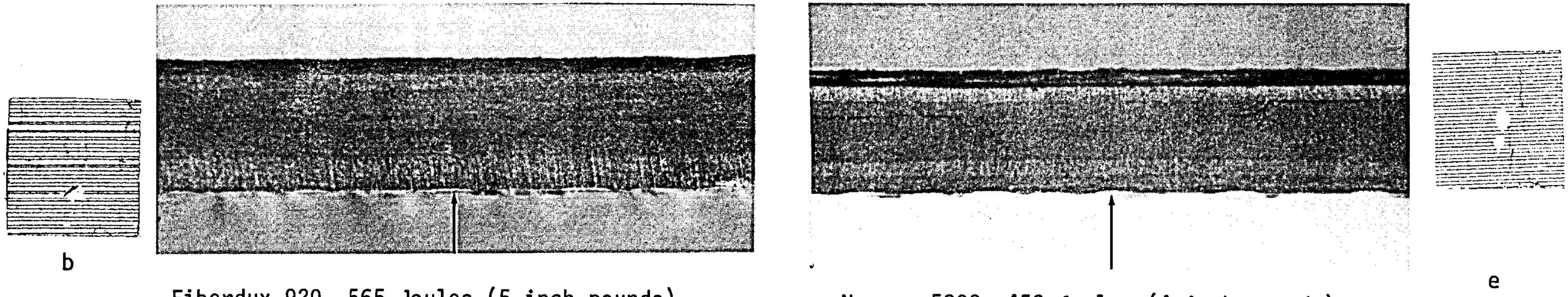


FIGURE 36. PHOTOMACROGRAPHS AT 20x & C-SCAN OF 1.13 JOULES (10 INCH POUNDS) IMPACT



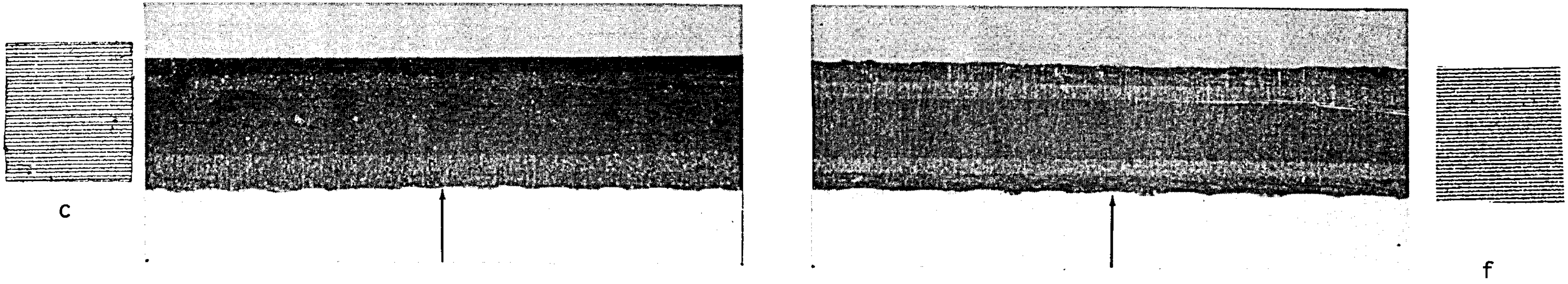
Narmco 5208 5.65 Joules (5 inch pounds)

Ciba Geigy #4 .565 Joules (5 inch pounds)



Fiberdux 920 .565 Joules (5 inch pounds)

Narmco 5208 .452 Joules (4 inch pounds)



BP-907 .565 Joules (5 inch pounds)

Narmco 5208 .339 Joules (3 inch pounds)

FIGURE 37. PHOTOMACROGRAPHS AT 20x AT IMPACT LEVELS BELOW VISUAL SURFACE DAMAGE

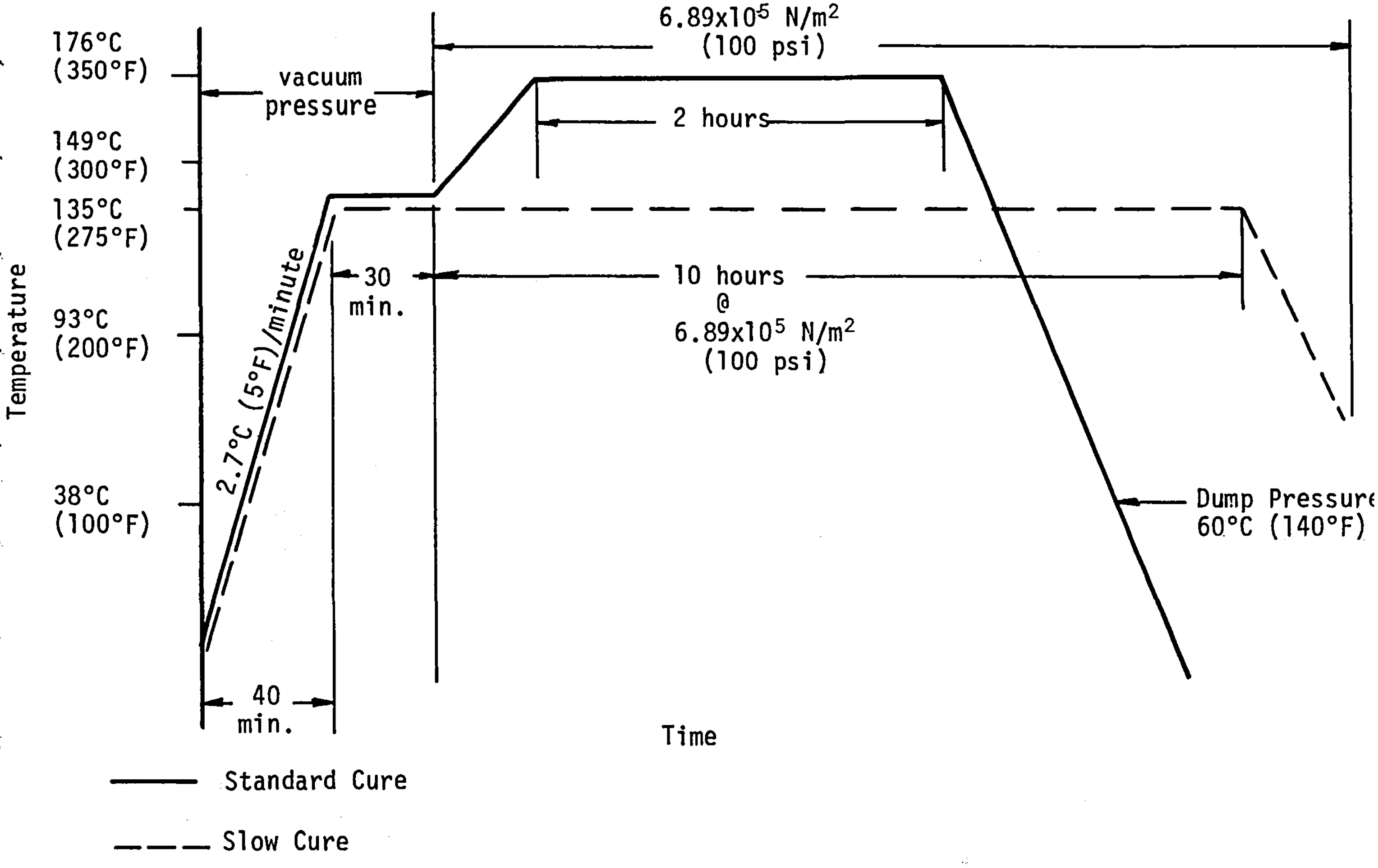
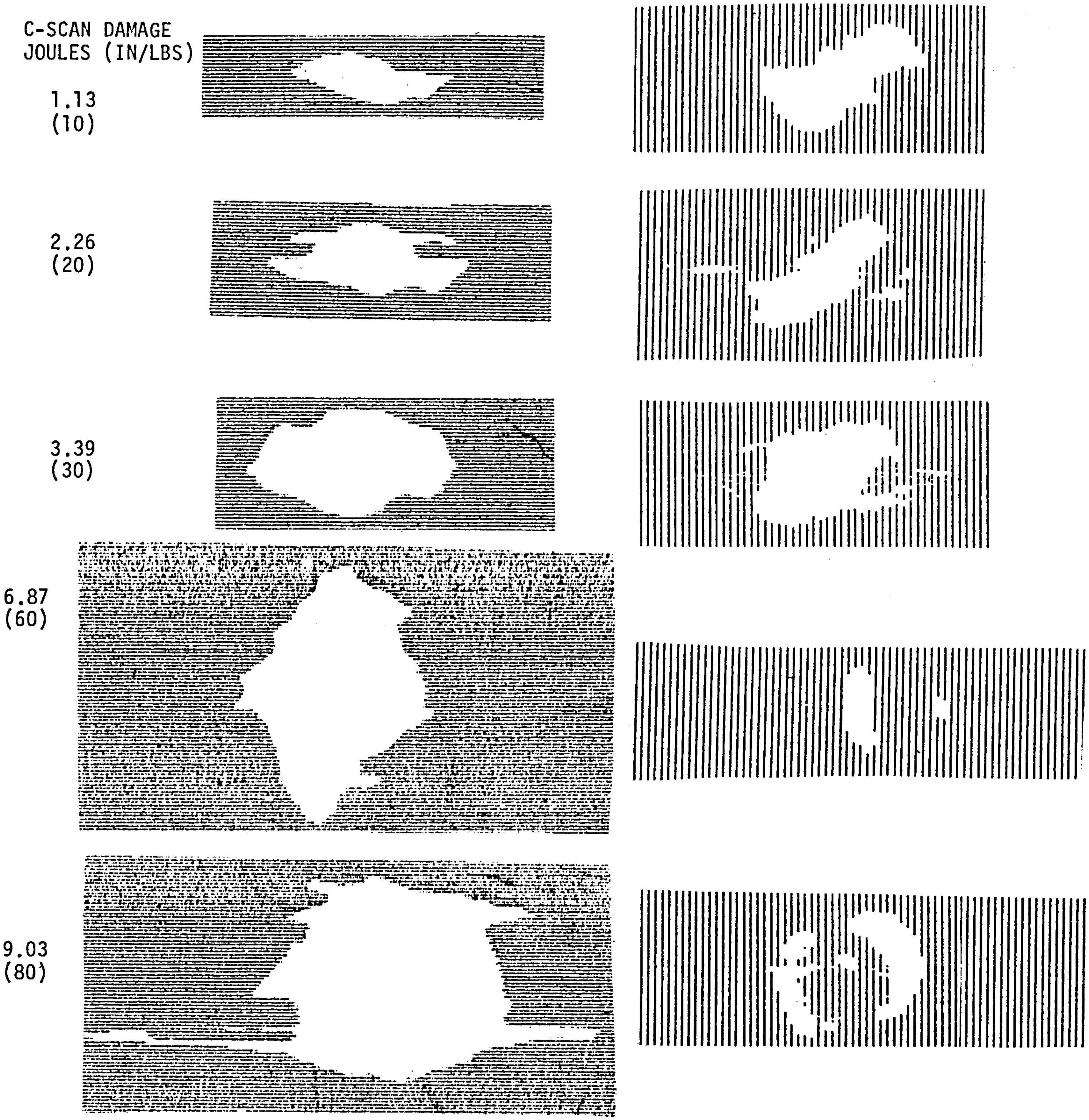


FIGURE 38. STANDARD AND SLOW CURE CYCLE FOR NARMCO 5208/T300

FIGURE 39. TWO CURING CYCLES - MECHANICAL AND IMPACT PROPERTIES

	5208 REFERENCE PANEL STANDARD CURE	5208 SLOW CURE
TEN STR	1.5x10^9 N/m^2 (218,000 psi)	1.9x10^6 N/m^2 (276,000 psi)
TEN MOD	1.31x10^{11} N/m^2 (19,000,000 psi)	1.49x10^{11} N/m^2(21,700,000 psi)
COMP STR	1.45x10^9 N/m^2 (210,000 psi)	1.94x10^9 N/m^2 (281,000 psi)
COMP MOD	1.24x10^{11} N/m^2 (18,000,000 psi)	1.34x10^{11} N/m^2 (19,500,000 psi)
SHEAR STR	1.31x10^8 N/m^2 (19,000 psi)	1.36x10^8 N/m^2 (19,800 psi)



damage to be higher. The impact area of damage at 6.78 (60) and 9.03 joules (80 inch pounds) was actually less than the 3.39 joules (30 inch pound) impact with the round head.

The curing cycle time/temperature/pressure conditions used to cure the neat resin specimens was always a long slow process, without pressure, and completely different than the laminate curing cycle. This infers that the reported neat resin properties are probably entirely different than the resin properties in the laminates used for mechanical and impact property tests. One material, Fiberdux 914, from Ciba Geigy, was tested for neat resin properties in two different laboratores (USA and England) on separate batches of resin. The reported resin properties are very different as shown in Table 7.

TABLE 7
NEAT RESIN PROPERTIES - TWO TEST SOURCES

TEST	ENGLAND	USA
Tensile Strength (psi)	(7,200)	(7,000)
N/M^2	4.9×10^7	4.82×10^7
Tensile Modulus (psi)	(580,000)	(280,000)
N/M^2	3.99×10^9	1.92×10^9
Elongation (%)	1.4	3

2.7 CONCLUSIONS

1. There is strong evidence that modification of the epoxy matrix resin system tensile properties can have significant influence on resultant graphite structural panel mechanical and impact properties.

2. It also is evident that considerable improvement in impact properties can be expected with no significant loss of room temperature mechanical properties. In fact, a reasonable improvement in both tensile and compression properties, as well as improved impact resistance can be predicted for future resin development programs.

3. The results of this program suggest that an improved composite matrix system should have neat resin tensile ultimate properties of over 6.89×10^7 N/M^2 (10,000 psi), a tensile modulus of elasticity above 3.1×10^9 N/M^2 (450,000 psi) and a tensile elongation of between 5 and 7%.

4. Since no testing was accomplished at elevated temperature, humidity or other environments, no inference can be drawn that these materials can be used in their present form as a commerical product.

5. Identification of commercial products in this report is used to adequately describe the test materials. Neither the identification of these commercial products nor the results of the investigation published therein constitute official endorsement, expressed or implied, of any such product by either The Douglas Aircraft Company or NASA.

2.8 RECOMMENDATIONS

1. The more promising resin systems from this development should have some level of process optimization study to develop the best available material and impact properties.

2. The best of these systems should be fabricated into panels, damaged to various levels of impact, and tested for retained strength in tensile, compression and shear load conditions.

3. The best of these materials should then be fabricated into panels, damaged and tested for propagation of damage at various fatigue stress levels.

4. The best surviving materials should be tested after environmental preconditioning (temperature, humidity, aggressive solvents, etc.), then damaged and tested again for comparative retained strength properties.

5. A tooling and processing concept should be developed for making neat resin tensile specimens that will incoprorate the same time/temperature/pressure processing cycle required for the final structural panel. Only then can a true relationship between neat resin and laminate properties by developed.

2.9 REFERENCES

1. Impact Damage Tolerance of Thick Graphite/Epoxy Laminates; N. M. Bhatia, Northrup Corporation for the Naval Air Development Center; Report No. NADC-79038-60, January 1979.

2. Low-Velocity Impact Damage in Graphite Fiber Reinforced Epoxy Laminates; Marvin D. Rhodes; Jerry G. Williams; and James H. Starnes, Jr.: NASA; 34th Annual Conference on Reinforced Plastics/Composites, The Society of the Plastics Industry, January 1979.

3. Impact Damage Characteristics of Graphite/Epoxy Laminates; N. M. Bhatia, Northrup Corporation Report No. NOR 76-186, June 1977.

4. Williams, Jerry G.; Angerson, Melvin S.; Rhodes, Marvin D.; Starnes, James H.; Stroud, W. Jefferson: Recent Developments in the Design, Testing and Impact-Damage Tolerance of Stiffened Composite Panels. Fibrous Composites In Structural Design, Plenum Press, 1980. pp 259-291.

APPENDIX 1

GARDNER IMPACT DATA

The Gardner impact results are recorded in Appendix 1 for impact energy, front side visual damage, back side visual damage, "C" scan and area of "C" scan damage and certain resin and impact panel physical properties for all materials tested.

FIGURE A-1 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING NARMCO 5208 RESIN REFERENCE PANEL

RESIN TYPE Epoxy - MY-720

HARDENER Aromatic Amine

MODIFICATION None

THICKNESS 1.07mm (.042")

% RESIN 28.0

VOID 1.0

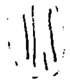
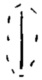
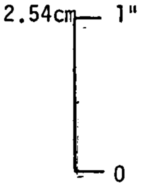
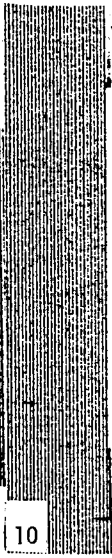
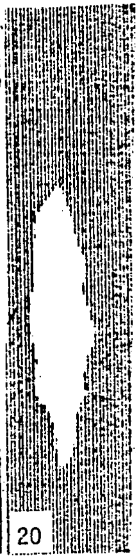
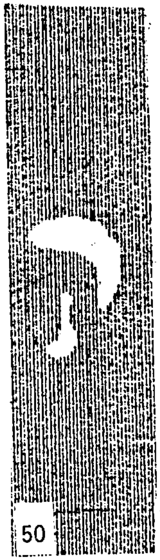
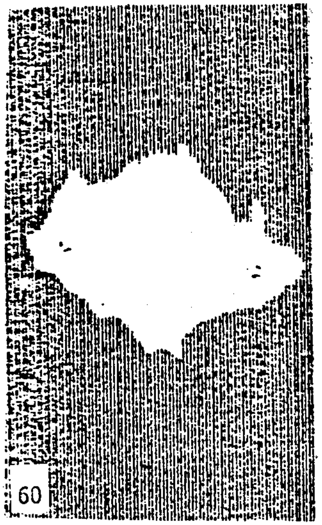
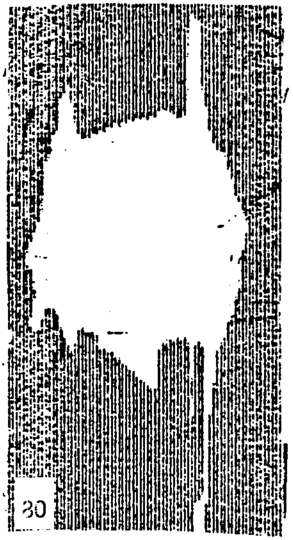
	3.17cm (125") SUPPORT			9.52cm (3.75") SUPPORT									
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT						
Joules (in lb)	1.13(10)	2.25(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.65(50)	6.78(60)	7.91(70)	9.04(80)	10.2(90)	11.3(100)	13.6(120)
VISUAL FRONT SIDE	OK	OK	3.2mm (1/8") hole broken fibers	OK	OK	OK		OK	1.58cm (5/8") hole broken fibers		1.58cm (5/8") hole broken fibers & 0° cracks			
in VISUAL BACK SIDE mm	.2 x .7  5x17.8	.3 X 1.2  7.6x30.5	.4 X 1.2  10.2x30.5	OK	.2 X 1.5  5x38	.3 X .3  7.6x7.6		OK	1.1X1.1  28x28		1.2X3.7  30.5x94			
C-SCAN -DAMAGE 														
C-SCAN cm^2 DAMAGE(in^2) AREA	1.69 (.26)	3.64 (.56)	5.33 (.82)	0 (.00)	3.96 (.61)	6.43 (.99)		1.5 (.23)	9.94 (1.53)		14.4 (2.22)			
COMMENTS	Splintering			Delamination and Some Splintering			Broken fibers and heavy delamination						

FIGURE A-2 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING NARMCO 5208 (Slow Cure)

RESIN TYPE Epoxy MY720

HARDENER Aromatic Amine

MODIFICATION None

THICKNESS 1.09mm (.043")

% RESIN 26.4

VOID

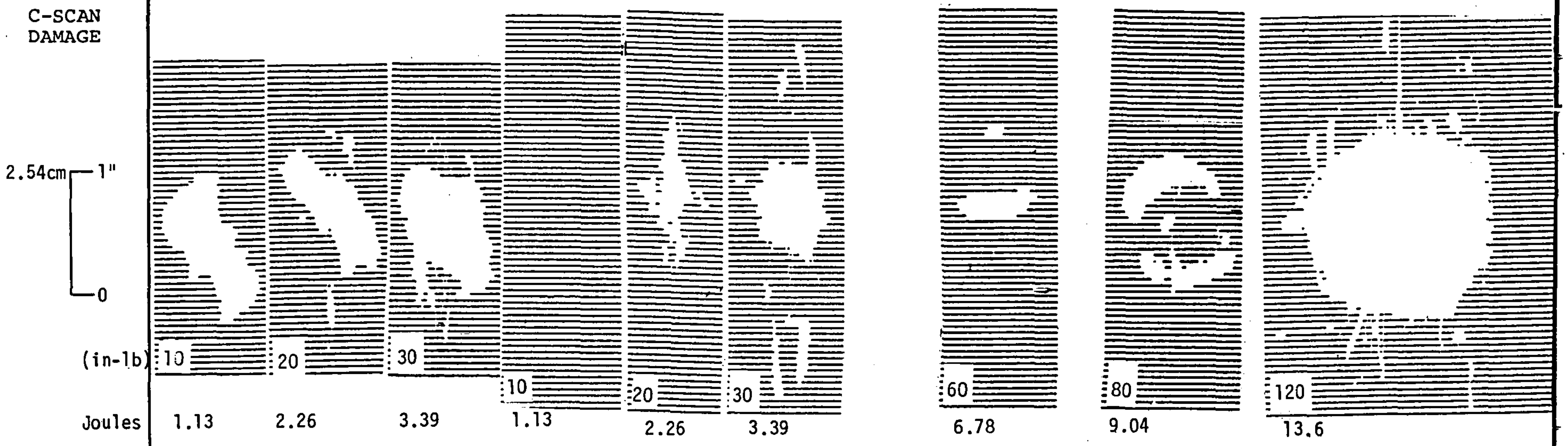
	3.17cm (125") SUPPORT			9.52cm (3.75") SUPPORT									
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm(5/8") FLAT						
Joules (in-lbs)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.65(50)	6.78(60)	7.91(70)	9.04(80)	10.2(90)	11.3(100)	13.6(120)
VISUAL FRONT SIDE	OK	OK	6.35mm (1/4") dent	OK	OK	6.35mm (1/4") dent			OK		OK			2.54x2.54cm (1x1") damage 1.58cm(5/8") hole broken fiber & splint.
VISUAL BACK SIDE in mm	OK	.2x1 5x25.4	.3x1.2 7.6x30.5	OK	.1x1 2.54x25.4	.3x2.5 7.6x63.5			OK		.1x.8 2.5x20.3			
C-SCAN DAMAGE														
C-SCAN DAMAGE cm^2 AREA (in^2)	3.12 (.48)	2.6 (.40)	3.9 (.60)	0 (.00)	1.36 (.21)	3.05 (.47)			1.04 (.16)		2.4 (.37)			14.04 (2.16)
COMMENTS	Splintering and delamination			Cracks in 0° direction - some delamination			Broken fibers & delamination, 0° cracks Heavy splintering at 13.6 joules (120 in lbs)							

FIGURE A-3 IMPACT DAMAGE DATA FOR (0,/±45/90)s Laminate Using Narmco 5208 (Resin Rich)

RESIN TYPE	Epoxy MY720	THICKNESS	1.12 (.044")
HARDENER	Aromatic Amine	% RESIN	29.9
MODIFICATION	None	VOID	0.10

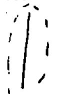
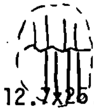
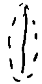
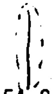
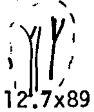
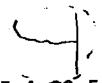
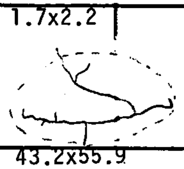
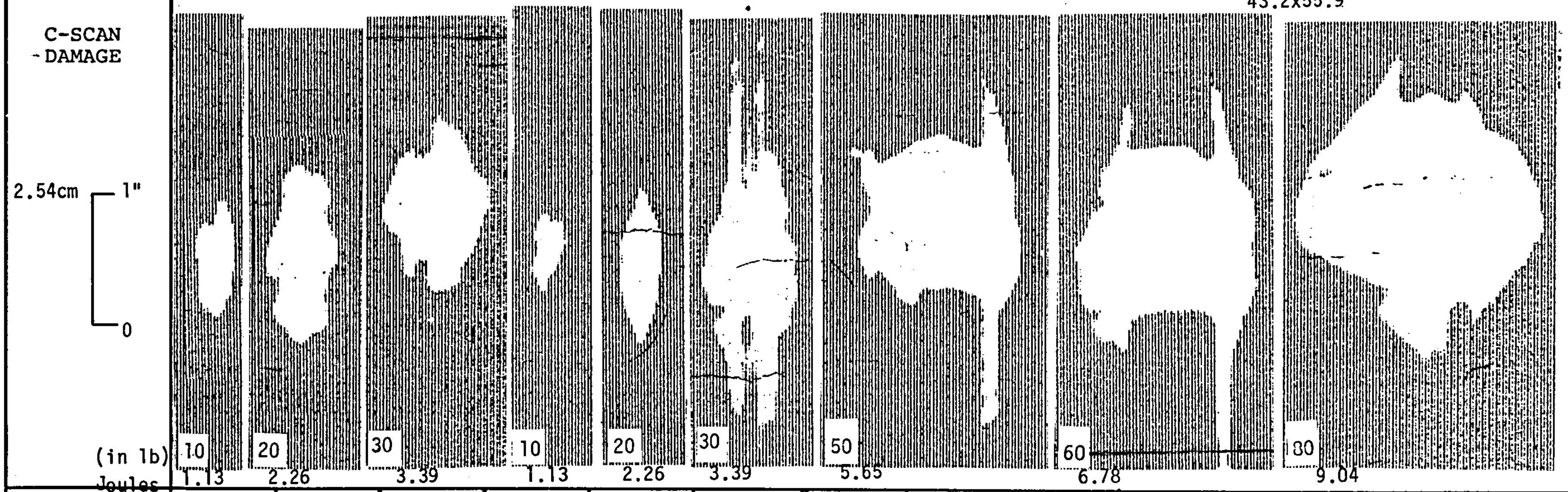
	3.17cm (125") SUPPORT			9.52cm(3.75")SUPPORT										
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
Joules (in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.2(90)	11.3(100)	13.6(120)
VISUAL FRONT SIDE	OK	6.35mm (1/4") dent	9.5mm (3/8") dent	OK	OK	6.35mm (1/4") dent		1.58cm (5/8") dent 0° crack	1.58cm (5/8") dent 0° crack		2.56cm (1") hole broken fibers & splinters			
VISUAL BACK SIDE in mm	.1x1  2.54x25.4	.3x.5"  7.6x12.7	.5x1  12.7x26.4	.1x.5  2.54x12.7	.1x1  2.54x25.4	.5x3.5  12.7x89		1x2.5"  25.4x63.5	1x3  25.4x76.2		1.7x2.2  43.2x55.9			
C-SCAN DAMAGE														
C-SCAN DAMAGE AREA cm² (in²)	1.36 (.21)	3.57 (.55)	4.61 (.71)	.585 (.09)	1.82 (.28)	7.93 (1.22)		10.2 (1.57)	12.15 (1.87)		16.57 (2.55)			
COMMENTS	Heavy splintering and some delamination			Delamination, some splintering at 3.39 (30)			Broken fibers and heavy delamination slight splintering							

FIGURE A-4 IMPACT DAMAGE DATA FOR (0/±45/90) LAMINATE USING NARMCO 5208 (Resin Poor)

RESIN TYPE Epoxy

HARDENER Aromatic Amine

MODIFICATION None

THICKNESS 1.02mm (.040")

% RESIN 24.6

VOID

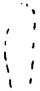
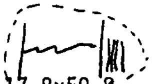
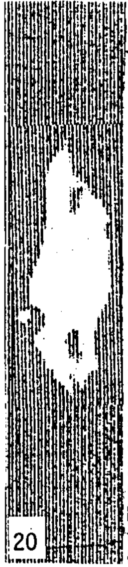
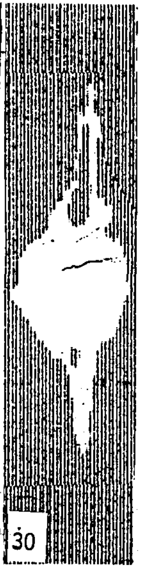
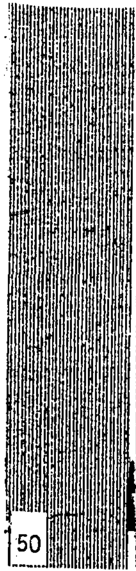
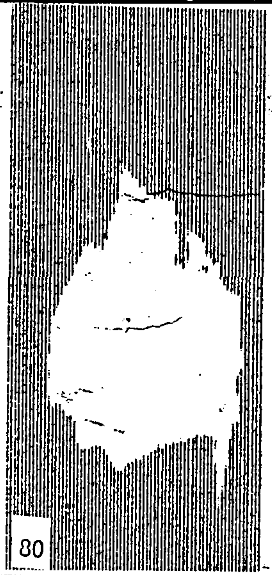
	3.17cm (125") SUPPORT			9.52cm (3.75") SUPPORT											
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
Joules(in-lbs)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.2(90)	11.3(100)	13.6(120)
VISUAL FRONT SIDE	OK	OK	3.2mm (1/8")hole broken fibers	OK	OK	1/4" dent		OK	OK		1.58cm (5/8")dent broken fibers & some splintering			
VISUAL BACK SIDE in mm	OK	.2x1.2  5.1x30.5	.6x1.5  15.2x38	OK	.1x1  2.54x25.4	.3x3  7.6x76		OK	.6x.5  15.2x12.7		.7x2  17.8x50.8			
C-SCAN -DAMAGE 2.54cm 1" 0														
C-SCAN DAMAGE AREA cm^2 (in^2)	1.36 (.21)	3.96 (.61)	4.68 (.72)	9.75 (.15)	2.92 (.45)	6.3 (.97)		0 (.00)	1.49 (.23)		10.98 (1.69)			
COMMENTS	Delamination and splintering			Delamination and slight splintering			Delamination and broken fibers - some splintering							

FIGURE A-5 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING NARMCO 95995 RESIN REFERENCE PANEL

RESIN TYPE Epoxy
HARDENER Aromatic Amine
MODIFICATION

THICKNESS 1.04 mm (.041)
% RESIN 32.7
VOID .3

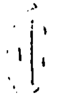
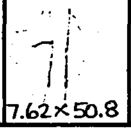
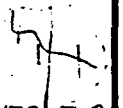
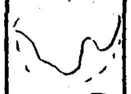
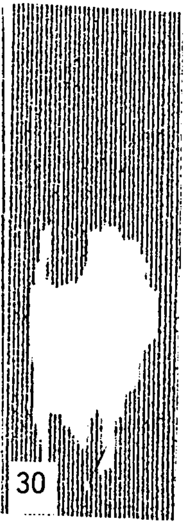
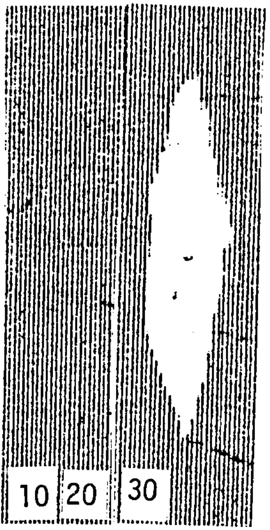
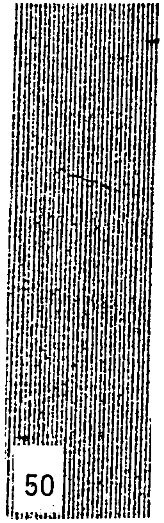
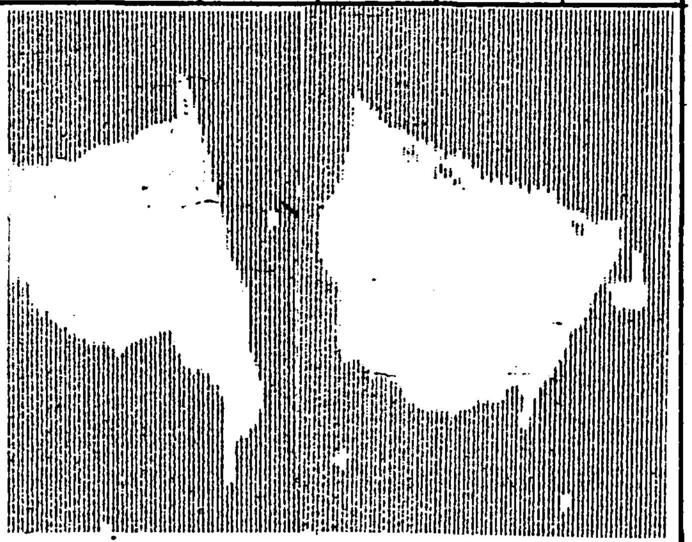
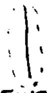
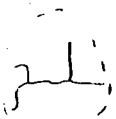
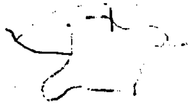
	3.17cm (125") SUPPORT			9.52 cm (3.75") SUPPORT									
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT						
JOULES(IN-LB)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	OK	Broken fibers	OK	OK	OK		OK	5/8" dent cracks spread 90°		5/8" dent 0° & 90° cracks			
VISUAL BACK SIDE in mm	.2x.8"  5.1×20.3	.3x2  7.62×50.8	.7x2  17.8×50.8	OK	OK	.4x1.7  10.1×17.8		OK	1.5x1.3  38×33		1.5x1.4  38×35			
C-SCAN DAMAGE 2.54cm 1" 0	 	 	 	 				 						
C-SCAN DAMAGE AREA cm² in²	1.36 (.21)	1.95 (.30)	3.70 (.57)	0 (.00)	0 (.00)	4.09 (.63)		0 (.00)	9.1 (1.40)		11.37 (1.75)			
COMMENTS	Internal delamination and splintering			Delamination			Very heavy delamination, slight spliners, numerous broken fibers, severe 90° cracks						

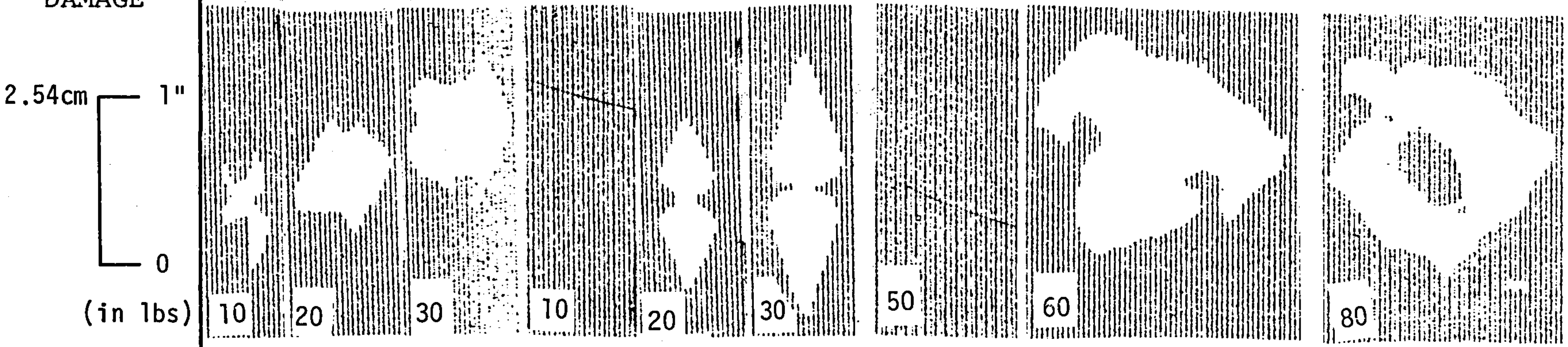
FIGURE A-6 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING NARMCO X107 RESIN REFERENCE PANEL

RESIN TYPE Epoxy Bis Phenol A
HARDENER Non-Aromatic Amine
MODIFICATION Elastomers

THICKNESS 1.22mm (.048")
% RESIN 29.8
VOID 1.5

	3.17cm (125") SUPPORT			9.52cm (3.75")SUPPORT										
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
JOULES(in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	OK	3.17mm (1/8") dent	OK	OK	OK		OK	1.9cm (.75") crack 90°		1.58cm (5/8") hole 0° cracks			
VISUAL BACK SIDE in / mm	.1x.5  2.5×12.7	.3x.5  7.6×12.7	.5x.1  12.7×2.5	OK	.5" crack  12.7	.1x.8  2.5×20.3		OK	.8x.5  20.3×12.7		1.2x1  30.5 × 25.4			

C-SCAN DAMAGE



Joules 1.13 2.26 3.39 1.13 2.26 3.39 5.56 6.78 9.04

JOULES(in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
C-SCAN DAMAGE AREA cm² (in²)	.65 (.10)	1.5 (.23)	2.4 (.37)	0 (.00)	1.5 (.23)	2.66 (.41)		0 (.00)	7.47 (1.15)		7.41 (1.14)			
COMMENTS	Broken fibers and delamination			0° cracks slight delam. at 3.39 joules (30 in lbs)			Broken fibers and delamination							

FIGURE A-7 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING NARMCO X108 RESIN REFERENCE PANEL

RESIN TYPE Epoxy - Bis Phenol A

HARDENER Aromatic Amine

MODIFICATION Elastomer

THICKNESS 1.02 mm (.040")

% RESIN 24.0

VOID 1.3

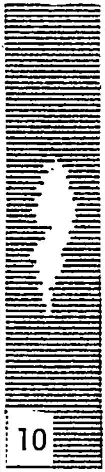
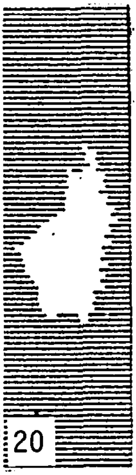
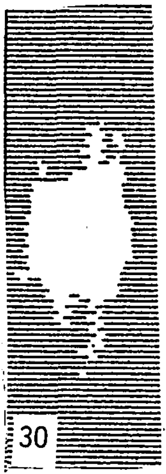
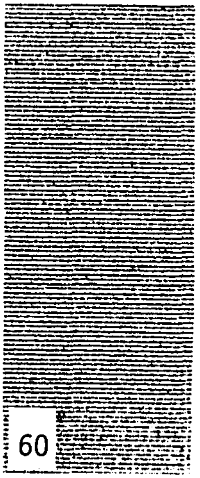
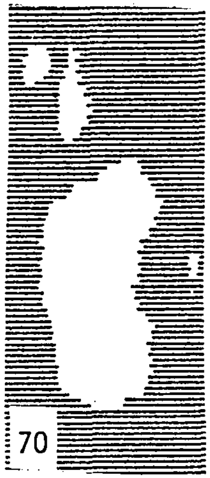
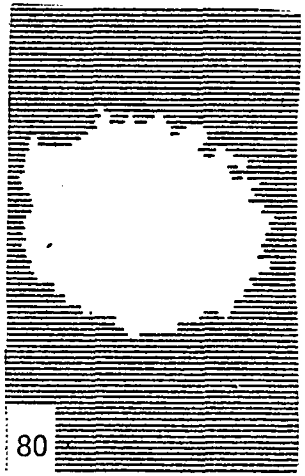
	3.17cm (125") SUPPORT			9.52cm(3.75") SUPPORT										
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
JOULES(in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	3.17 mm (1/8") dent	dent broken fibers						OK	OK	dent 0° cracks			
VISUAL BACK SIDE in mm	Crack 1" long 25.4	.3x1.5"  7.6×38	.4x1.5  10.2×38						OK	OK	1x1.2  25.4×30.5			
C-SCAN DAMAGE 2.54cm 1" 0 (in lbs) Joules	 1.13	 2.26	 3.39						 6.78	 7.91	 9.04			
C-SCAN cm² DAMAGE AREA	.91 (.14)	1.75 (.27)	2.79 (.43)						0 (0)	4.68 (.72)	7.80 (1.20)			
COMMENTS	Heavy splintering - some delamination and broken fibers						At 9.04 joules (80 in lbs) broken fibers, heavy delamination slight splinters							

FIGURE A-8 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING NARMCO X109 RESIN REFERENCE PANEL

RESIN TYPE Epoxy Bis Phenol A

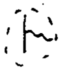
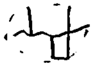
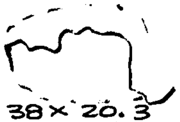
HARDENER Non Aromatic Amine

MODIFICATION Elastomers

THICKNESS 1.19mm (.047")

% RESIN 33.5

VOID 1.1

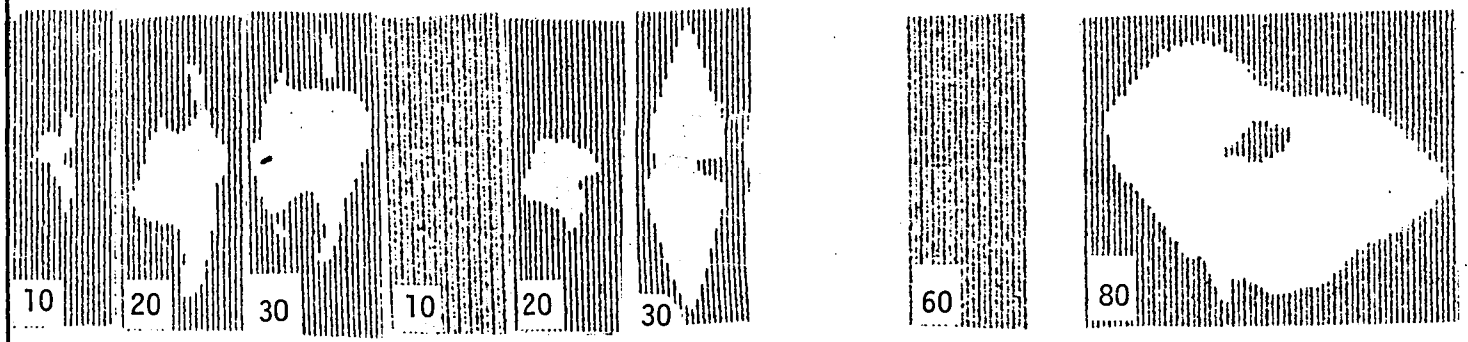
	3.17cm (125") SUPPORT			9.52cm (3.75")SUPPORT										
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
JOULES(in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	3.17mm (1/8") dent	3.17mm (1/8") puncture	OK	OK	3.17mm (1/8") dent			OK		1.58cm (5/8") dent			
in VISUAL BACK SIDE mm	.2x.2  5.1x5.1	.3x.6  7.6x15.2	.5x.6  12.7x15.2	OK	.3"90° crack  7.6	.1x1  25x25.4			OK		1.5x.8  38x20.3			

C-SCAN DAMAGE

2.54cm 1"

0

(in lbs)



Joules	1.13	2.26	3.39	1.13	2.26	3.39			6.78		9.04			
C-SCAN DAMAGE AREA cm² (in²)	.39 (.06)	2.01 (.31)	2.6 (.40)	0 (.00)	.84 (.13)	2.7 (.42)			0 (0.0)		9.94 (1.53)			
COMMENTS	Delamination and broken fibers			2.26 joules(20 in lb) broaken fibers 3.39 joules(30 in lb) delamination			Broken fibers - some delamination							

FIGURE A-9 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING NARMCO X1114 RESIN REFERENCE PANEL

RESIN TYPE Epoxy - Bis Phenol A

HARDENER Non-Aromatic Amine

MODIFICATION Elastomers - Max.

THICKNESS 1.27mm (.050")

% RESIN 30.8

VOID 4.7

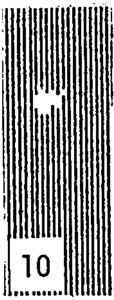
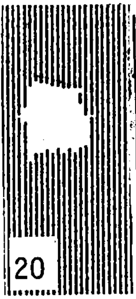
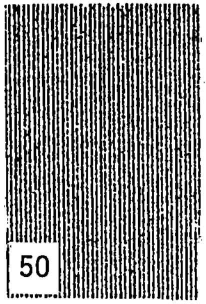
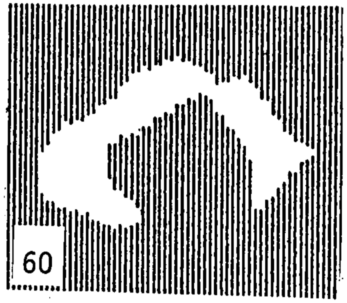
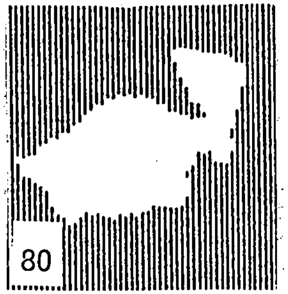
	3.17cm (125") SUPPORT			9.52cm (3.75")SUPPORT										
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
JOULES(in lb)	1.13 (10)	2.26(20)	3.39 (30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.6(120)
VISUAL FRONT SIDE	OK	3.17mm (1/8") dent	6.34mm (1/4") dent					OK	dent crack propag.	dent crack				
VISUAL BACK SIDE in mm	OK	.2x.1  5.1 × 2.54	.2x.3  5.1×7.6					OK	1.2x.2  30.5×5.1	1.0x.5  25.4×12.7				
C-SCAN DAMAGE 2.54cm 1" 0 (in lbs) Joules	 10 1.13	 20 2.26	 30 3.39					 50 5.56	 60 6.78		 80 9.04			
C-SCAN cm² DAMAGE AREA (in²)	.13 (.02)	.84 (.13)	1.43 (.22)					0 (.00)	3.25 (.50)	3.57 (.55)				
COMMENTS	No splintering, no delamination, only damage broken fibers						Only damage broken fibers							

FIGURE A-10 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING AMERICAN CYANAMIDE BP907 RESIN REFERENCE PANEL

RESIN TYPE Epoxy - Bis Phenol A

HARDENER Latent Aliphatic Amine

MODIFICATION Vinyl Resin

THICKNESS 1.24mm (.049")

% RESIN 31.7

VOID 0.6

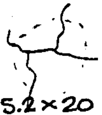
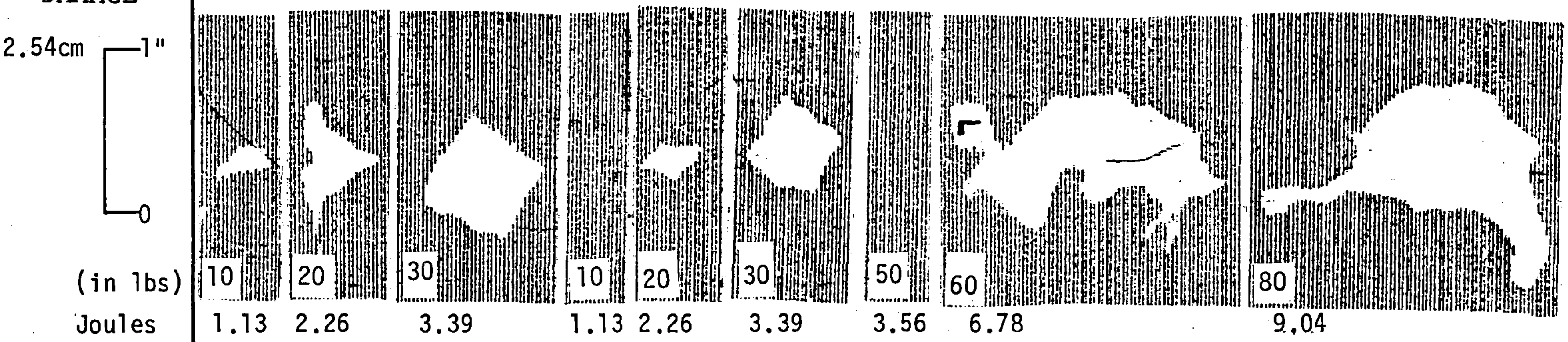
	3.17cm (125") SUPPORT			9.52cm (3.75") SUPPORT										
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
JOULES (in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	OK	6.34mm (1/4") dent broken fibers	OK	OK	Small dent		OK	6.35mm (1/2") 0° crack		19.05mm (3/4") 90° crack			
VISUAL BACK SIDE in		.3x1" 	.6x.8 		.1x.1" 	.3x.3 			1.3x.7 		1.3x.8 			
mm	OK	7.6x25.4	15.2x20	OK	2.5x2.5	7.6x7.6		OK	33x17.8		33x20			
C-SCAN DAMAGE														
C-SCAN DAMAGE AREA cm²	.26	1.04	1.95	0	.26	1.3		0	5.07		5.59			
(in²)	(.04)	(.16)	(.30)	(0.0)	(.04)	((.20)		(.00)	(.78)		(.86)			
COMMENTS	Broken fibers - slight delamination			Broken fibers - slight delamination			Broken fibers - some delamination							

FIGURE A-11 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING AMERICAN CYANAMIDE 907 RESIN REFERENCE PANEL

RESIN TYPE Epoxy - Bis Phenol A

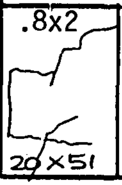
HARDENER Latent Aliphatic Amine

MODIFICATION Vinyl Resin

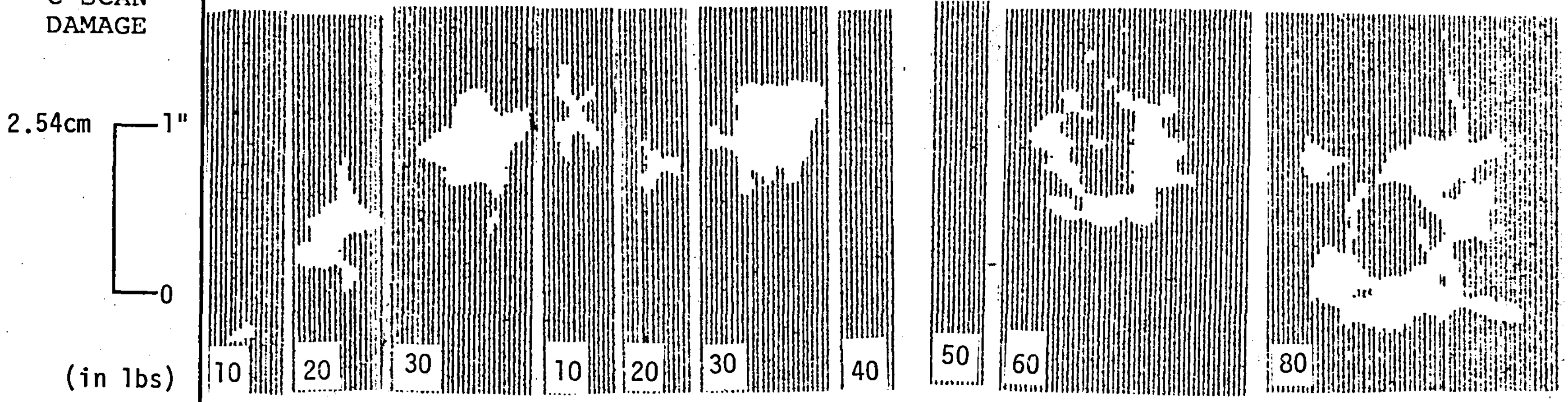
THICKNESS 1.17 mm (0.46")

% RESIN 31.4

VOID 0.3

	3.17cm (125") SUPPORT			9.52cm (3.75") SUPPORT										
	1.58cm (5/8" ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
JOULES(in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	3.17mm (1/8") dent	6.34mm (1/4") dent broken fibers	OK	OK	OK	OK	OK	15.8mm (5/8") dent broken fibers		19.05x15.8mm (3/4x5/8" hole cracks spread 0° & 90°			
in VISUAL BACK SIDE mm	.2x.2  5.1x5.1	.2x.4  5.1x10.2	.7x.8  17.8x20	OK	OK	OK	OK	OK	.8x1.5  20x38		.8x2  20x51			

C-SCAN DAMAGE



Joules	1.13	2.26	3.39	1.13	2.26	3.39	4.52	5.56	6.78		9.04			
C-SCAN cm² DAMAGE AREA (in²)	.065 (.01)	1.04 (.16)	1.3 (.20)	.39 (.06)	.65 (.1)	1.82 (.28)	0 (.00)	0 (.00)	3.77 (.58)		6.11 (.94)			
COMMENTS	Broken fibers, some delamination			No visible damage			Laminate pushed through, heavy with broken fibers, cracks spread in 0° & 90°. Some delamination.							

FIGURE A-12 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING AMERICAN CYANAMIDE 919 RESIN REFERENCE PANEL

RESIN TYPE Epoxy Novalak and Bis Phenol A

HARDENER Latent Aliphatic Amine

MODIFICATION Elastomer

THICKNESS 1.02mm (.040")

% RESIN 31.7

VOID -2.8

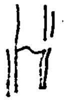
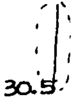
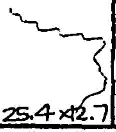
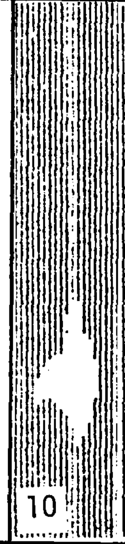
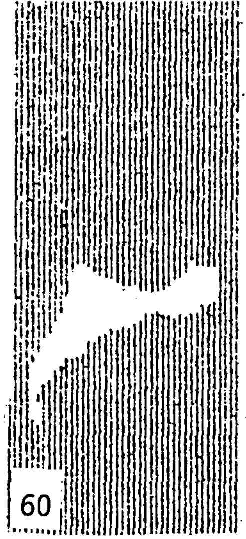
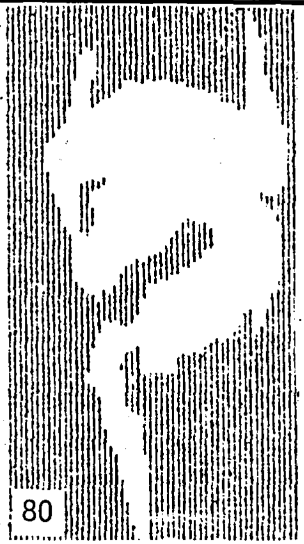
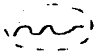
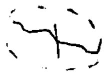
	3.17cm (125") SUPPORT			9.52cm (3.75") SUPPORT									
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT						
JOULES(in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	6.34mm (1/4") dent	dent broken fibers	OK	OK	OK			OK		15.8cm (5/8") hole broken fiber 90° cracks			
VISUAL BACK SIDE in	.2x1" 	.3x1.2 	.4x.12 		.3x.7" 	1.2" crack 			1x.5 					
mm	5.1×25.4	7.6×30.5	10.2×30.5	OK	7.6×17.8	30.5			25.4×12.7					
C-SCAN DAMAGE (scale 2.54cm 1" – 0)	 10	 20	 30	 10	 20	 30			 60		 80			
C-SCAN DAMAGE AREA cm²	1.3	3.18	3.90	.26	1.36	2.99			2.08		10.85			
(in²)	.20	.49	.60	.04	.21	.46			.32		1.67			
COMMENTS	Heavy splintering			Delamination and some broken fibers, no splintering			Broken fibers at 9.04 joules (80 in-lbs) broke through laminate.							

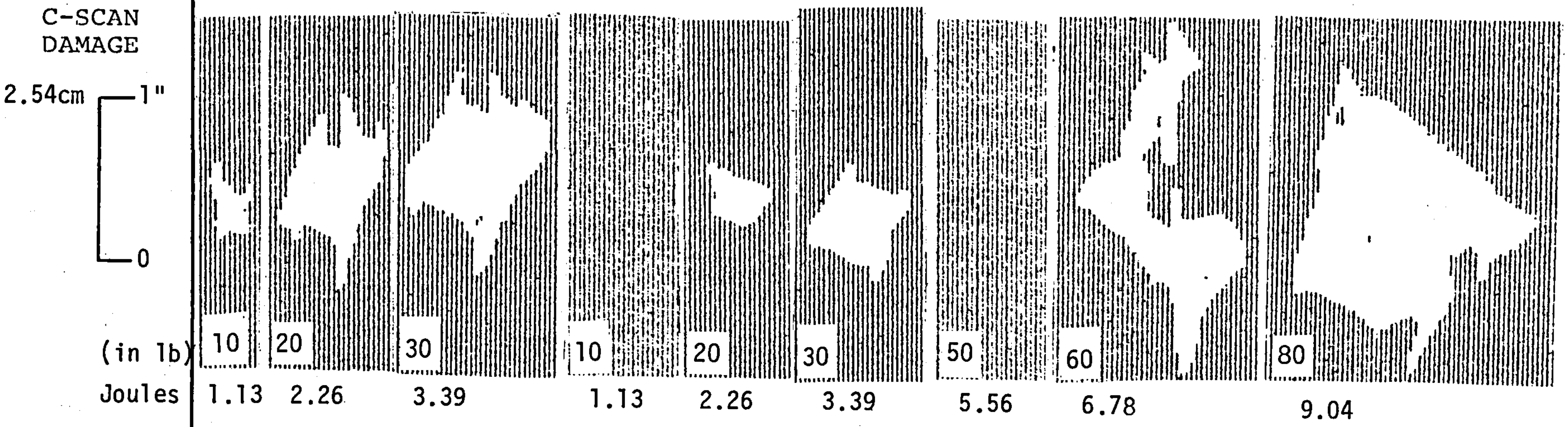
FIGURE A-13 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING AMERICAN CYANAMIDE 937 RESIN REFERENCE PANEL

RESIN TYPE Epoxy - Bis A & Specialty
HARDENER Latent Aromatic and Aliphatic Amines
MODIFICATION Elastomers

THICKNESS 1.09mm (.043")
% RESIN 31.7
VOID -1.4

	3.17cm (125") SUPPORT			9.52cm(3.75") SUPPORT											
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
JOULES(in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	OK	dent broken fibers	OK	OK	OK		OK	Cracks 0°		1.58cm (5/8") dent - broken fibers and 0° cracks			
in VISUAL BACK SIDE mm	.2x.1  5.1x2.54	.5x1.2  12.7x30.5	.7x1.3 17.8x33	OK	.3x.2  7.6x5.1	.6x.4  15.2x10.2		OK	.5x2  12.7x50.8		1.3x1.5  33x38			

C-SCAN DAMAGE

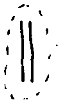
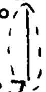
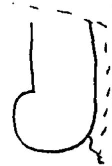


JOULES(in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
C-SCAN DAMAGE AREA cm² (in²)	.455 (.07)	2.67 (.41)	4.29 (.66)	0 (.00)	.78 (.12)	1.30 (.20)			4.61 (.71)		9.03 (1.39)			
COMMENTS	Broken fibers & delamination, some splintering			Delamination and broken fibers			Heavy delamination, broken fibers and slight splintering							

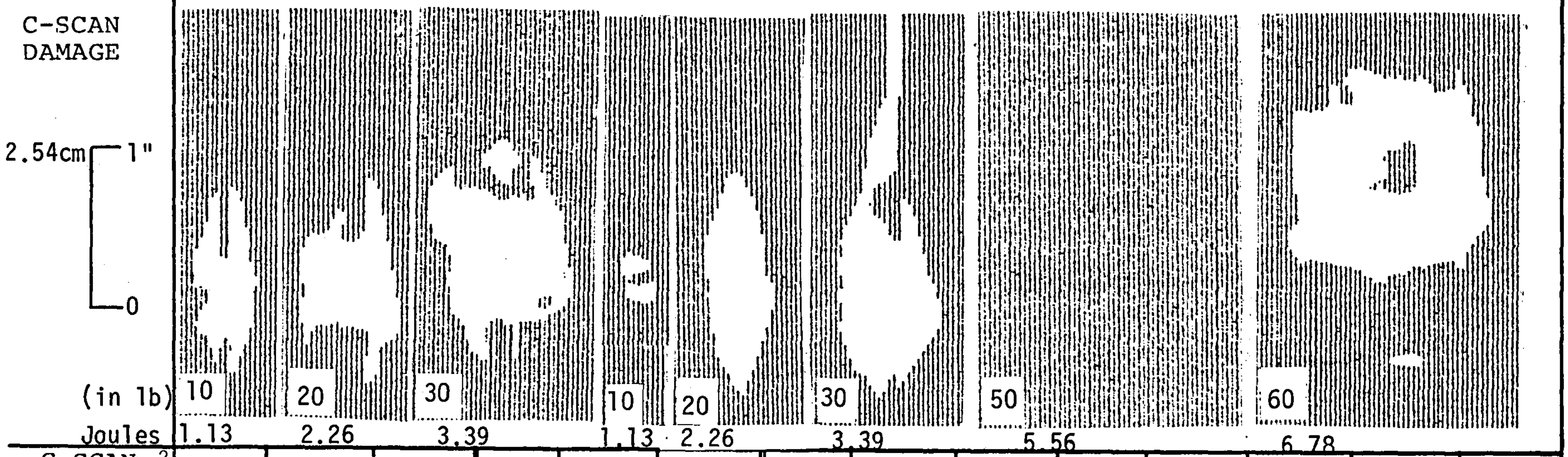
FIGURE A-14 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING AMERICAN CYANAMIDE 982 RESIN REFERENCE PANEL

RESIN TYPE Epoxy Novalak & Bis Phenol A
HARDENER Latent Aromatic and Aliphatic Amines
MODIFICATION None

THICKNESS 1.07mm (0.42")
% RESIN 27.0
VOID 0.7

	3.17cm (125") SUPPORT			9.52cm(3.75") SUPPORT										
	1.58cm (5/8" ROUND			1.58cm (5/8") ROUND			1.58cm (5/8" FLAT							
JOULES(in lb)	(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	6.34cm (1/4") dent	dent broken fibers	OK	OK	OK		OK	1.58 cm (5/8") hole broken fibers					
VISUAL BACK SIDE in mm	.1x.7"  2.5x 17.8	.5x1"  12.7×25.4	.7x1.3 17.8×33	OK	1/2" crack 0°  12.7	.3x3  7.6×76.2		OK						

C-SCAN DAMAGE



C-SCAN DAMAGE AREA cm^2 (in^2)	1.95 (.30)	2.73 (.42)	4.87 (.75)	.325 (.05)	2.6 (.40)	4.16 (.64)		0 (.00)	8.35 (1.29)					
COMMENTS	Very heavy splintering, some delamination & broken fibers			No splintering or broken fibers, surface delamination is heavy			Very heavy delamination, slight spintering							

FIGURE A-15 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING CIBA GEIGY #1M RESIN REFERENCE PANEL

RESIN TYPE Hydantoin Epoxy

HARDENER Aromatic Amine

MODIFICATION Thermoplastic

THICKNESS 1.09 mm (0.43")

% RESIN 26.5

VOID -.45

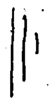
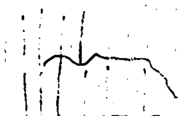
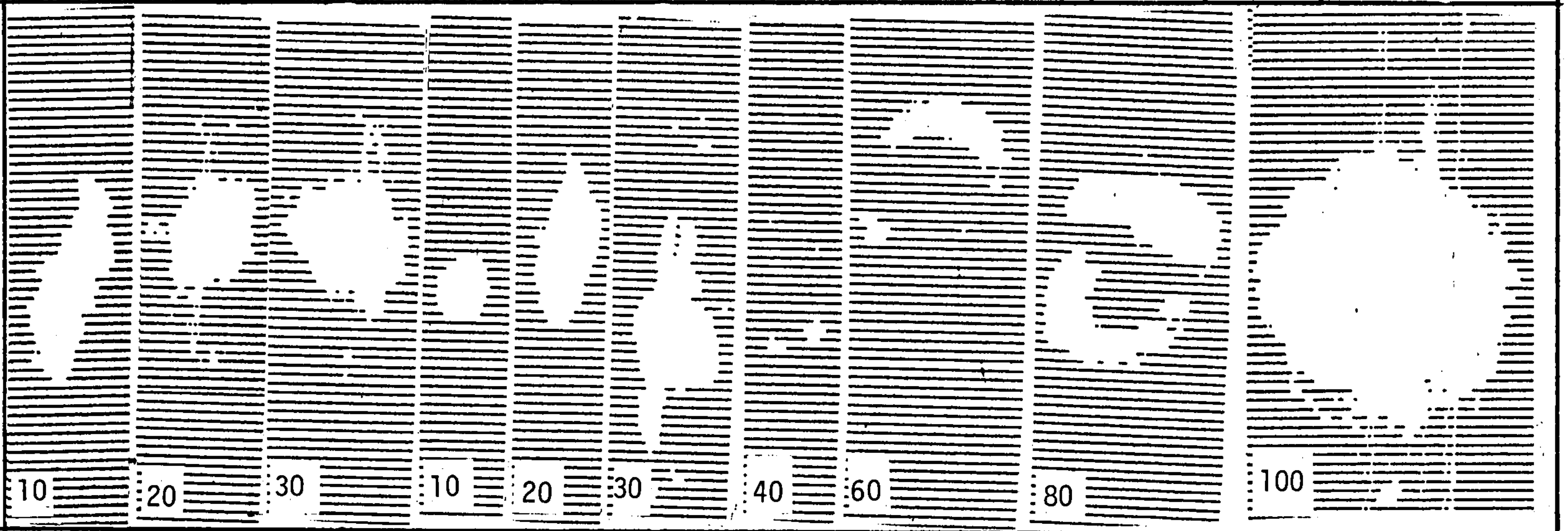
	3.17cm (125") SUPPORT			9.52cm (3.75") SUPPORT										
	1.58cm (5/8" ROUND			1.58cm (5/8" ROUND			1.58cm (5/8" FLAT							
JOULES(in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	OK	Broken Fibers	OK	OK	1/4" dent	OK		OK		OK		1.58cm (5/8") Dent Splint-ering	
VISUAL BACK SIDE in mm	OK	.2x1.5"  5.1x38	.4x1.3"  10.2x33	OK	.7" Crack  17.8	.3x2.4"  7.6x61	OK		OK		OK		1x3.7"  25.4x17.8	
C-SCAN DAMAGE 2.54cm 1" 0														
C-SCAN DAMAGE AREA cm² (in²)	1.95 (.30)	1.82 (.28)	2.86 (.44)	.78 (.12)	1.56 (.24)	2.40 (.37)	.52 (.08)		1.56 (.24)		3.96 (.61)		10.27 (1.58)	
COMMENTS	Heavy splintering - slight delamination			Delamination, no broken fibers, no splinters			Very heavy splintering, heavy delamination, broken fibers							

FIGURE A-16 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING CIBA GEIGY #3 RESIN REFERENCE PANEL

RESIN TYPE Hydantoin Epoxy

HARDENER Aromatic Amine

MODIFICATION

THICKNESS 1.07mm (.042")

% RESIN 24.6

VOID 1.3

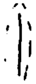
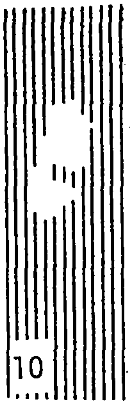
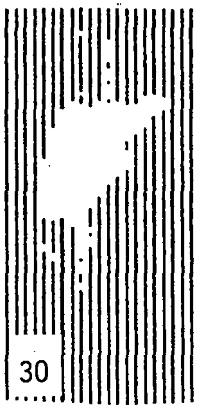
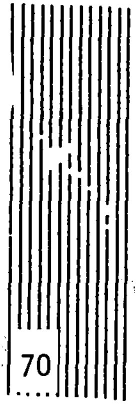
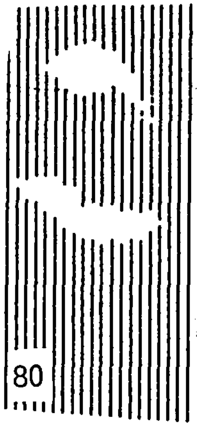
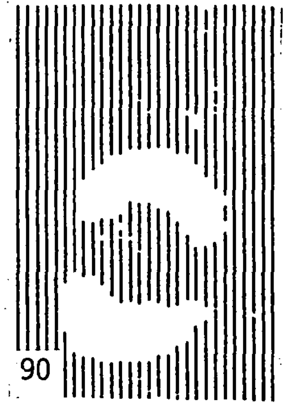
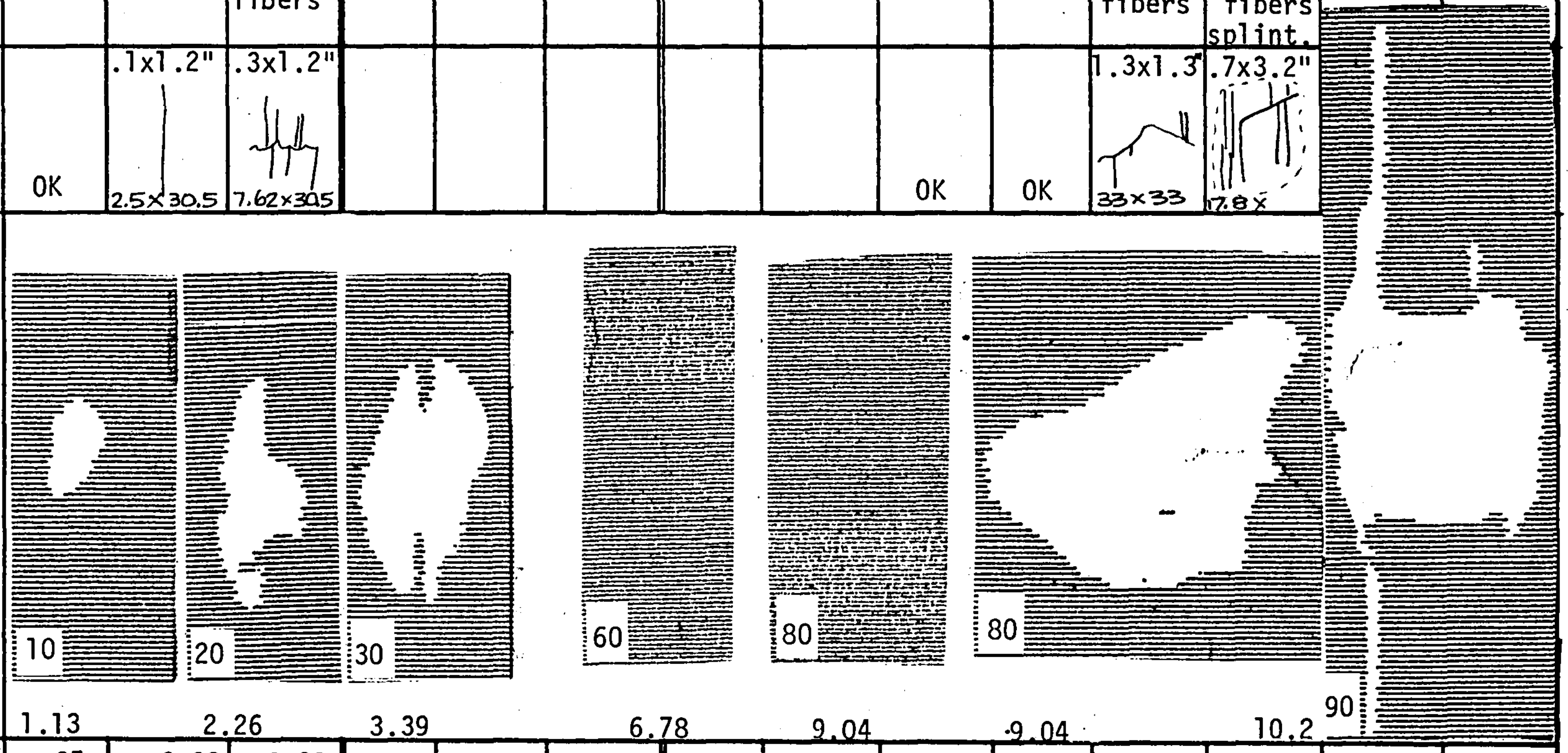
	3.17cm (125") SUPPORT			9.52cm (3.75") SUPPORT										
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
JOULES(in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	OK	6.34mm (1/4") dent							OK	OK	OK		
VISUAL BACK SIDE in mm	 OK	.2x1  5.1x25.4	.3x1.5  7.6x38							 OK	 OK	 OK		
C-SCAN DAMAGE 2.54cm 1" 0														
(in lbs)	10	20	30							70	80	90		
Joules	1.13	2.26	3.39							7.91	9.04	10.2		
C-SCAN cm² DAMAGE AREA (in²)	.845 (.13)	1.30 (.20)	2.34 (.36)							.065 (.01)	1.75 (.27)	2.99 (.46)		
COMMENTS	Splintering and delamination						No visible damage							

FIGURE A-17 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING CIBA GEIGY #4 RESIN REFERENCE PANEL

RESIN TYPE Epoxy (Not Identified)
HARDENER Aliphatic Amine
MODIFICATION Thermoplastic

THICKNESS 1.19mm (.047")
% RESIN 27.5
VOID 0.9

	3.17cm (125" SUPPORT			9.52cm (3.75") SUPPORT										
	1.58cm (5/8" ROUND			1.58cm (5/8" ROUND			1.58cm (5/8") FLAT			#1	#2			
JOULES(IN LB)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	9.04(80)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	OK	.2 dent, some broken fibers						OK	OK	1.58cm (5/8") dent broken fibers	1.58cm (5/8") dent broken fibers splint.		
VISUAL BACK SIDE in mm	OK	.1x1.2" 2.5X30.5	.3x1.2" 7.62x30.5						OK	OK	1.3x1.3" 33x33	.7x3.2" 17.8X		
C-SCAN DAMAGE 2.54cm 1" 0 (in lbs) JOULES														
C-SCAN DAMAGE AREA cm² (in²)	.65 (.10)	2.08 (.32)	3.83 (.59)						0 (.00)	0 (.00)	10.4 (1.60)	10.07 (1.55)		
COMMENTS	Splintering, broken fibers and slight delamination						Delamination, broken fibers and slight splinters.							

* Two 9.04 joules (80 in-lb) impacts in same location.

FIGURE A-18 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING FIBREDUX 914 RESIN REFERENCE PANEL

RESIN TYPE Multifunctional Epoxy

HARDENER Undisclosed

MODIFICATION Thermoplastic

THICKNESS 1.07mm (.042")

% RESIN 23.5

VOID 1.2

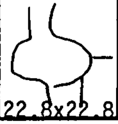
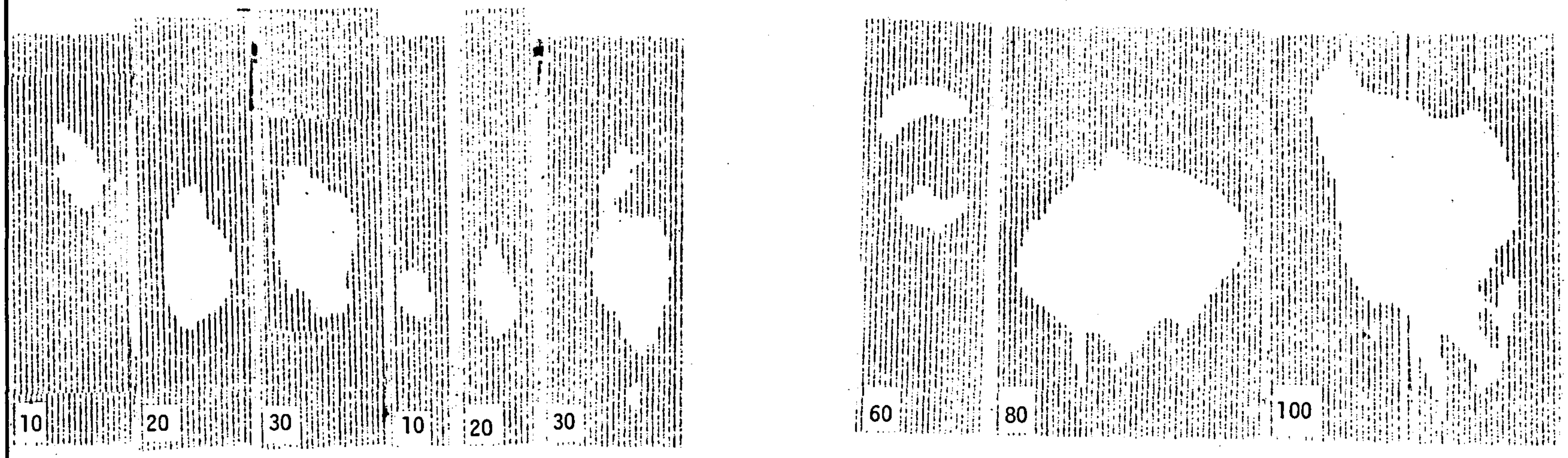
	3.17cm (125") SUPPORT			9.52cm(3.75")SUPPORT										
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8")FLAT							
JOULES (IN LBS)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	OK	OK	OK	OK	OK			OK		Broken Fibers & 0° Cracks		1.58cm (5/8" Dent Broken Fibers	
VISUAL BACK SIDE in mm	OK	.2 X .4  5.1x10.2	.3 X .5  7.6x12.7	OK	OK	.3 X .7  7.6x17.8			.1 X .4  2.54x10.2		.6 X .8  15.2x20.3		.9 X .9  22.8x22.8	
C-SCAN DAMAGE 2.54cm 1" 0 (inch lbs)														
Joules	1.13	2.26	3.39	1.13	2.26	3.39			6.78		9.04		11.3	
C-SCAN cm² DAMAGE (in²) AREA	1.17 (.18)	2.21 (.34)	2.73 (.42)	0 (.00)	1.23 (.19)	3.18 (.49)			2.01 (.31)		10.6 (1.64)		13.97 (2.15)	
COMMENTS														

FIGURE A-19 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING FIBREDUX 920 RESIN REFERENCE PANEL

RESIN TYPE Bis Phenol A
HARDENER Aliphatic Amine
MODIFICATION Thermoplastic

THICKNESS 1.12mm (.044")
% RESIN 31.7
VOID 1.3

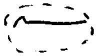
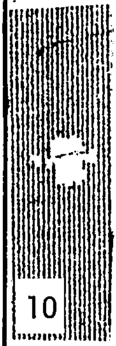
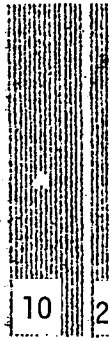
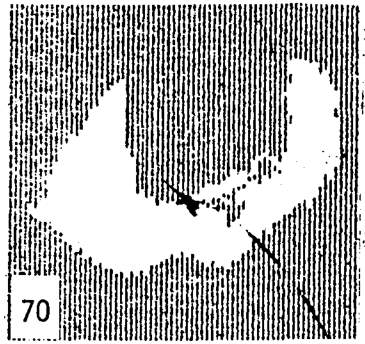
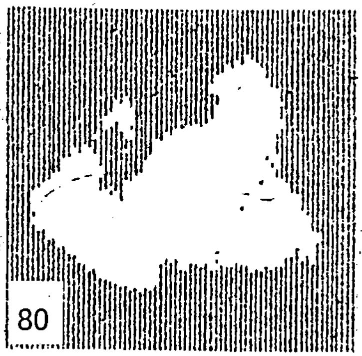
	3.17cm (125") SUPPORT			9.52cm(3.75") SUPPORT											
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT								
Joules(in lb)	1.13(10)	2.26(20)	3.39 (30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56 (50)	6.78 (60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	OK	6.35mm (1/4") dent	OK	OK	3.17mm (1/8") dent				Broken fibers & 0° cracks	broken fibers & 0° cracks			
VISUAL BACK SIDE in mm	OK	.4x.3"  10.2×7.5	.5x.5"  12.7×12.7	OK	OK	.5x.3"  12.7× 7.5				1.4x.5  35.6×12.7	2.7x.6"  68.6× 15.2			
C-SCAN DAMAGE 2.54cm 1" 0 (inch lbs)	 10	 20	 30	 10	 20	 30				 70	 80			
Joules	1.13	2.26	3.39	1.13	2.26	3.39				7.91	9.04			
C-SCAN DAMAGE AREA cm² (in²)	.325 (.05)	1.10 (.17)	1.43 (.22)	.065 (.01)	.65 (.10)	1.56 (.24)				5.39 (.83)	6.63 (1.02)			
COMMENTS	Broken fibers - slight splintering			Broken fibers & slight splintering			Broken fibers, long 90° cracks							

FIGURE A-20 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING FIBREDUX 920 (LOW RESIN) RESIN REFERENCE PANEL

RESIN TYPE Bis Phenol A

HARDENER Aliphatic Amine

MODIFICATION Thermoplastic

THICKNESS 1.09 mm (.043")

% RESIN 29.2

VOID 0.5

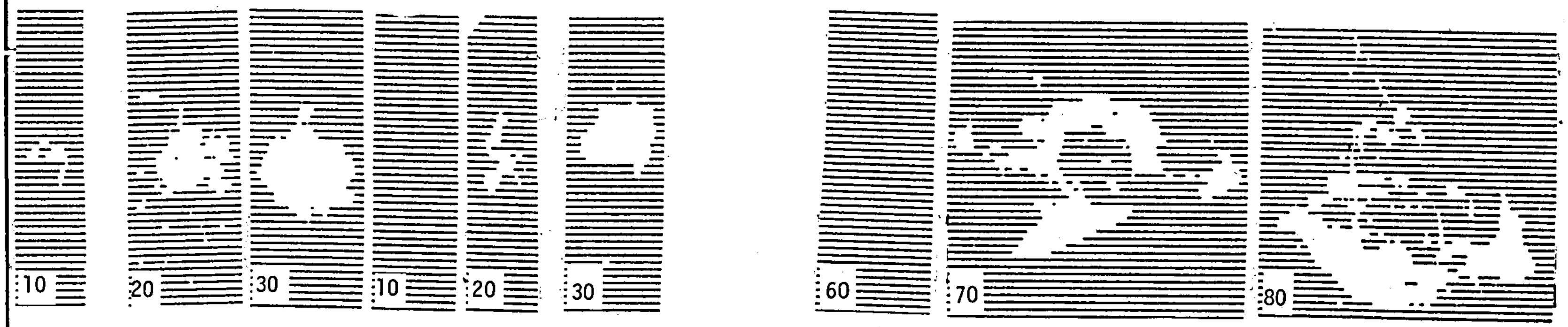
	3.17cm (125") SUPPORT			9.52cm (3.75")SUPPORT										
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm(5/8")FLAT							
JOULES (IN LB)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	3.17mm (1/8") dent	6.35mm (1/4") dent	OK	OK	6.35mm (1/4")dent broken fibers			OK	1.58cm (5/8") dent	1.58cm (5/8") dent 90° crack			
VISUAL BACK SIDE in mm	.2x.1"  5.1x2.5	.4x.3"  10.2x7.6	.5x.5"  12.7x12.7	OK	.2x.4"  5.1x10.2	.4x.4"  10.2x10.2			OK	1.5x1.0  38x25.4	1.5x1.7  38x43.2			
C-SCAN DAMAGE 2.54cm 1" 0 (in lbs) Joules	 10 1.13	20 2.26	30 3.39	10 1.13	20 2.26	30 3.39			60 6.78	70 7.91	80 9.04			
C-SCAN cm² DAMAGE AREA(in²)	.195 (.03)	1.43 (.22)	2.27 (.35)	0 (.00)	.45 (.07)	1.49 (.23)			0 (.00)	4.87 (.75)	4.81 (.74)			
COMMENTS	Broken fibers and delamination			Broken fibers, delamination at 3.39 joules (30 in lb)			Broken fibers and heavy delamination							

FIGURE A-21 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING U.S. POLY #1 RESIN REFERENCE PANEL

RESIN TYPE Bis Phenol A
HARDENER Specialty Aromatic Amine
MODIFICATION Elastomers

THICKNESS 1.02mm (.040")
% RESIN 24.6
VOID 1.3

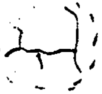
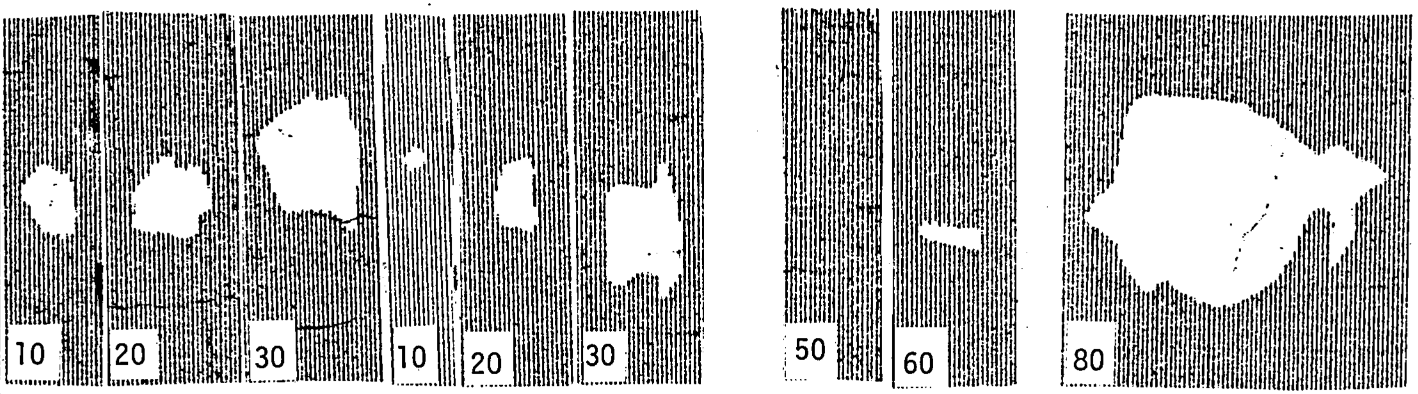
	3.17cm (125") SUPPORT			9.52cm (3.75") SUPPORT										
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
Joules(in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	3.17mm (1/8") dent	dent broken fibers	OK	OK	3.17mm (1/8") dent		OK	OK		dent broken fibers			
VISUAL BACK SIDE in	.2x.1	.3x.2	.4x.7		.2x.1	.4x.6					1.5x.5			
														
mm	5.1×2.5	7.6×5.1	10.2×17.8	OK	5.1×2.5	10.2×15.2		OK	OK		38×12.7			
C-SCAN DAMAGE 2.54cm 1" 0														
(in lbs)	10	20	30	10	20	30		50	60		80			
Joules	1.13	2.26	3.39	1.13	2.26	3.39		5.56	6.78		9.04			
C-SCAN cm² DAMAGE AREA (in²)	.58 (.09)	.84 (.13)	1.75 (.27)	.065 (.01)	.52 (.08)	1.49 (.23)		0 (.00)	.19 (.03)		6.95 (1.07)			
COMMENTS	Broken fibers & delamination			Broken fibers and delamination			Broken fibers and delamination							

FIGURE A-22 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING U.S. POLY #2 RESIN REFERENCE PANEL

RESIN TYPE Bis Phenol A
HARDENER Specialty Aromatic Amine
MODIFICATION Elastomers

THICKNESS 1.02mm (.040")
% RESIN 24.8
VOID 0.9

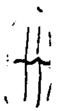
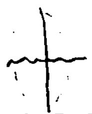
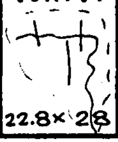
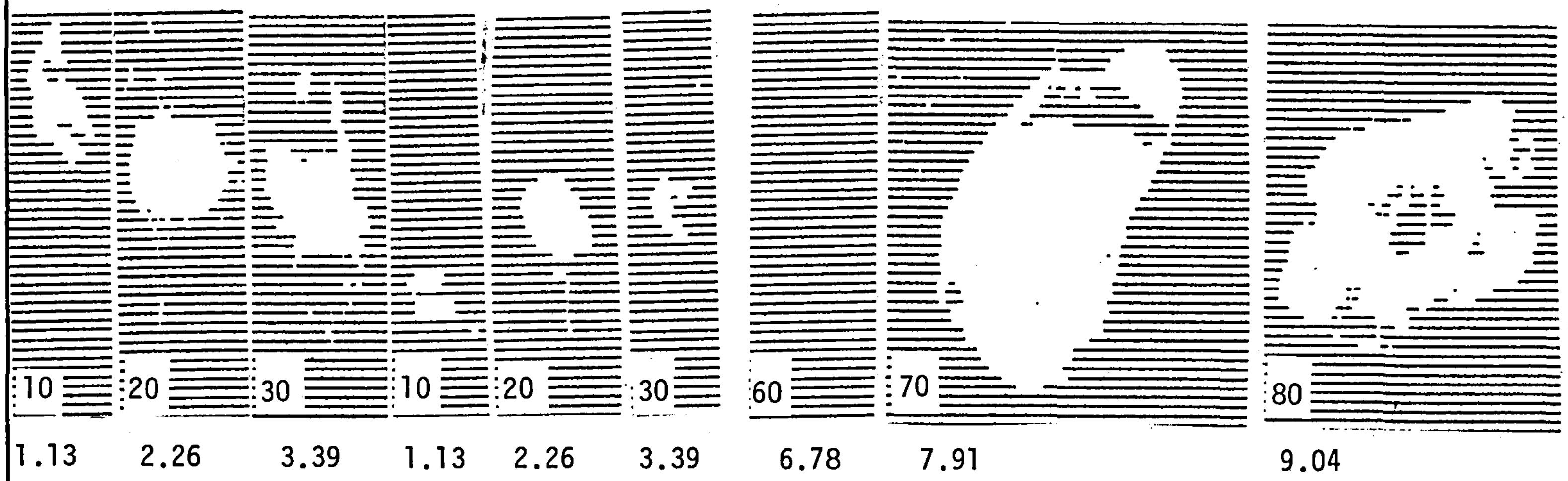
	3.17cm (125") SUPPORT			9.52cm(3.75") SUPPORT										
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
Joules(in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	OK	3.17mm (1/8") dent broken fibers	OK	OK	OK			OK	OK	1.58cm (5/8") hole broken fibers 90° crack			
VISUAL BACK SIDE in mm	OK	.2x1"  5.1×25.4	.4x1.2"  10.2×30.5	OK	OK	OK			OK	.1x.1 ~ 2.5×2.5	.9x1.1  22.8×28			
C-SCAN DAMAGE 2.54cm 1" 0 (in lbs) Joules														
C-SCAN DAMAGE AREA cm² (in²)	1.10 (.17)	1.82 (.28)	1.69 (.26)	.52 (.08)	1.23 (.19)	.455 (.07)				9.68 (1.49)	7.67 (1.18)			
COMMENTS	Delamination, some splintering and broken fibers			Undamaged			Broken fibers, no splintering, delamination at 9.04 joules (80 in lbs)							

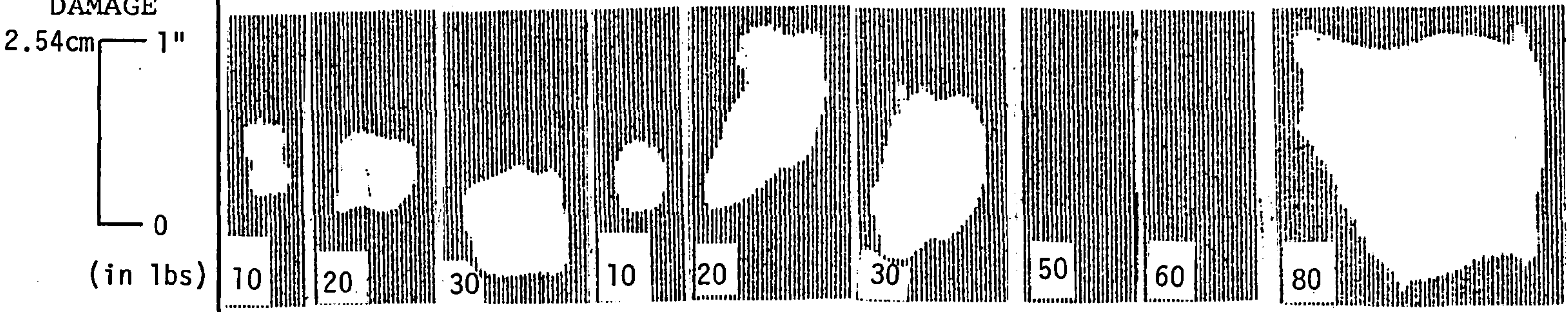
FIGURE A-23 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING HEXCEL #1 RESIN REFERENCE PANEL

RESIN TYPE Bis Phenol A
HARDENER Dicyandiamide
MODIFICATION Elastomer

THICKNESS 1.09mm (.043")
% RESIN 28.8
VOID -1.0

	3.17cm (125") SUPPORT			9.52cm(3.75") SUPPORT										
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
Joules(in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	3.17mm (1/8") dent	6.35mm (1/4") dent	OK	OK	6.35mm (1/4") dent		OK	OK		1.58cm (5/8") dent broken fibers			
VISUAL BACK SIDE in mm	OK	.3x.2"  7.6×5.1	.3x.3"  7.6×7.6	OK	.4x.4"  10.2×10.2	.4x1.0"  10.2×25.4		OK	OK		1.1x.7"  28×17.8			

C-SCAN DAMAGE



Joules 1.13 2.26 3.39 1.13 2.26 3.39 5.56 6.78 9.04

C-SCAN cm² DAMAGE AREA (in²)	.52 (.08)	1.10 (.17)	2.01 (.31)	.455 (.07)	2.86 (.44)	2.86 (.44)					9.94 (1.53)			
COMMENTS	Broken fibers - slight splintering but no spread, slight delamination			Broken fibers and delamination - slight splintering			Broken fibers, crack propagated 0° no splintering, no delamination							

FIGURE A-24 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING HEXCEL #2 RESIN REFERENCE PANEL

RESIN TYPE Bis-Phenol A

HARDENER Dicyandiamide

MODIFICATION Elastomer

THICKNESS 1.14mm (.045")

% RESIN 28.9

VOID 1.5

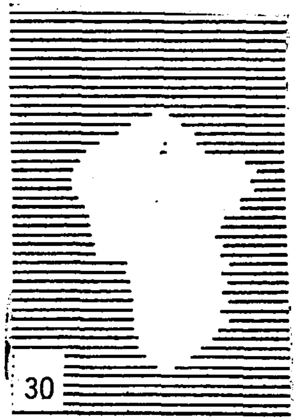
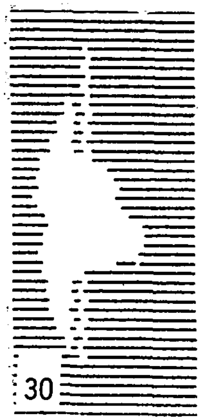
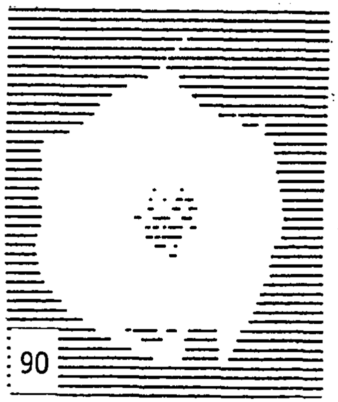
	3.17cm(125") SUPPORT			9.52cm (3.75") SUPPORT										
	1.58cm(5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
Joules(in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(900)	11.30(100)	13.60(120)
VISUAL FRONT SIDE			OK			OK						1.58cm (5/8") hole cracks prop. 0° & 90°		
VISUAL BACK SIDE in mm			1"crack 0° 25.4			.2x1.2  5.1x30.5						1x1.5  25.4x38		
C-SCAN DAMAGE 2.54cm 1" 0 (in lb) Joules			 30 3.39			 30 3.39						 90 10.20		
C-SCAN cm² DAMAGE AREA(in²)			5.2 (.80)			1.95 (.30)						9.68 (1.49)		
COMMENTS	Blister			Slight splinters, some broken fibers			Heavy delamination, broken fibers, some splintering							

FIGURE A-25 IMPACT DAMAGE DATA FOR (0/±45/90)s LAMINATE USING FIBERITE HY-E 976 RESIN REFERENCE PANEL

RESIN TYPE High Functionality Epoxy

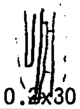
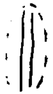
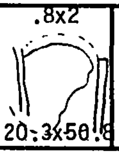
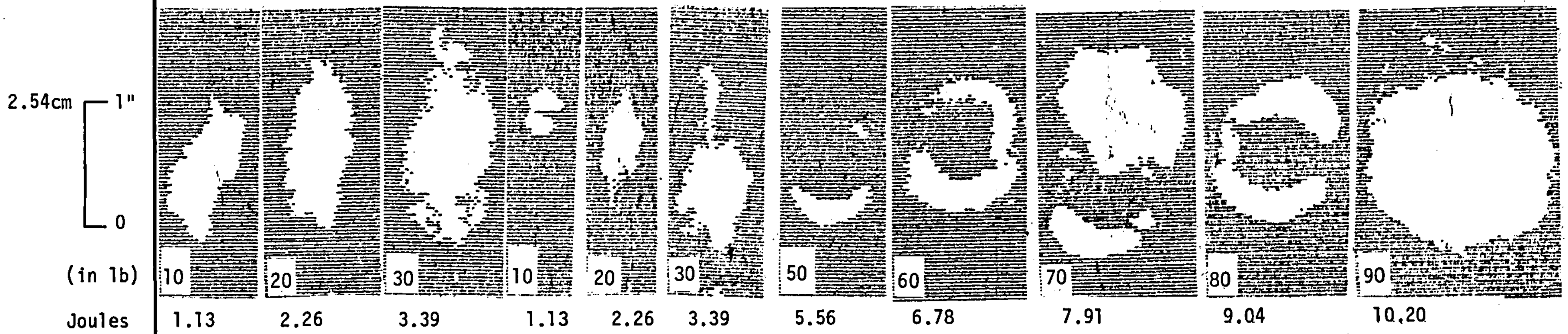
HARDENER Aromatic Amine

MODIFICATION None

THICKNESS 1.17 (0.46)

% RESIN 29.6

VOID 1.12

	3.17cm (125") SUPPORT			9.52cm (3.75") SUPPORT										
	1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
Joules (in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(20
VISUAL FRONT SIDE	OK	3.17mm (1/8") dent	6.35mm (1/4") dent	OK	OK	3.17mm (1/8") dent		OK	OK	OK	OK	1.58cm (5/8") hole broken fibers and splinters		
VISUAL BACK SIDE in mm	OK	.2x1.2  5.1x30.5	.4x1.2  10.2x30.5	OK	.2x.8  5.08x20.3	.2x2  5.08x50.8		OK	OK	.2x.3  5.08x7.62	.1x.3  2.54x7.62	.8x2  20.3x50.8		
C-SCAN DAMAGE														
C-SCAN DAMAGE AREA cm^2 (in^2)	2.34 (.36)	3.31 (.51)	5.13 (.79)	.455 (.07)	1.17 (.18)	2.40 (.37)		.975 (.15)	2.73 (.42)	5.59 (.86)	3.64 (.56)	10.27 (1.58)		
COMMENTS	Delamination at 3.39 joules (30 in lb) heavy splintering			90° cracks delamination			Broken fibers, 10.20 joules (90 in lb) heavy damage with come splintering							

APPENDIX 2

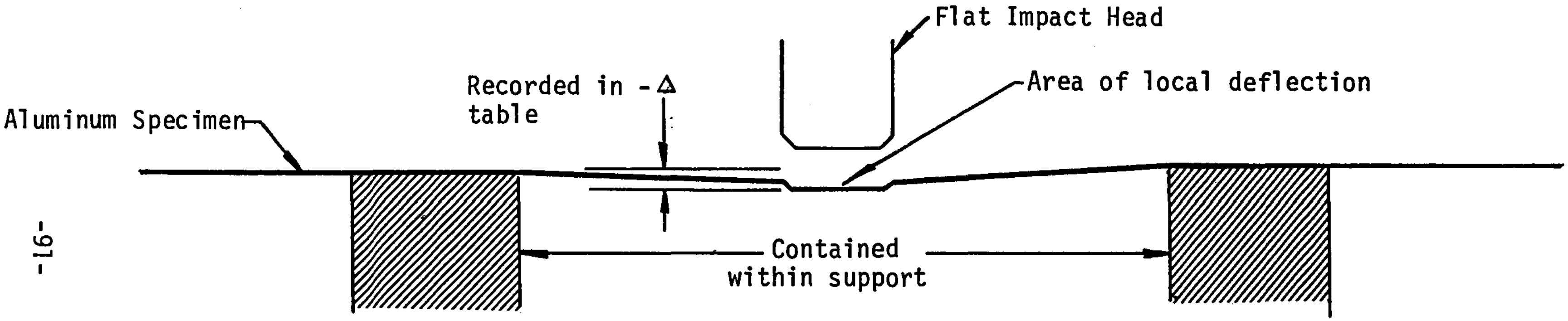
ALUMINUM IMPACT DATA (GARDNER)

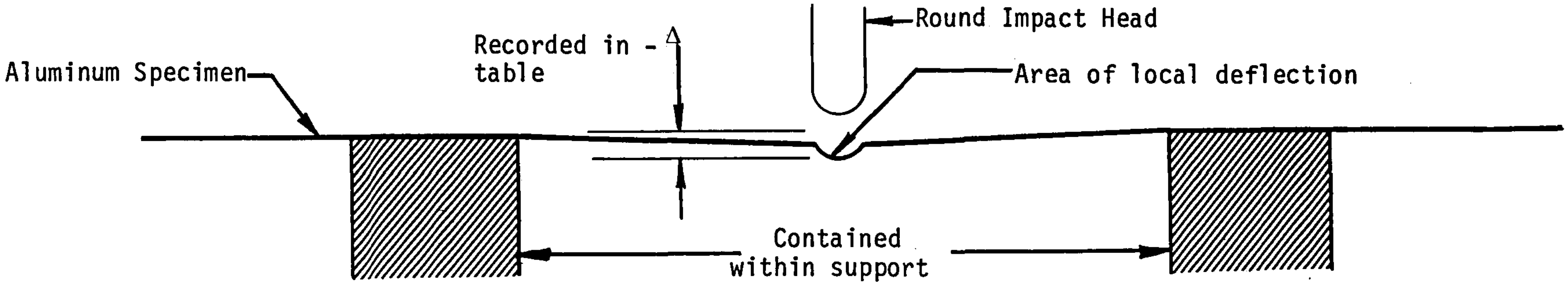
Photographs B-1 through B-12 show the damage to .98 mm and .61 mm thick aluminum alloy 2024-T3 impacted at the same levels as the graphite/epoxy laminates. The .98 mm sheet is approximately the same thickness as the GR/EP panels and the .61 mm sheet is approximately equal weight for a given surface area as the composite panels.

There was no fracturing, however the aluminum yielded significantly in the direction of impact; the area of damage was equal to the area within the back support. As would be expected the maximum deformation took place at the point of impact, this deflection is recorded in Table B-1.

TABLE B-1 DEFORMATION AFTER IMPACT

	3.17cm (1.25") SUPPORT			9.52cm (3.75") SUPPORT						
	5/8" ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT			
Joules (in lb)	1.13 (10)	2.26 (20)	3.39 (30)	1.13(10)	2.26 (20)	3.39 (30)	4.52 (40)	6.78 (60)	9.04 (80)	11.3 (100)
Δ for 2024-T3 .98mm (.040")	0.66 (.026)	1.07 (.042)	1.57 (.062)	0.51 (.020)	0.91 (.036)	1.40 (.055)	1.47 (0.58)	2.13 (0.84)	2.69 (.106)	2.79 (.110)
Δ for 2024-T3 .61mm (0.25")	1.22 (.048)	1.65 (0.65)	1.85 (0.73)	0.99 (.039)	1.35 (.053)	1.55 (.061)	1.73 (.068)	2.51 (0.99)	2.82 (.111)	3.86 (.152)





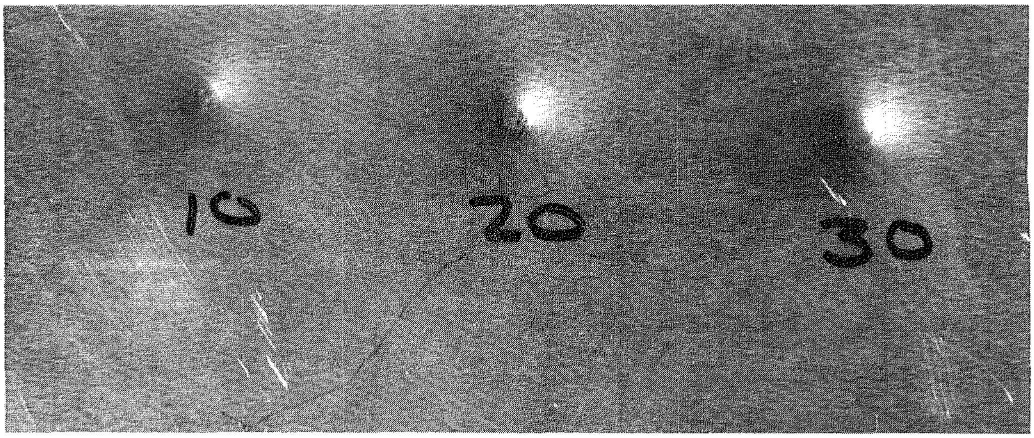


FIGURE B-1 2024-T3 .98 mm (.040") 14.9 mm (5/8") ROUND, 31.7 mm (1.25") SUPPORT 1.13 (10), 2.25 (20), 3.39 JOULES (30 INCH POUNDS)

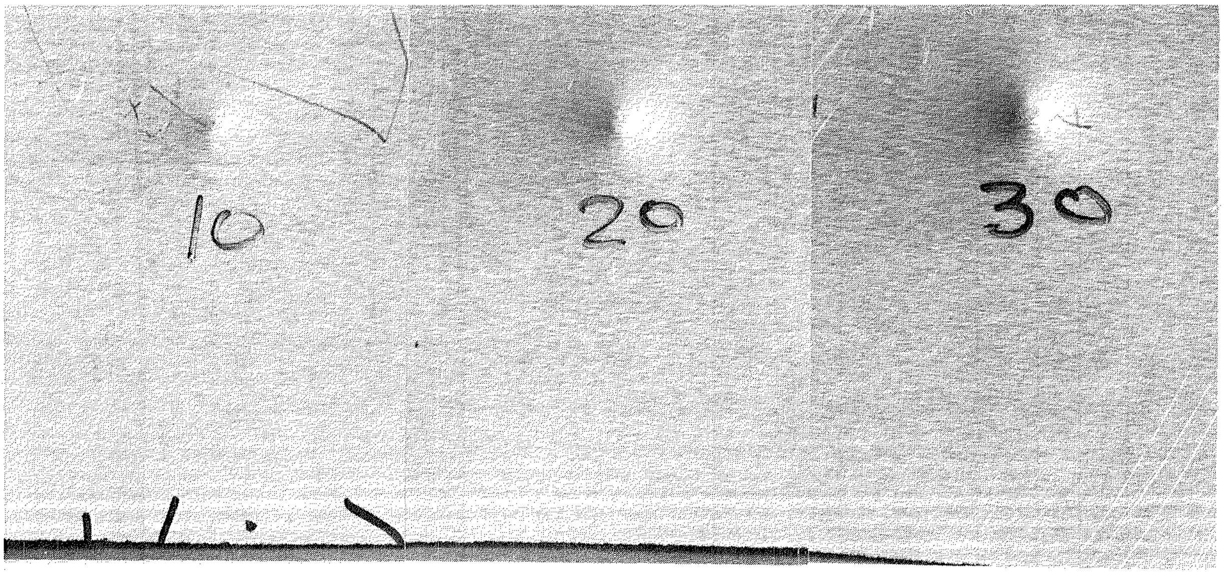


FIGURE B-2 2024-T3 .98 mm (.040") 15.9 mm (5/8") ROUND, 95.3 mm (3.75") SUPPORT 1.13 (10), 2.26 (20), 3.39 JOULES (30 INCH POUNDS)

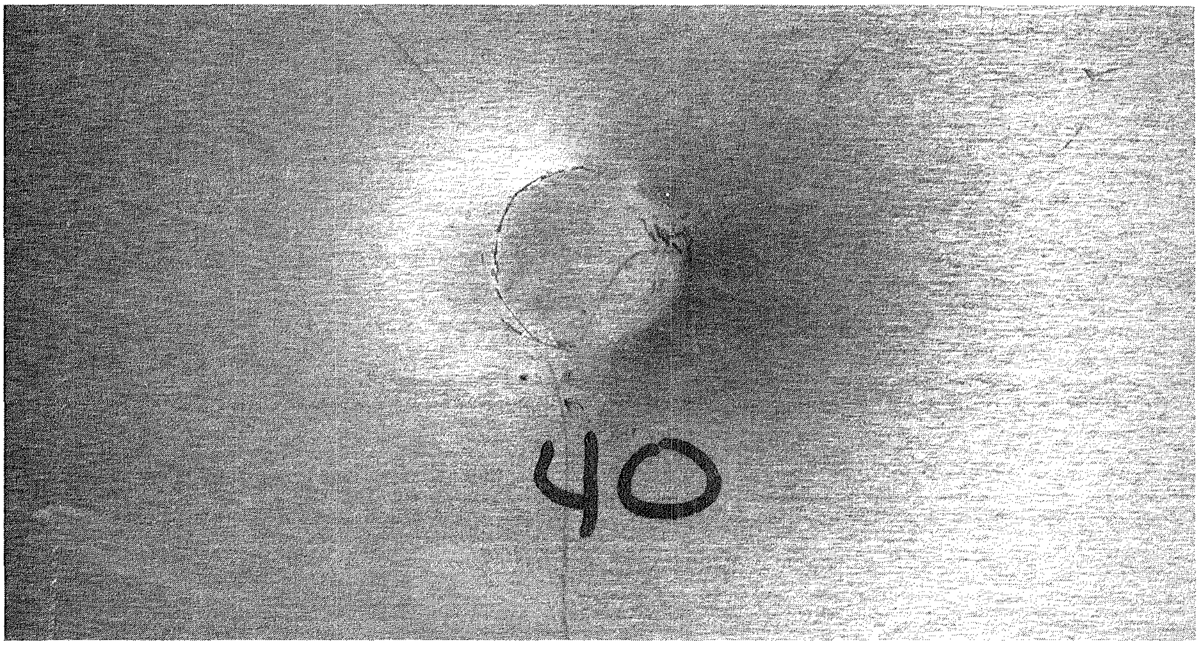


FIGURE B-3 2024-T3 .98 mm (.040") 15.9 mm (5/8") FLAT, 95.3 mm (3.75") SUPPORT 4.52 JOULES (40 INCH POUNDS)

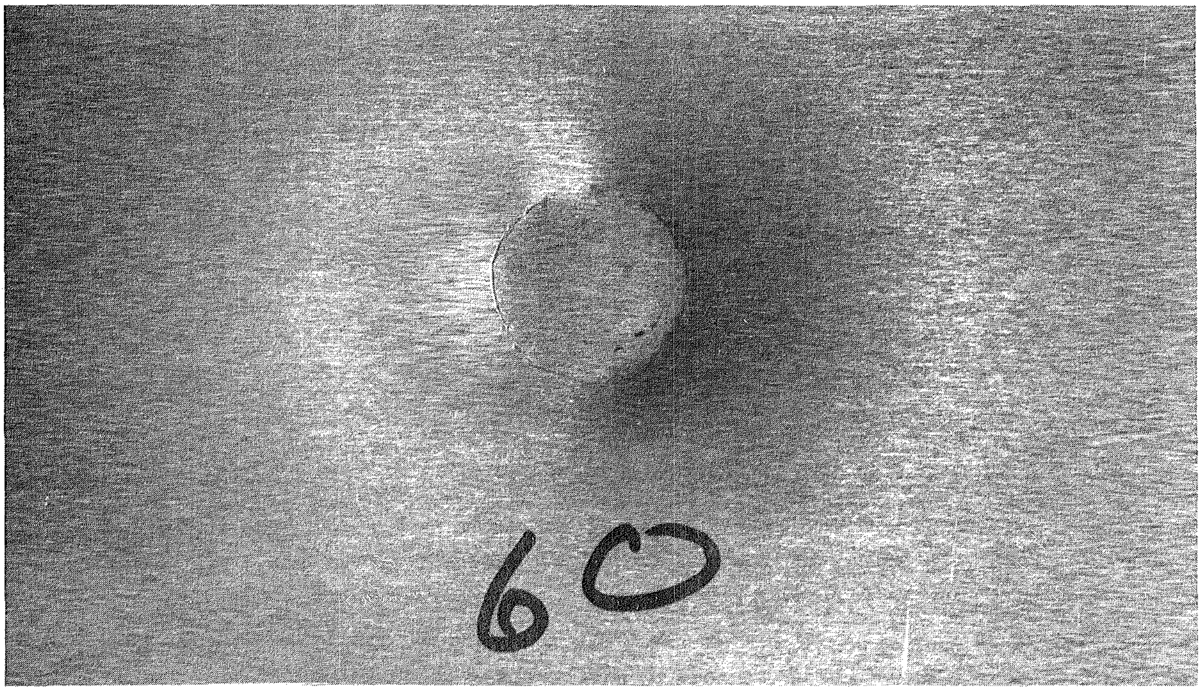


FIGURE B-4 2024-T3 .98 mm (.040") 15.9 mm (5/8") FLAT 95.3 mm (3.75") SUPPORT 6.78 JOULES (60 INCH POUNDS)

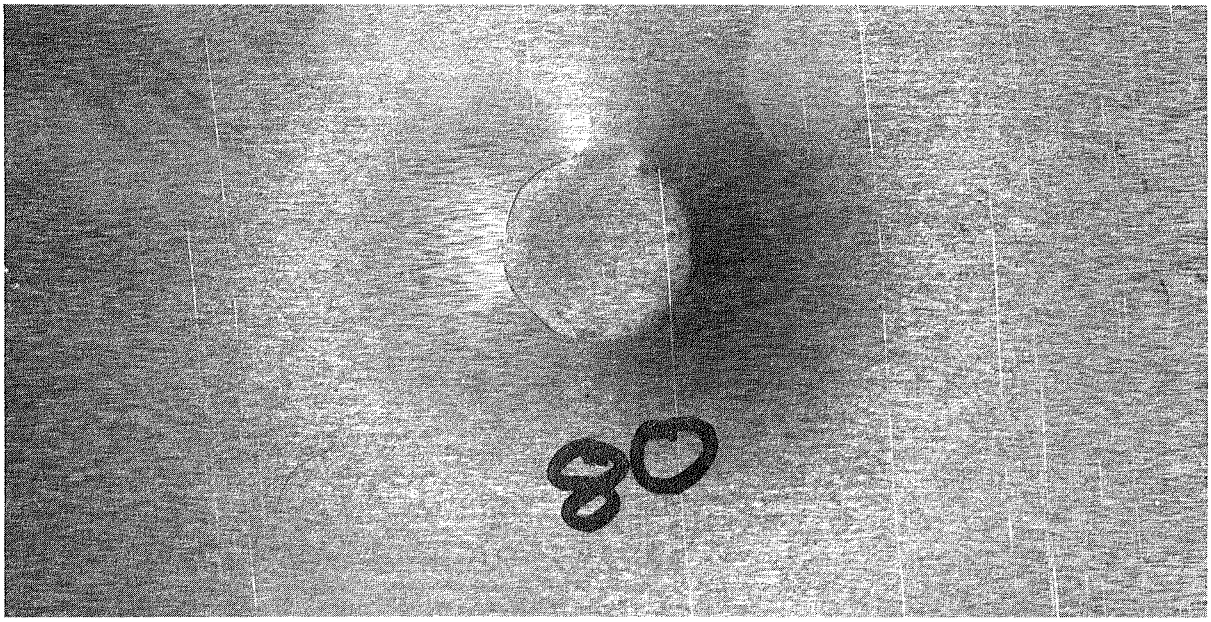


FIGURE B-5 2024-T3 .98 mm (.040") 15.9 mm (5/8") FLAT 95.3 mm (3.75") SUPPORT 6.78 JOULES (60 INCH POUNDS)

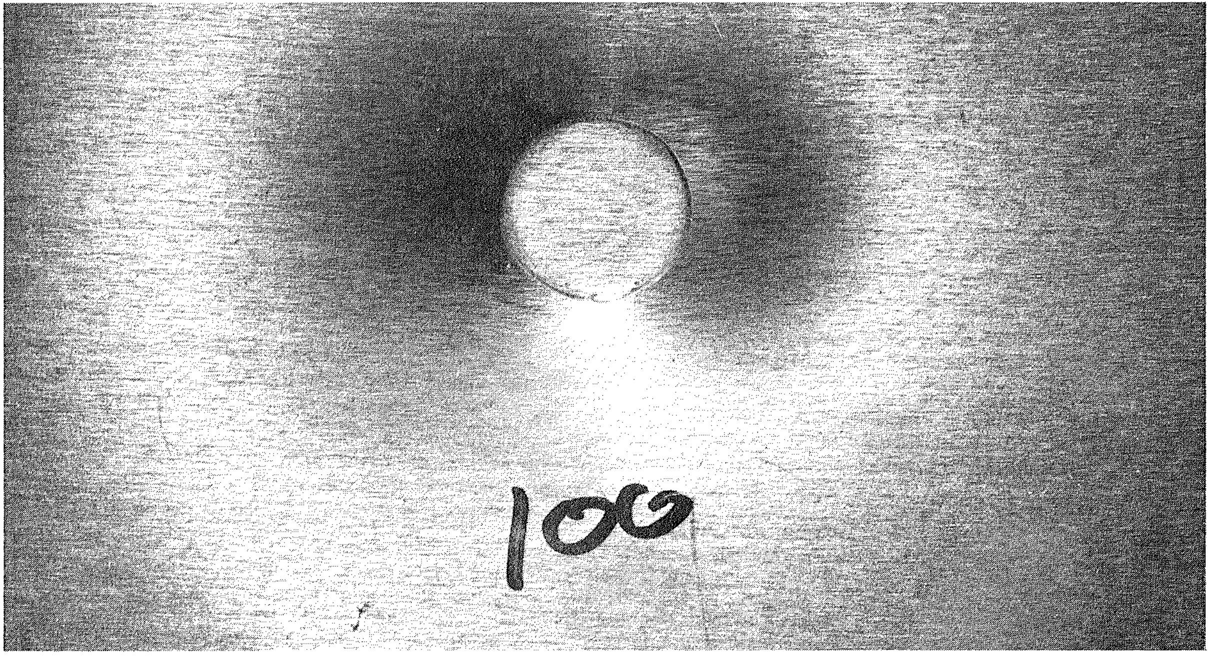


FIGURE B-6 2024-T3 .98 mm (.040") 15.9 mm (5/8") FLAT 95.3 mm (3.75") SUPPORT 11.3 JOULES (100 INCH POUNDS)

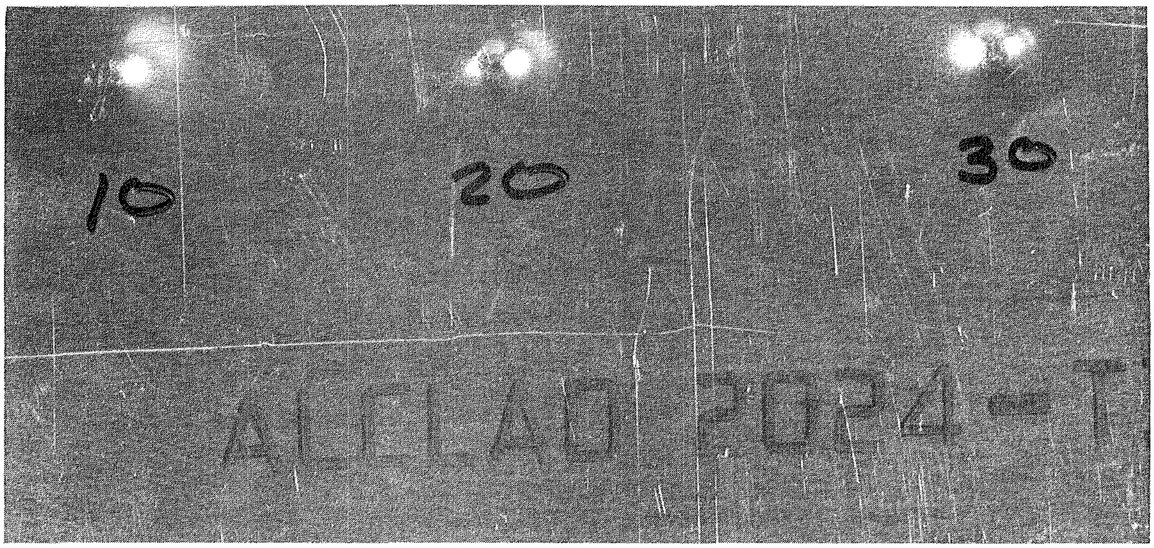


FIGURE B-7 2024-T3 .61 mm (0.25") 15.9 mm (5/8") ROUND, 31.7 mm (1.25") SUPPORT 1.13 (10), 2.26 (20), 3.39 JOULES (30 INCH POUNDS)

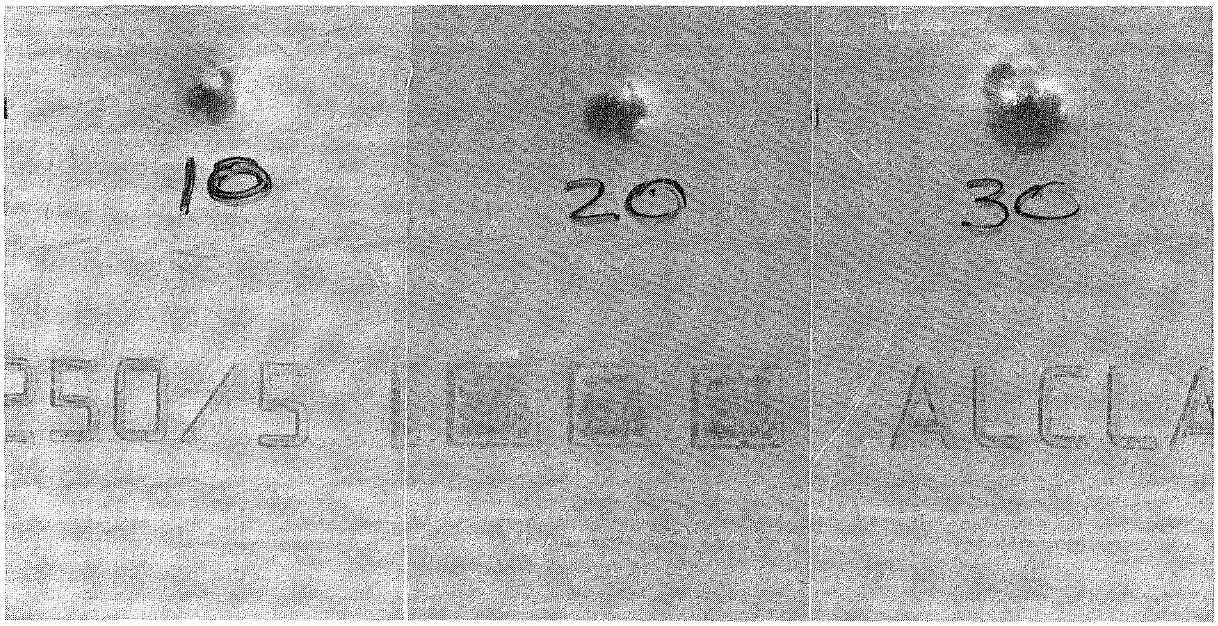


FIGURE B-8 2024-T3 .61 mm (.025") 14.9 mm (5/8") ROUND, 95.3 mm (3.75") SUPPORT 1.13 (10), 2.25 (20), 3.39 JOULES (30 INCH POUNDS)

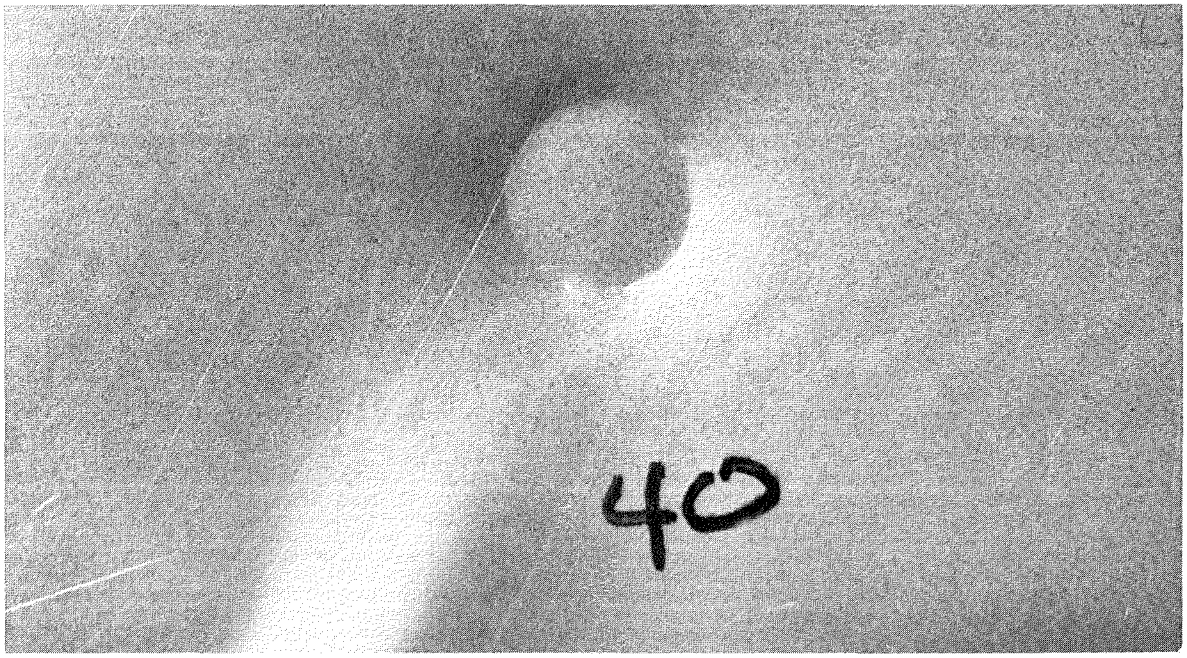


FIGURE B-9 2024-T3 .61 mm (.025") 15.9 mm (5/8") FLAT, 95.3 mm (3.75") SUPPORT 4.52 JOULES (40 INCH POUNDS)

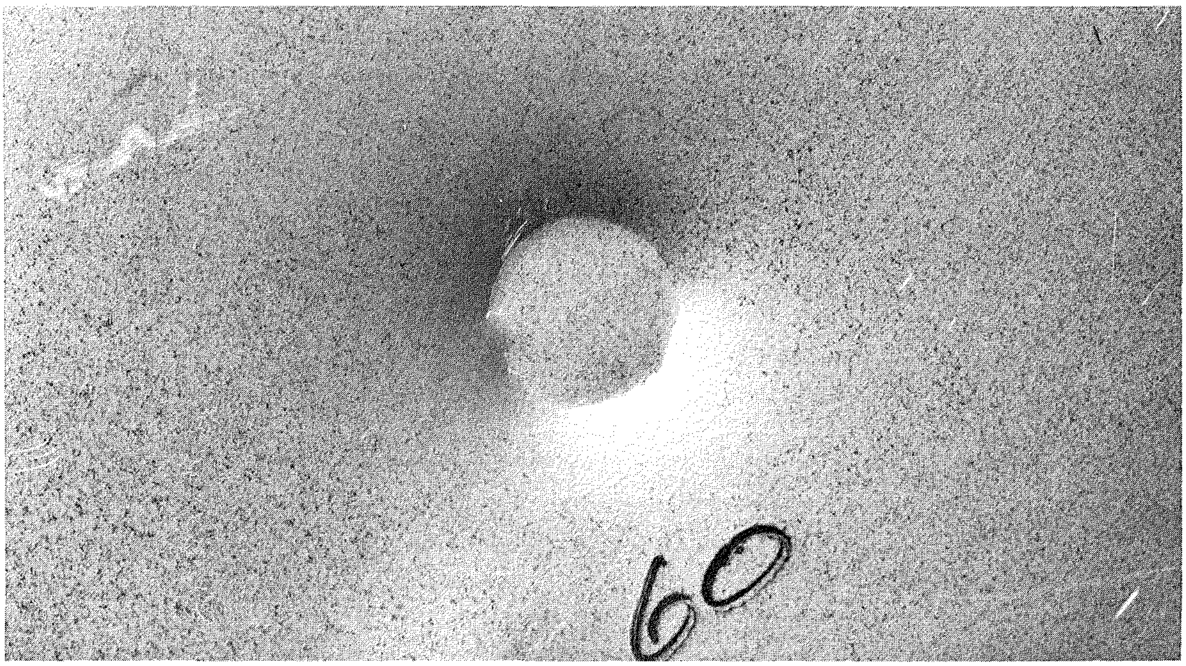


FIGURE B-10 2024-T3 .61 mm (.025") 15.9 mm (5/8") FLAT 95.3 mm (3.75") SUPPORT 6.78 JOULES (60 INCH POUNDS)

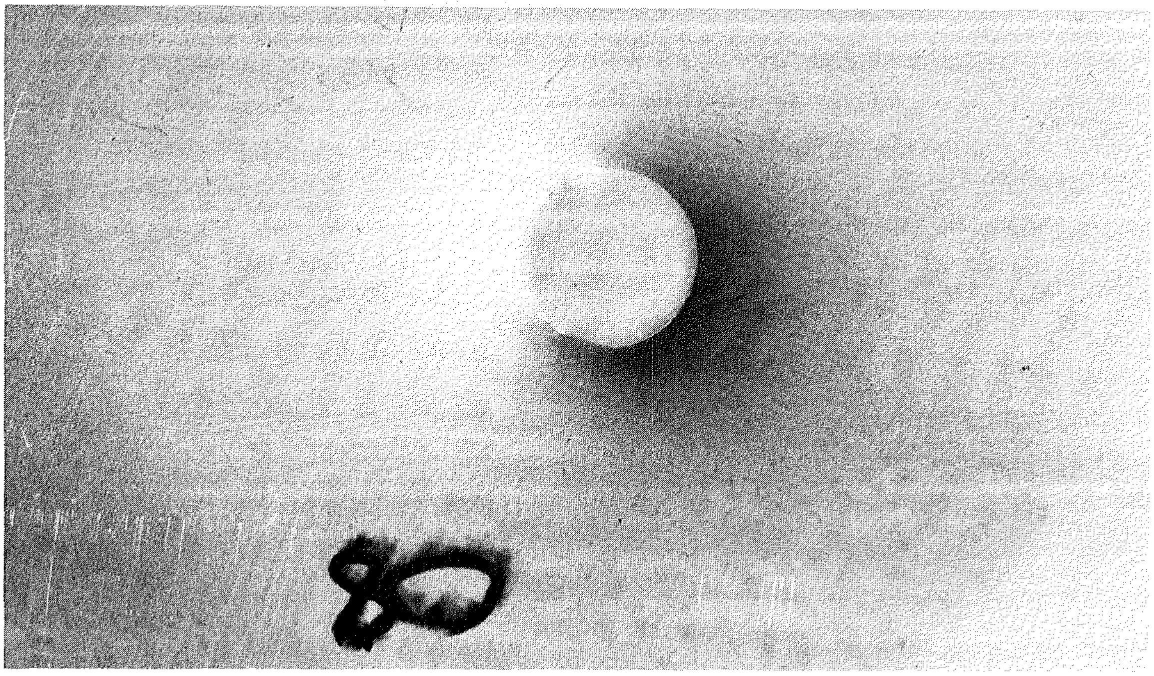


FIGURE B-11 2024-T3 .61 mm (.025") 15.9 mm (5/8") FLAT 95.3 mm (3.75") SUPPORT 9.04 JOULES (80 INCH POUNDS)

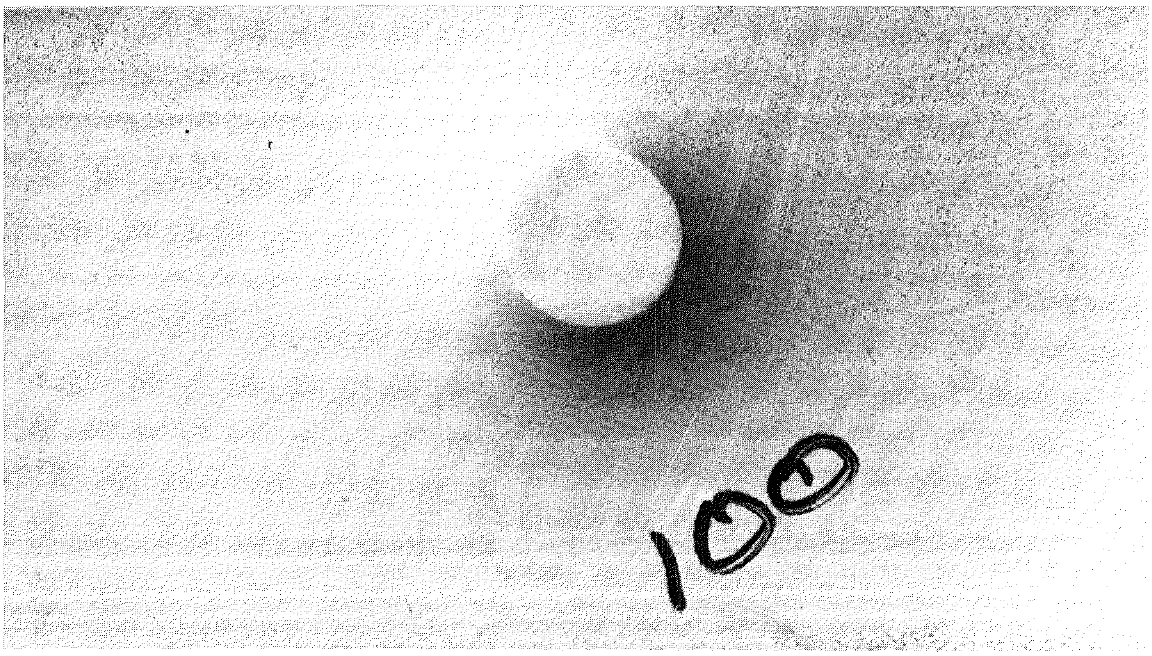


FIGURE B-12 2024-T3 .61 mm (.025") 15.9 mm (5/8") FLAT 95.3 mm (3.75") SUPPORT 11.3 JOULES (100 INCH POUNDS)

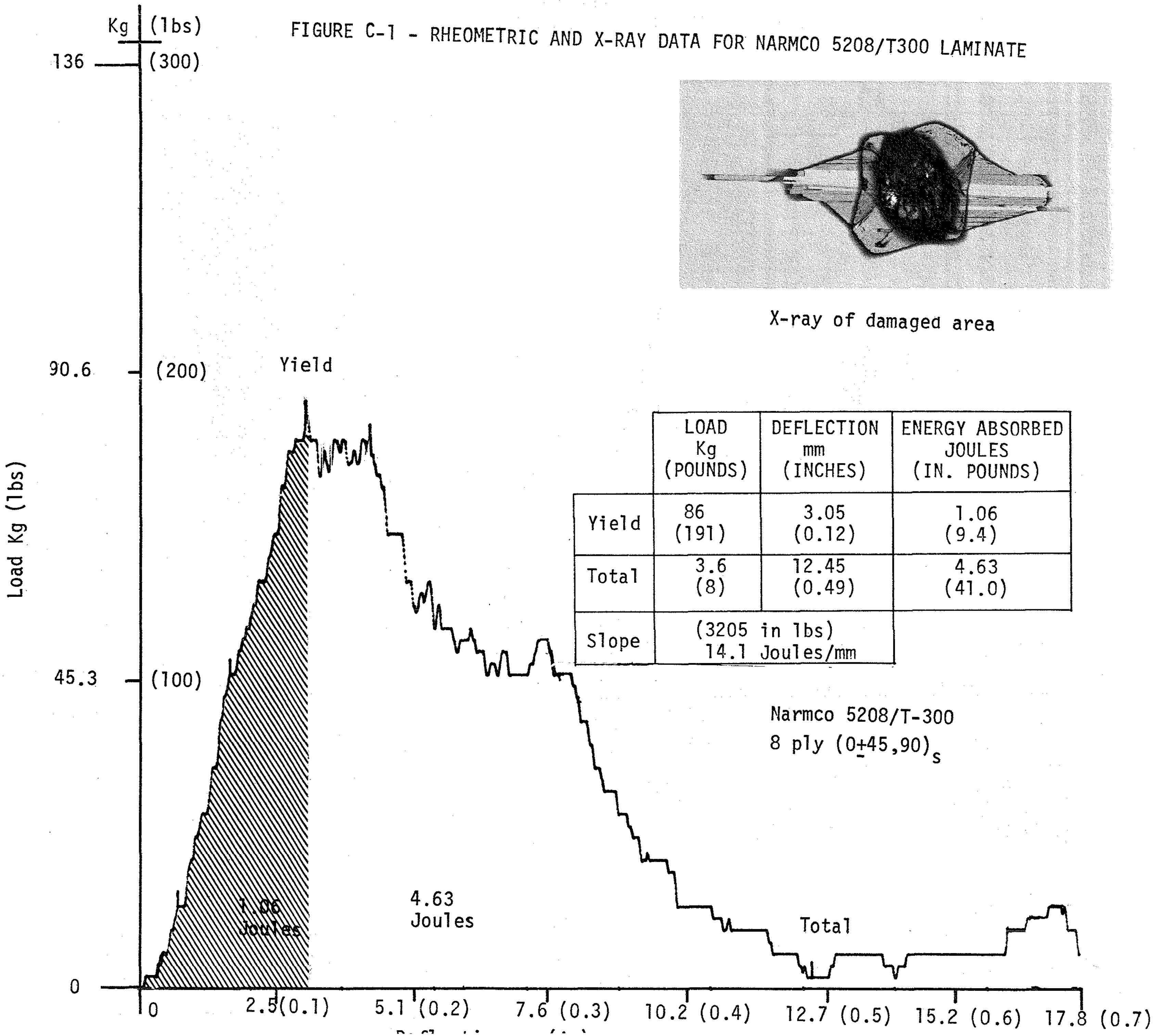
APPENDIX 3

RHEOMETRIC CONSTANT SPEED IMPACT DATA

The Rheometric Constant Speed Penetrating Impact machine load deflection curves, data reduction for slope of curve and impact energy absorbed and X-ray of the damaged areas are recorded for ten materials in Appendix 3. Diiodobutane (DIB) was used to aid X-ray.

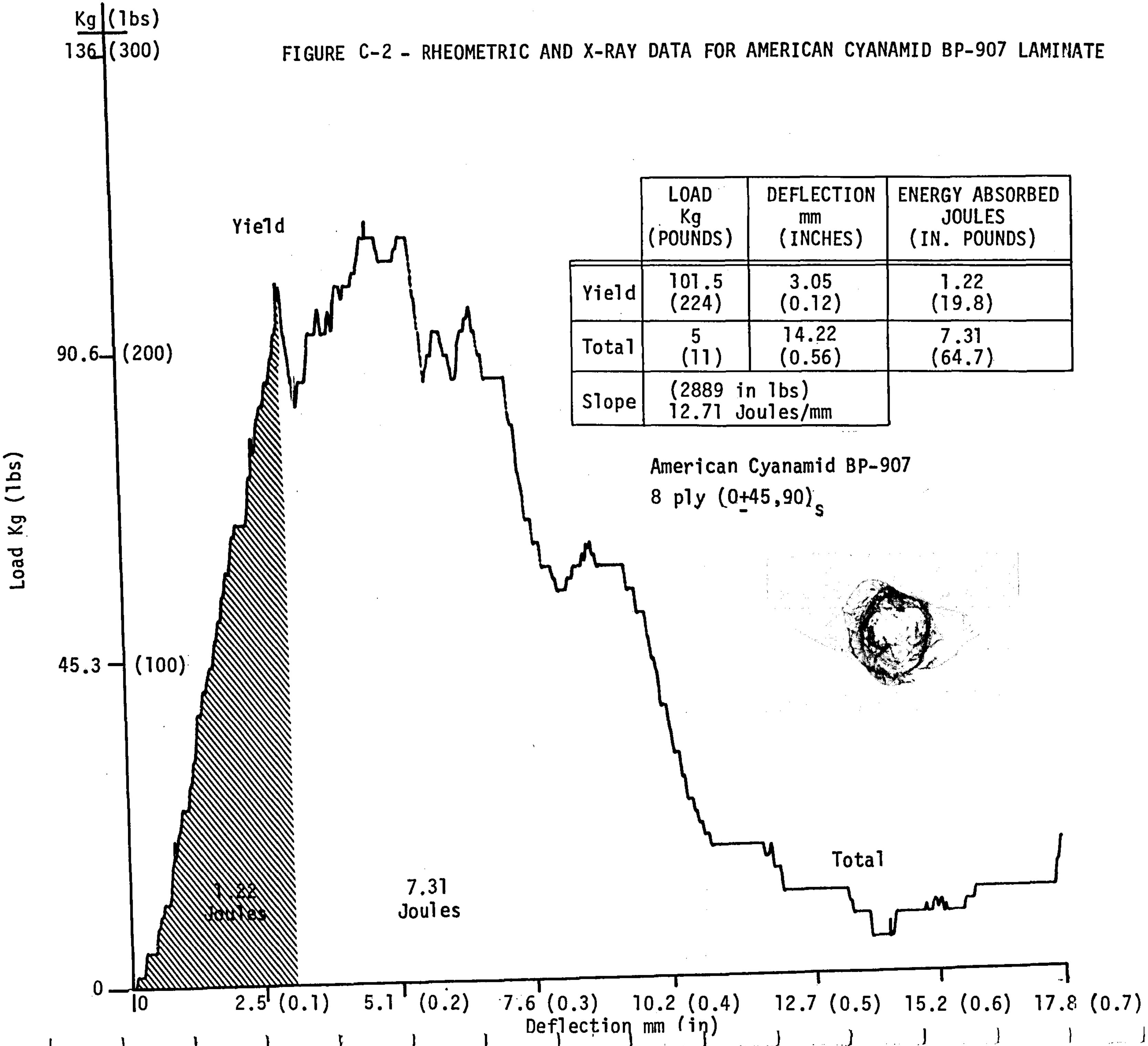
- Narmco 5208
- American Cyanamide BP-907
- Ciba Geigy #4
- Ciba Geigy #1M
- Narmco X1114
- Ciba Geigy Fiberdux 920
- American Cyanamide 982
- Narmco X-107
- American Cyanamide 919
- U. S. Polymeric #2

FIGURE C-1 - RHEOMETRIC AND X-RAY DATA FOR NARMCO 5208/T300 LAMINATE



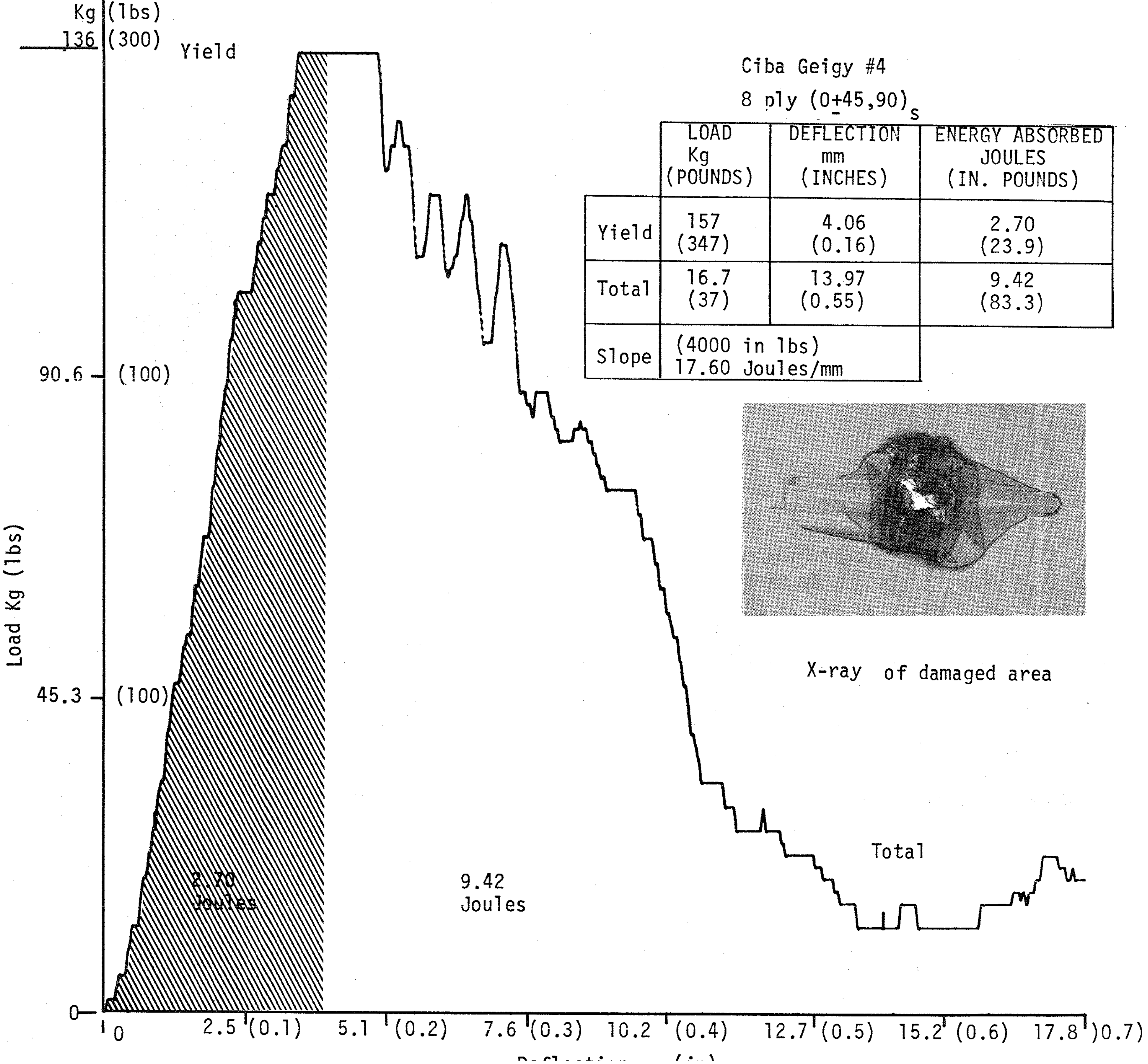
	LOAD Kg (POUNDS)	DEFLECTION mm (INCHES)	ENERGY ABSORBED JOULES (IN. POUNDS)
Yield	86 (191)	3.05 (0.12)	1.06 (9.4)
Total	3.6 (8)	12.45 (0.49)	4.63 (41.0)
Slope	(3205 in lbs) 14.1 Joules/mm		

FIGURE C-2 - RHEOMETRIC AND X-RAY DATA FOR AMERICAN CYANAMID BP-907 LAMINATE



	LOAD Kg (POUNDS)	DEFLECTION mm (INCHES)	ENERGY ABSORBED JOULES (IN. POUNDS)
Yield	101.5 (224)	3.05 (0.12)	1.22 (19.8)
Total	5 (11)	14.22 (0.56)	7.31 (64.7)
Slope	(2889 in lbs) 12.71 Joules/mm		

FIGURE C-3 - RHEOMETRIC AND X-RAY DATA FOR CIBA GEIGY #4



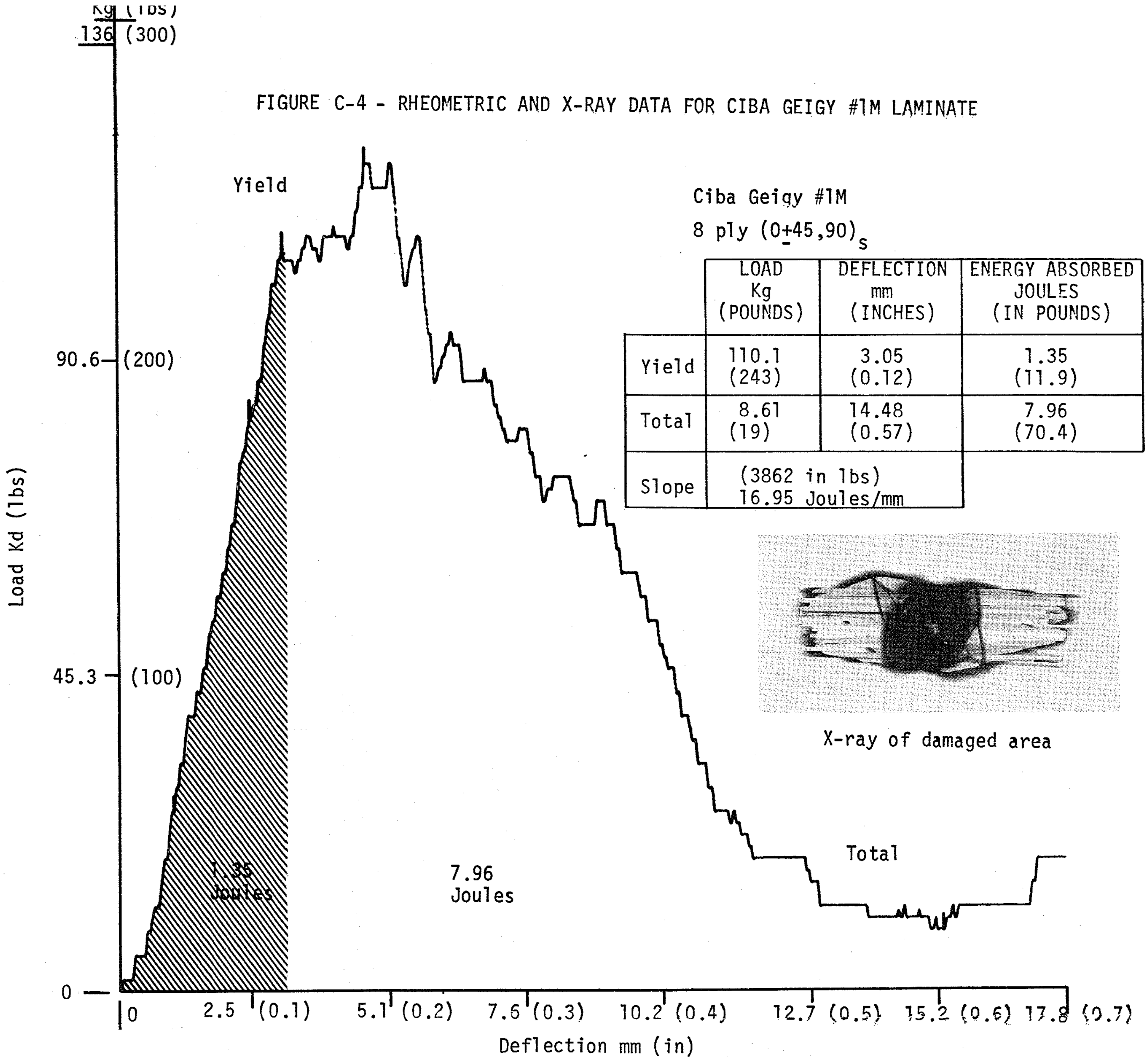
Ciba Geigy #4

8 ply $(0\pm45,90)_s$

	LOAD Kg (POUNDS)	DEFLECTION mm (INCHES)	ENERGY ABSORBED JOULES (IN. POUNDS)
Yield	157 (347)	4.06 (0.16)	2.70 (23.9)
Total	16.7 (37)	13.97 (0.55)	9.42 (83.3)
Slope	(4000 in lbs) 17.60 Joules/mm		

X-ray of damaged area

FIGURE C-4 - RHEOMETRIC AND X-RAY DATA FOR CIBA GEIGY #1M LAMINATE



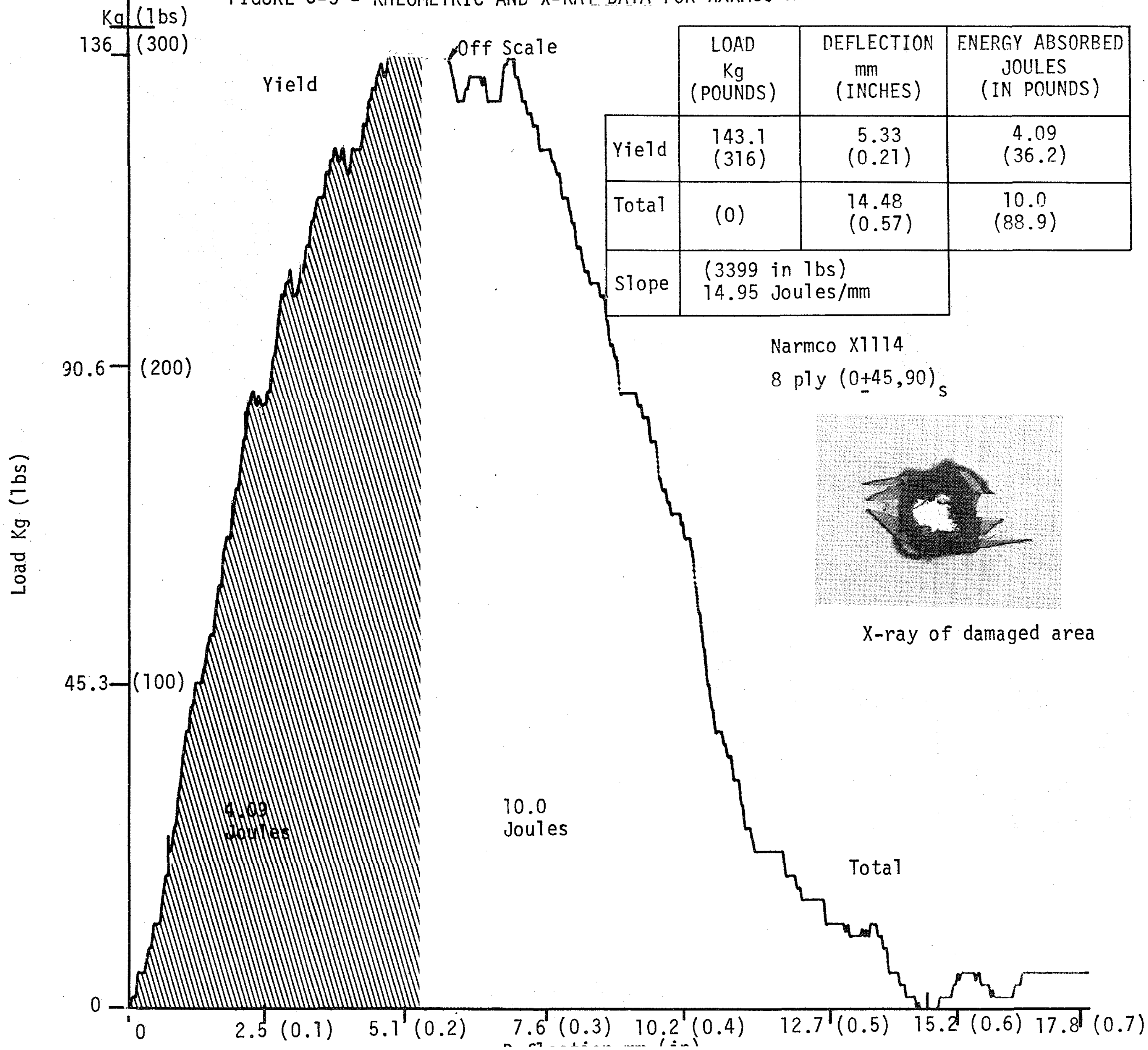
Ciba Geigy #1M

8 ply $(0\pm45,90)_s$

	LOAD Kg (POUNDS)	DEFLECTION mm (INCHES)	ENERGY ABSORBED JOULES (IN POUNDS)
Yield	110.1 (243)	3.05 (0.12)	1.35 (11.9)
Total	8.61 (19)	14.48 (0.57)	7.96 (70.4)
Slope	(3862 in lbs) 16.95 Joules/mm		

X-ray of damaged area

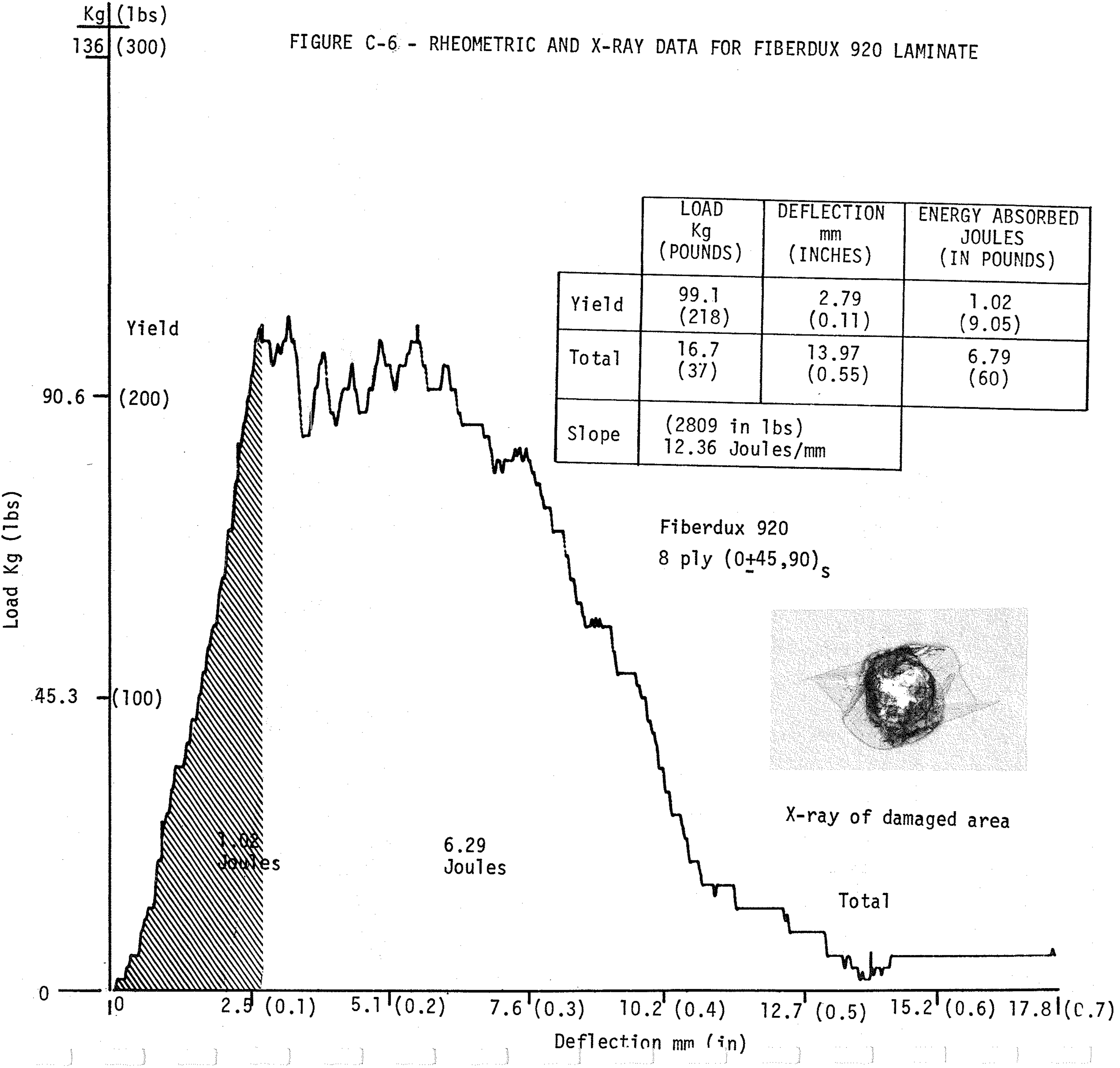
FIGURE C-5 - RHEOMETRIC AND X-RAY DATA FOR NARMCO X1114 LAMINATE



	LOAD Kg (POUNDS)	DEFLECTION mm (INCHES)	ENERGY ABSORBED JOULES (IN POUNDS)
Yield	143.1 (316)	5.33 (0.21)	4.09 (36.2)
Total	(0)	14.48 (0.57)	10.0 (88.9)
Slope	(3399 in lbs) 14.95 Joules/mm		

X-ray of damaged area

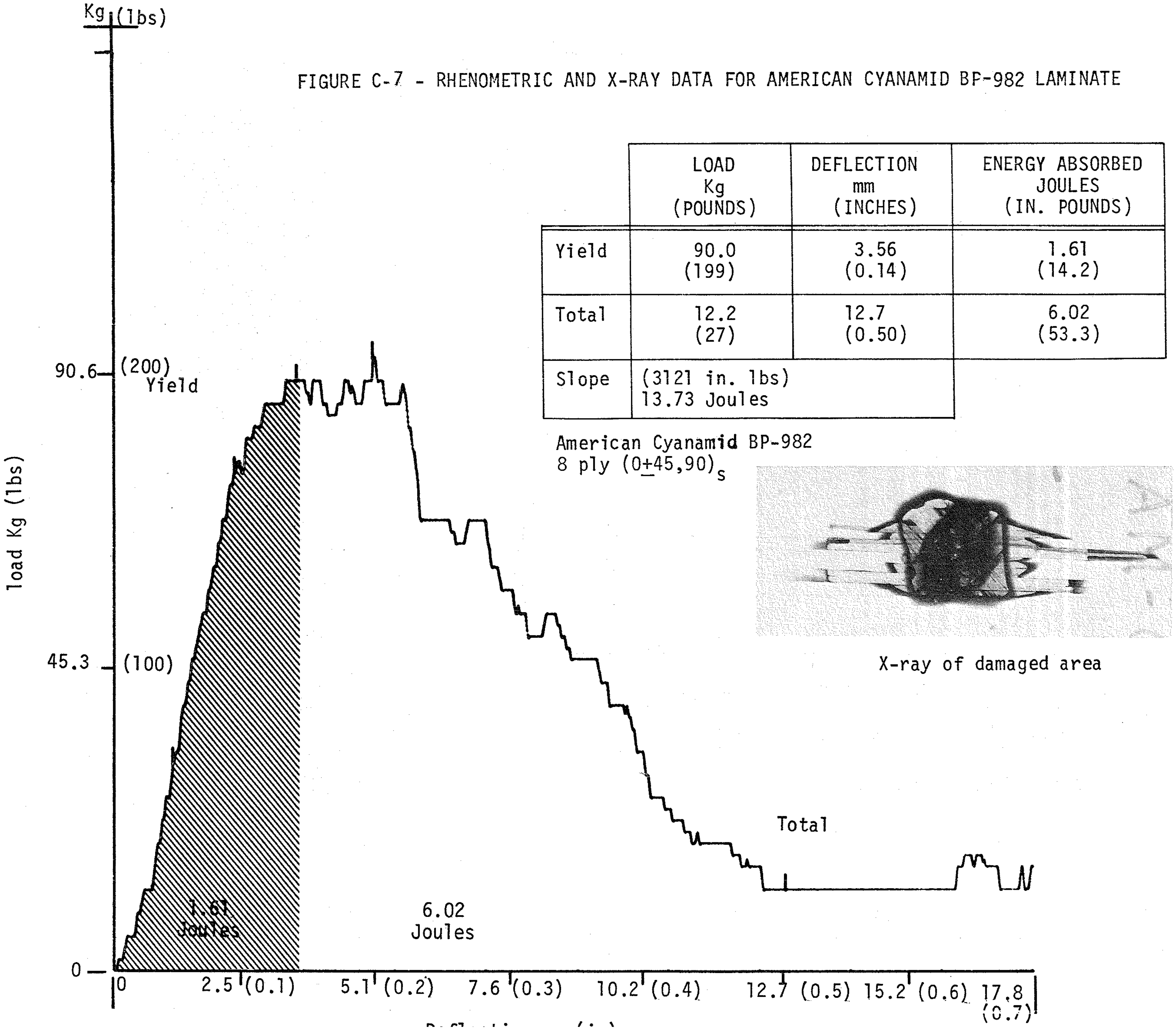
FIGURE C-6 - RHEOMETRIC AND X-RAY DATA FOR FIBERDUX 920 LAMINATE



X-ray of damaged area

	LOAD Kg (POUNDS)	DEFLECTION mm (INCHES)	ENERGY ABSORBED JOULES (IN POUNDS)
Yield	99.1 (218)	2.79 (0.11)	1.02 (9.05)
Total	16.7 (37)	13.97 (0.55)	6.79 (60)
Slope	(2809 in lbs) 12.36 Joules/mm		

FIGURE C-7 - RHENOMETRIC AND X-RAY DATA FOR AMERICAN CYANAMID BP-982 LAMINATE



	LOAD Kg (POUNDS)	DEFLECTION mm (INCHES)	ENERGY ABSORBED JOULES (IN. POUNDS)
Yield	90.0 (199)	3.56 (0.14)	1.61 (14.2)
Total	12.2 (27)	12.7 (0.50)	6.02 (53.3)
Slope	(3121 in. lbs) 13.73 Joules		

American Cyanamid BP-982
8 ply $(0\pm45,90)_S$

X-ray of damaged area

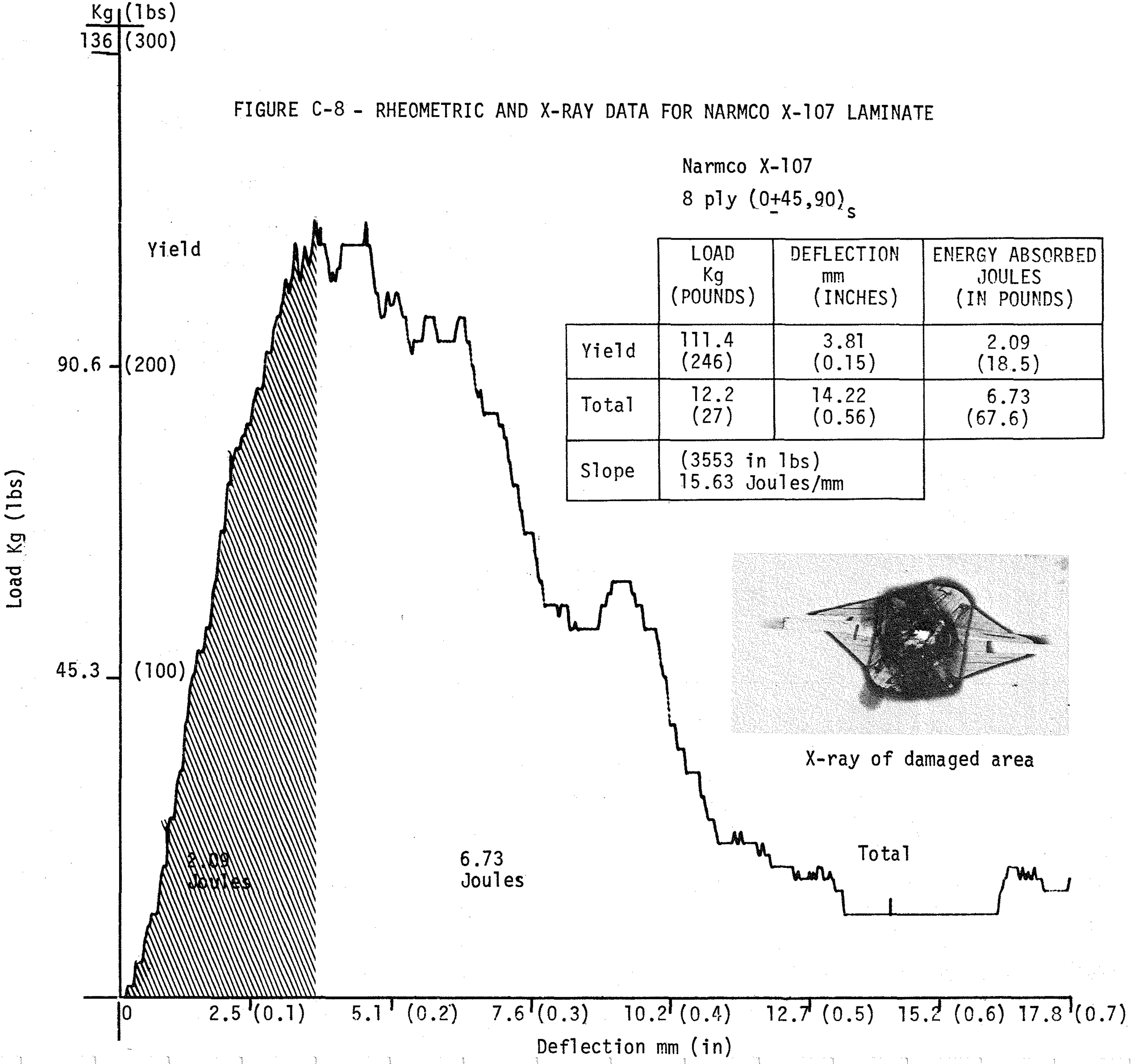


FIGURE C-8 - RHEOMETRIC AND X-RAY DATA FOR NARMCO X-107 LAMINATE

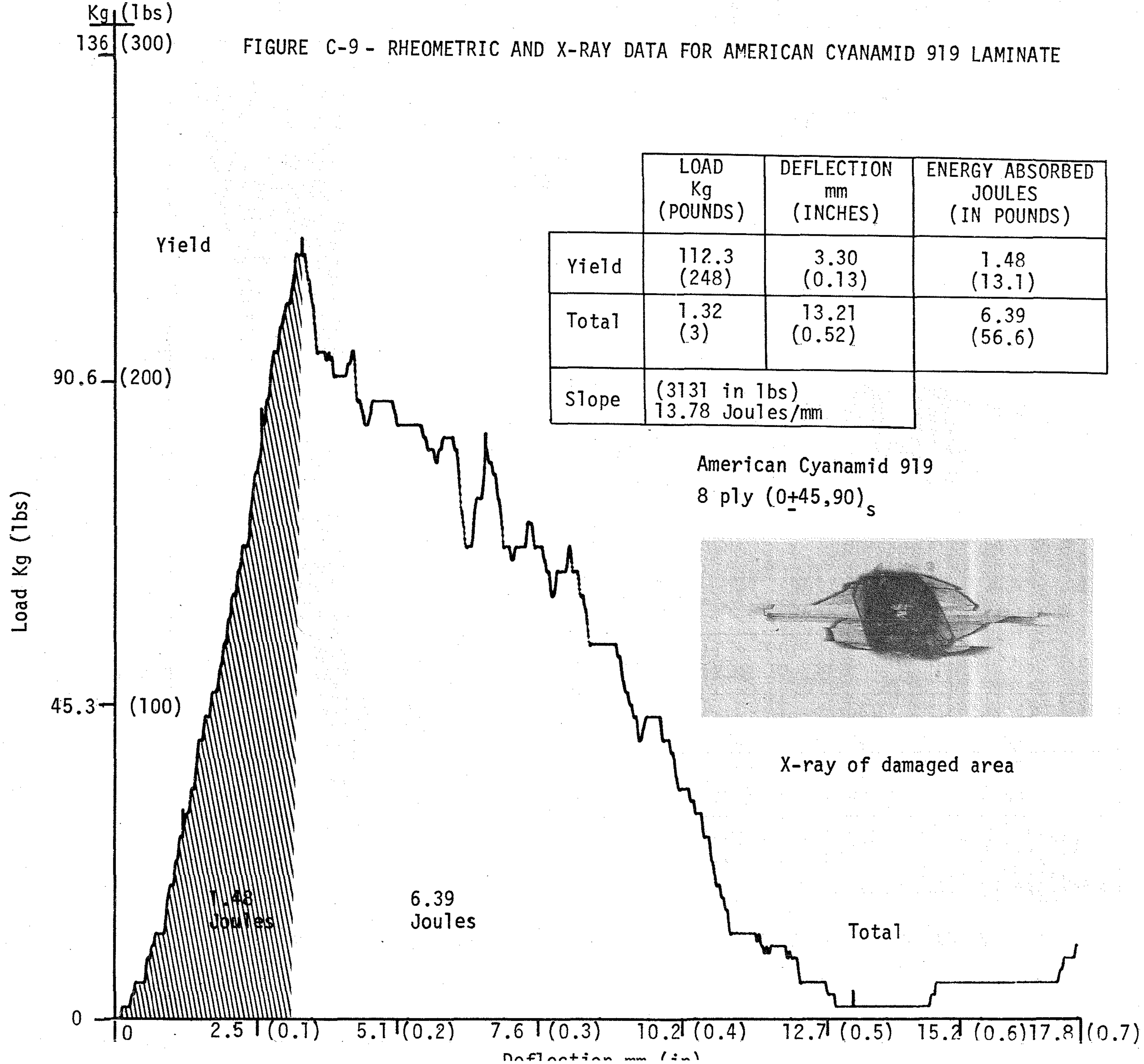
Narmco X-107

8 ply $(0\pm45,90)_s$

	LOAD Kg (POUNDS)	DEFLECTION mm (INCHES)	ENERGY ABSORBED JOULES (IN POUNDS)
Yield	111.4 (246)	3.81 (0.15)	2.09 (18.5)
Total	12.2 (27)	14.22 (0.56)	6.73 (67.6)
Slope	(3553 in lbs) 15.63 Joules/mm		

X-ray of damaged area

FIGURE C-9 - RHEOMETRIC AND X-RAY DATA FOR AMERICAN CYANAMID 919 LAMINATE



	LOAD Kg (POUNDS)	DEFLECTION mm (INCHES)	ENERGY ABSORBED JOULES (IN POUNDS)
Yield	112.3 (248)	3.30 (0.13)	1.48 (13.1)
Total	1.32 (3)	13.21 (0.52)	6.39 (56.6)
Slope	(3131 in lbs) 13.78 Joules/mm		

American Cyanamid 919
8 ply $(0 \underline{+} 45, 90)_s$

X-ray of damaged area

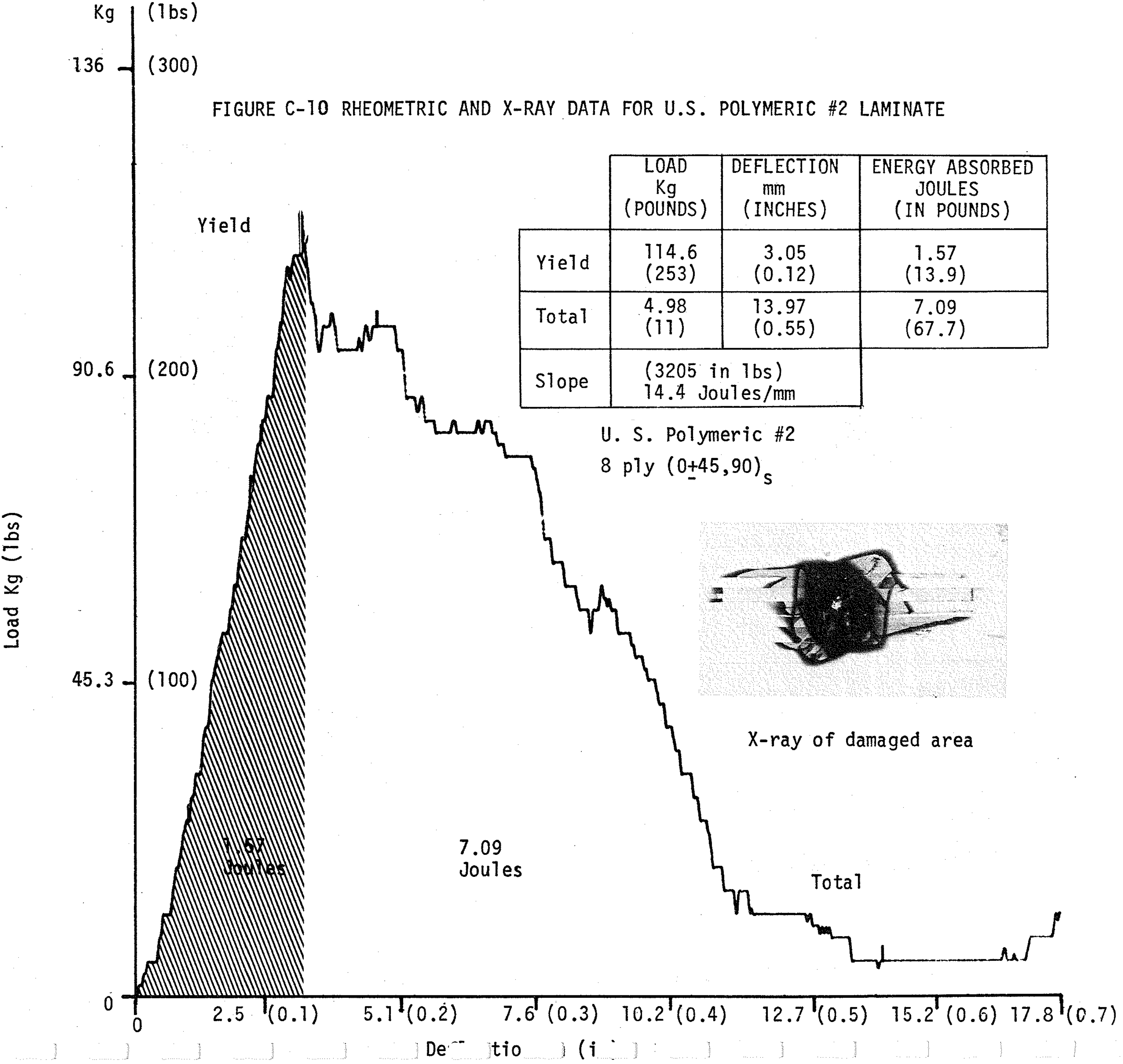


FIGURE C-10 RHEOMETRIC AND X-RAY DATA FOR U.S. POLYMERIC #2 LAMINATE

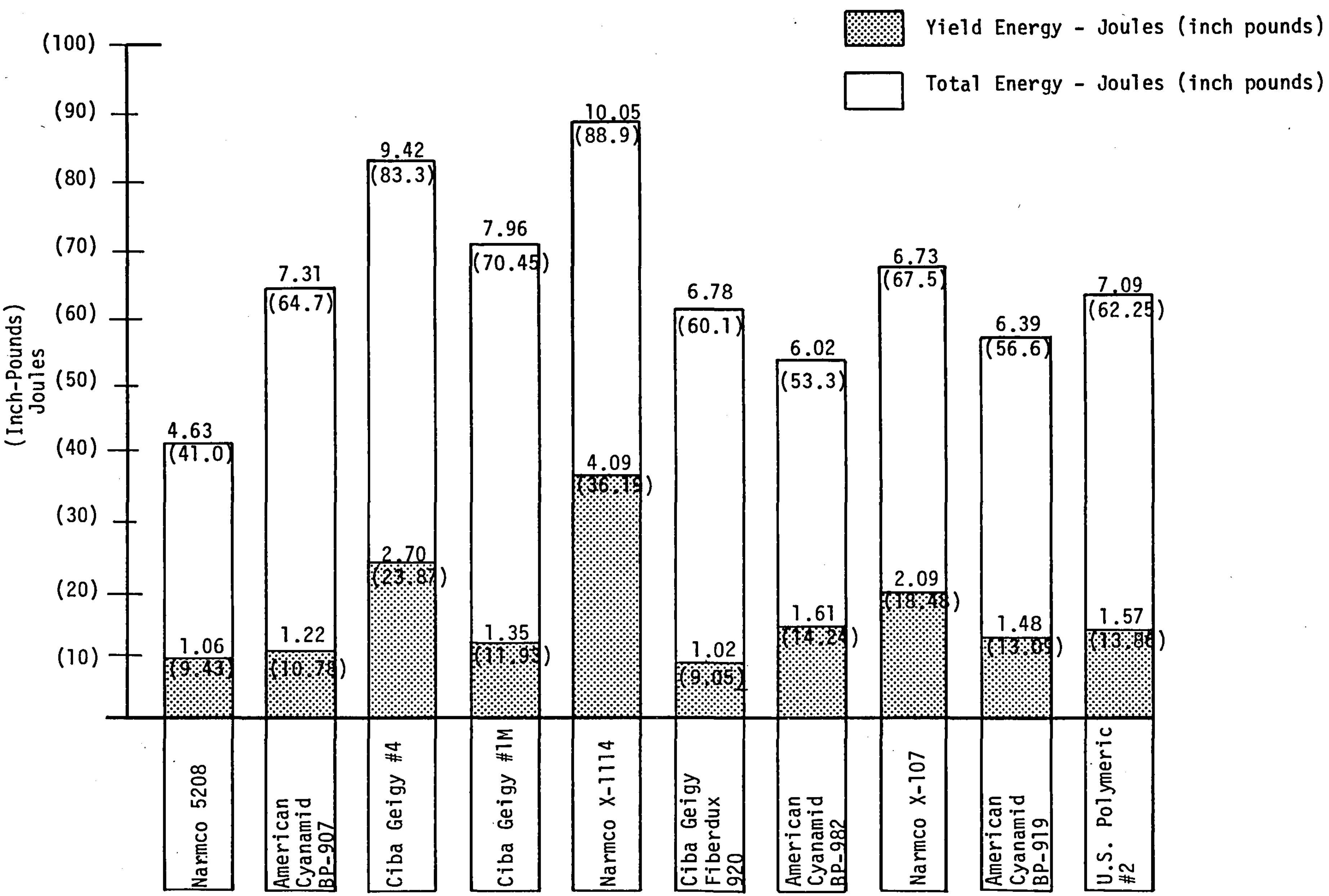
	LOAD Kg (POUNDS)	DEFLECTION mm (INCHES)	ENERGY ABSORBED JOULES (IN POUNDS)
Yield	114.6 (253)	3.05 (0.12)	1.57 (13.9)
Total	4.98 (11)	13.97 (0.55)	7.09 (67.7)
Slope	(3205 in lbs) 14.4 Joules/mm		

U. S. Polymeric #2

8 ply $(0\underline{+}45,90)_s$

X-ray of damaged area

FIGURE C-11 SUMMARY RHEOMETRIC IMPACT



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