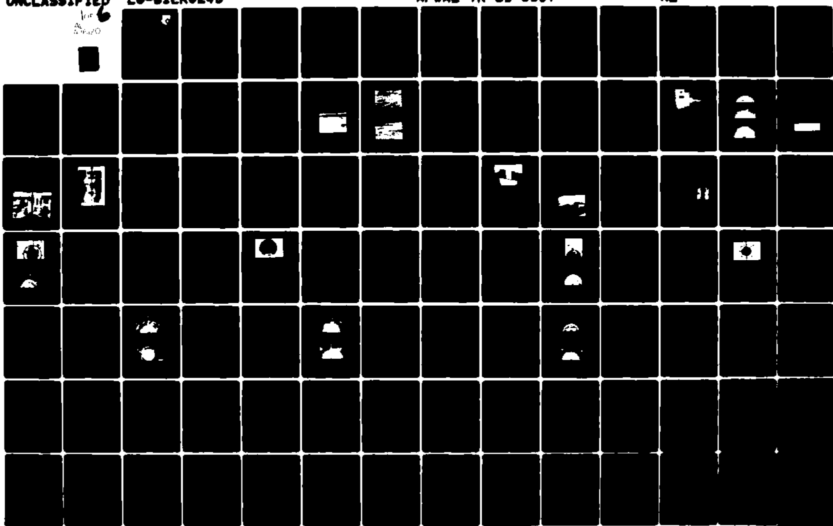
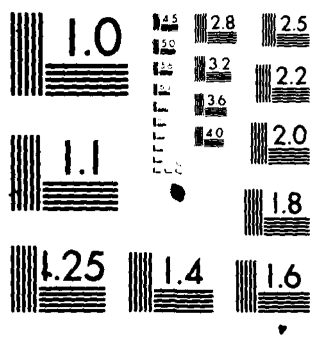
AD-A116 120 LOCKHEED-GEORGIA CO MARIETTA F/G 11/4
DAMAGE PROGRESSION IN GRAPHITE-EPOXY BY A DEPLYING TECHNIQUE.(U)
DEC 81 S M FREEMAN F33615-80-C-3224

UNCLASSIFIED LG-81ER0245 AFWAL-TR-81-3157 NL

1 of 6
AD A116120



116120



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 1963 A

ADA116120 (2)

AD A116120

AFWAL-TR-81-3157

DAMAGE PROGRESSION IN GRAPHITE-EPOXY BY A DEPLYING TECHNIQUE

S. M. FREEMAN

Lockheed-Georgia Company
A Division of Lockheed Corporation
Marietta, Georgia 30063

December 1981

FINAL REPORT FOR PERIOD
JUNE 1980 TO DECEMBER 1981

Approved for public release; distribution unlimited.

FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

George P. Sendeckyj

GEORGE P. SENDECKYJ, Aerospace Engineer
Fatigue, Fracture & Reliability Group

Davey L. Smith

DAVEY L. SMITH, Chief
Structural Integrity Branch

FOR THE COMMANDER

Ralph L. Kuster Jr.

RALPH L. KUSTER, JR., Colonel, USAF
Chief, Structures and Dynamics Division
Flight Dynamics Laboratory

"If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify AFWAL/FIBEC *W-PAFB, OH 45433 to help us maintain a current mailing list".*

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

AIR FORCE/56780/18 June 1982 — 400

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFWAL-TR-81-3157	2. GOVT ACCESSION NO. AD-A116 120	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DAMAGE PROGRESSION IN GRAPHITE-EPOXY BY A DEPLYING TECHNIQUE		5. TYPE OF REPORT & PERIOD COVERED Final Report June 1980 - December 1981
		6. PERFORMING ORG. REPORT NUMBER LG 81ER0245
7. AUTHOR(s) S. M. Freeman		8. CONTRACT OR GRANT NUMBER(s) F33615-80-C-3224
9. PERFORMING ORGANIZATION NAME AND ADDRESS Lockheed-Georgia Company Marietta, Georgia		10. PROGRAM ELEMENT PROJECT, TASK AREA & WORK UNIT NUMBERS PE 61101F PROJECT 0100 WORK UNIT 24010148
11. CONTROLLING OFFICE NAME AND ADDRESS Flight Dynamics Laboratory (AFWAL/FIBE) AF Wright Aeronautical Laboratories, AFSC Wright-Patterson Air Force Base, Ohio 45433		12. REPORT DATE December 1981
		13. NUMBER OF PAGES 507
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) N/A		
18. SUPPLEMENTARY NOTES N/A		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) COMPOSITES GRAPHITE-EPOXY NONDESTRUCTIVE EVALUATION (NDE)	DAMAGE ACCUMULATION BOLTED JOINTS DEPLYING ACOUSTIC EMISSION MONITORING PENETRANT ENHANCED X-RAY RADIOGRAPHY	

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

Open hole and mechanically fastened joint specimens employing three different symmetric stacking sequences were used for this project. Replicates for each specimen type and stacking sequence were loaded to ultimate and four load levels below ultimate to produce specimens containing progressive amounts of damage. During loading of each specimen Acoustic Emissions (AE) were monitored as a function of load. Specimens from each of the four load levels were inspected for matrix cracking, delamination and fiber bundle fractures using →

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) penetrant enhanced X-ray radiography and the deply technique. The deply technique, a unique but destructive inspection method, was used to separate the graphite-epoxy composite into its individual laminae while maintaining the integrity of each lamina. With the application of a gold chloride penetrant before deplying, the internal matrix damage as well as fiber bundle fracture could be readily observed on the surface of the individual laminae. These damage observations were recorded on a Lamina Damage Characterization Chart for each specimen. These charts contain pictorial sketches, with fiber orientations shown, for each lamina of the specimen segment deplied.

A summary of the inspection results including photomacrographs of typical observed damage along with examples of charted damage is presented in the main body of the report. Detail inspection results are presented in a separate appendix for each set of specimens. These results are presented in the form of figures which include prints of radiographs, plots of accumulative AE events vs load and Lamina Damage Characterization Charts.

FOREWORD

This technical report was prepared by the Materials Sciences and Testing Laboratory Department of the Lockheed-Georgia Company, Marietta, Georgia, under USAF Contract F33615-80-C-3224, Project 0100, Work Unit 24010148. The program was administered under the direction of the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio 45433. Dr. G. P. Sendeckyj (AFWAL/FIBE) was the Air Force Project Monitor.

Mr. S. M. Freeman was the principal investigator. Other Lockheed-Georgia Company personnel associated with the program and their respective areas of responsibility include:

C. D. Bailey and W. M. Pless, Acoustic Emission

R. T. Beall, Specimen Fabrication

Dr. R. T. Cole, Structural Analysis

G. J. Gilbert, Mechanical Testing

This report is also identified as LG81ER0245 for Lockheed internal control purposes.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

PRECEDING PAGE BLANK-NOT FILMED

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF TABLES

SECTION I
INTRODUCTION

1. HISTORICAL BACKGROUND

In the case of metallic structure the procedures for assessing damage are well defined, and a good correlation can usually be made between nondestructive evaluations and a post-failure metallurgical examination. Evidence of damage progression is generally evident on the fracture surfaces and in many cases can be interpreted down to the individual load cycles. Unfortunately, these procedures are not applicable to failed graphite-epoxy composite structure. The damage accumulation process for graphite-epoxy composite is extremely complicated and consists of matrix cracks parallel to the fiber direction, delaminations, and fiber fractures. In most cases fiber fracture could be verified only after catastrophic failure had occurred. In this case evidence of fiber fracture progression was either lost or beyond current technology to assess. Probably the most common nondestructive inspection (NDI) method for detailed damage assessment is conventional enhanced x-ray radiography using tetrabromoethane (TBE) as the enhancement medium (ref. 1). This technique reveals matrix cracks, delaminations, and on occasions indications that can be interpreted (subjectively) as fiber fracture but only in a planar distribution. Although informative, these radiographs do not give a precise through-the-thickness location of damage. Microscopic studies of polished cross sections of the composite can reveal microcracks between lamina, matrix cracks within a lamina, delaminations, and fiber fracture but only as exhibited in the plane of the cross-section. This technique is tedious, time consuming, and always carries the risk of destroying fiber fracture features in the sectioning operation. Fully visualizing the extent of early onset of fiber fracture using the polished section technique leaves much to be desired. A technique using a dye penetrant combined with careful grinding away of successive laminae has been reported (ref. 2). Likewise this technique is tedious, time consuming, and the laminae are destroyed in the process.

Details of fracture modes as they occur and progress through the various laminae of graphite-epoxy composite are needed to support development of predictive analytical methods to design efficient composite structure that conforms to the structural integrity policy of the Air Force. Therefore, the real need is to determine the precise location of fiber fracture, delaminations, and matrix cracks to provide for better interpretation of radiographs and to provide the analyst with accurate knowledge of damage initiation and progression. In late 1976 the "deply" technique was conceived and experimental development initiated at the Lockheed-Georgia Company. This technique, a partial pyrolysis of the resin matrix, permits the individual laminae to be separated without destroying fiber fracture features. In late 1978 a complimentary technique was conceived at the Lockheed-Georgia Company for marking matrix cracks and delaminations. Experimental development of the marking technique continued into 1979. By midyear 1979 it was possible to apply a penetrant of gold chloride in diethyl ether to a piece of graphite-epoxy before deplying and mark the matrix cracks and delaminations that were connected to the surface or edge of the composite. Thus a destructive inspection procedure was now available for precisely locating fiber fracture on a lamina basis and determining the exact interlaminar location and size of delaminations. As a result of these technical accomplishments the Lockheed-Georgia Company was awarded this contract.

2. PROGRAM OBJECTIVES

The program objectives were as follows:

- To demonstrate a destructive inspection procedure for finding fiber fracture and matrix damage in graphite-epoxy composites.

- To use this procedure in conjunction with acoustic emission and penetrant enhanced x-ray nondestructive inspection methods to provide a complete description of damage produced around loaded holes in graphite-epoxy composites.

3. DESCRIPTION OF PROGRAM

The program to be reported later herein consisted of four tasks, and a brief description of each follows.

- Task I - Specimen Fabrication

Twenty-four-ply laminates were fabricated in three distinct symmetric laminate stacking sequences from the same lot of Hercules AS1/3501-6 350°F curing graphite-epoxy prepreg tape. The density and resin content was determined for each of the three stacking sequences. Specimen details for each of two basic types, open hole and mechanically fastened joint, were removed from the laminate panels of each stacking sequence. Specimen configurations are shown in Figures 1 and 2. A summary of specimen types, laminate configuration, and quantity produced is presented in Table 1. Upon completion of machining and drilling, the specimen details were inspected for fabrication-induced damage using TBE enhanced x-ray radiography. In addition, two specimens selected at random from each of eight sets were destructively inspected (deplied) for fabrication-induced fiber fractures.

- Task II - Introduction of Load-Induced Damage

For each of the eight sets of specimens shown in Table I, five replicate specimens, selected at random, were loaded in tension to failure. During loading of each specimen acoustic emission was monitored as a function of load. Based on these data, acoustic emission (AE) and ultimate load, 4 load levels were selected for the remaining 20 specimens in each group. The lowest load level (A) was somewhat higher than the load at which the first significant damage occurred according to (AE) data. The highest load level (B) was 90% of the minimum failure load for that set. Two other load levels (C & D) were approximately equally spaced between load levels A and B. All specimens were loaded in the same MTS 880 automated test system. Acoustic emission was monitored as a function of load during the loading of each specimen. Upon reaching the required load level the specimen was unloaded at the same rate as it was loaded.

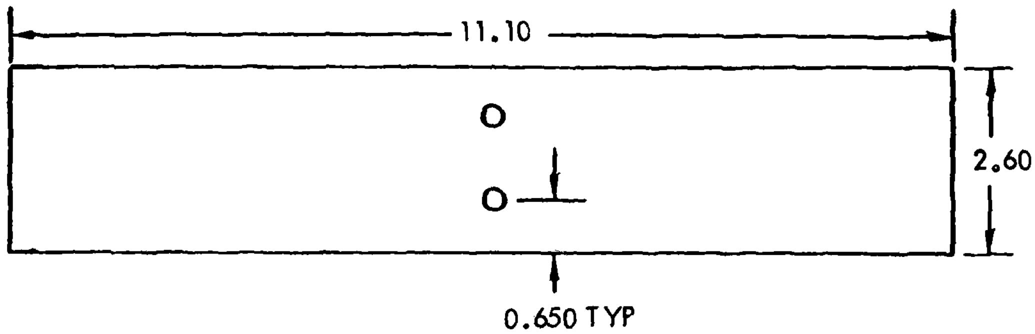
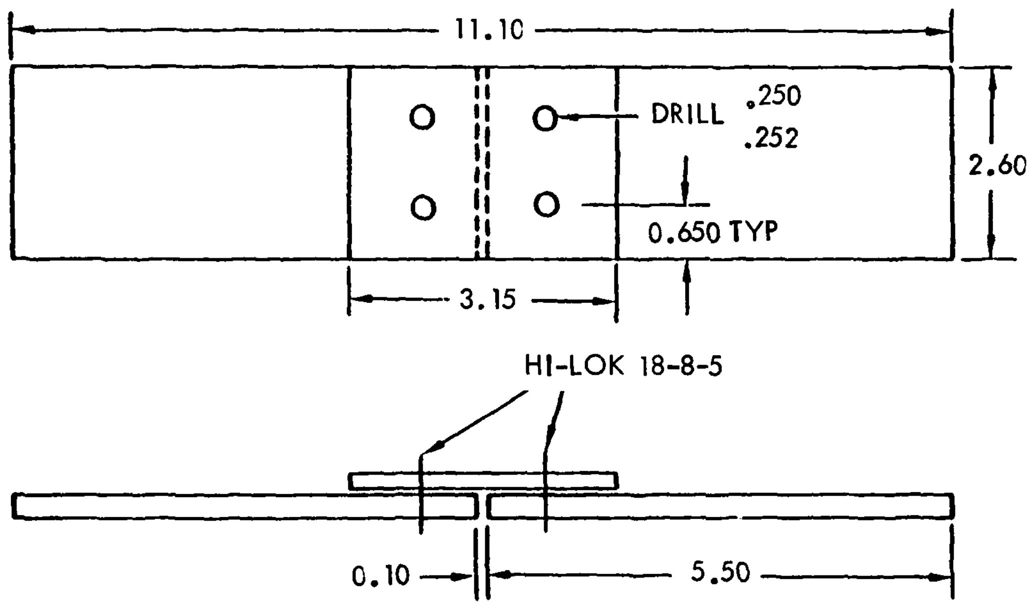


Figure 1. Configuration of Open Hole Specimen



NOTE: STRAPS AND SPLICE PLATE ARE THE SAME LAMINATE CONFIGURATION

Figure 2. Configuration of Mechanically Fastener Joint Specimen

TABLE 1

SUMMARY OF SPECIMEN TYPES, LAMINATE CONFIGURATIONS AND QUANTITY PRODUCED

SPECIMEN TYPE	LAMINATE CONF. (1)	EDGE DISTANCE	HOLE/ FASTENER	NUMBER OF SPECIMENS
I OPEN HOLE	A	NA	STRAIGHT	27
	B	NA	STRAIGHT	27
	C	NA	STRAIGHT	27
IIA BOLTED JOINT	A	2	BUTTON HEAD	27
	B	2	BUTTON HEAD	27
	C	2	BUTTON HEAD	27
IIB BOLTED JOINT	A	3	BUTTON HEAD	27
	C	3	BUTTON HEAD	27

(1) LAMINATE CONFIGURATIONS

LAMINATE A $(\pm 45°, 0_2, \mp 45°, 0_2, \pm 45°, 0_2)s$ -17 LAMINAE

LAMINATE B $(\pm 45°, \mp 45°, \pm 45°, 0_6)s$ - 9 LAMINAE

LAMINATE C $(\pm 45°, 0, 90, \mp 45°, 0, 90, \pm 45°, 0, 90)s$ -23 LAMINAE o Task III - Damage Assessment by X-ray Radiography and Deply Technique

The test areas of all specimens subjected to a load level below ultimate were inspected using TBE enhanced x-ray radiography to determine the extent of matrix cracking, delaminations, and fiber fractures. Penetrant enhanced stereo x-ray pairs were prepared for one specimen from each set and load level. After completion of enhanced x-ray radiography, a gold chloride solution was applied to the hole walls and the specimen deplied. The individual laminae of each specimen were then observed under a microscope for fiber fracture and indications of delaminations and matrix cracks. Damage features observed were recorded using two methods, charts and photographs. The chart method for each specimen contains a pictorial sketch, with fiber orientations shown, for each lamina of the deply area. In the case of the mechanically fastened joint specimens, an outline of the fastener heads is shown on the lamina sketches. As each lamina was examined the damage observed was marked on the appropriate sketch. This method provides at a glance the relationship of fiber fractures and indications of delaminations and matrix cracks. Photomacrographs typical of fiber bundle fractures and matrix damage indications in laminae of different orientations and stack positions were made to provide the needed clarity for understanding the damage characterization charts.

o Task IV - Inspection Results

The inspection results are summarized in Section 2 of this report. This summary includes photomacrographs of typical observed damage along with examples of charted damage of the same area. The detail results of the inspections are presented in the form of figures. These figures include prints of radiographs, plots of accumulative AE events vs. load and damage characterization charts. The figures for these detail results are presented in a separate appendix for each set of specimens.

4. SUMMARY

o Destructive Inspection

The following details of damage accumulation can be found at the lamina and interlaminae level using a gold-chloride penetrant in combination with the deply technique:

1. The precise locations of delaminations and their sizes and configurations.

2. Matrix crack indications or splitting.

3. Fiber-bundle fractures as small as 0.5mm in length.

o Acoustic Emission Monitoring

In the case of the open hole specimens, AE monitoring results and deply damage analysis showed rather close agreement. The AE data for the bolted joints gave a rough correlation with the total damage revealed in the deply analysis of one strap segment. In both types of specimens, AE data proved to be a good indicator of significant matrix and fiber-damage initiation and total relative damage.

o Penetrant-Enhanced X-Ray Radiography

Delaminations, matrix cracks, and saw-tooth fiber fractures are easily identified, although one may have to use a pocket magnifier to see the saw-tooth effect. Overlapping delaminations can obscure configuration details as well as matrix cracks and small fiber fractures.

SECTION II
EXPERIMENTAL

1. TASK I - SPECIMEN FABRICATION

(A) Laminate Panel Fabrication

Two 24-ply laminates were fabricated for each of three laminate configurations to provide specimen details. They were fabricated from the same lot of 12-inch-wide Hercules AS1/3501-6 preimpregnated graphite-epoxy tape. The orientations and stacking sequences are presented in Table 2.

TABLE 2.
STACKING SEQUENCE FOR LAMINATE CONFIGURATIONS

LAMINATE CONFIGURATIONS	STACKING SEQUENCE	NO. OF LAMINAE
A	$(\pm 45^\circ/0^\circ_2/\mp 45^\circ/0_2^\circ/\pm 45^\circ/0^\circ_2)_s$	17
B	$(\pm 45^\circ/\mp 45^\circ/\pm 45^\circ/0_6^\circ)_s$	9
C	$(\pm 45^\circ/0^\circ/90^\circ/\mp 45^\circ/0^\circ/90^\circ/\pm 45^\circ/0^\circ/90^\circ)_s$	23

The two panels for each configuration were laid up consecutively, placed adjacent to one another on the autoclave platen and cured under the same vacuum bag. The laminates were produced with controlled resin bleed processing, and the cure cycle was in general accordance with the manufacturers recommendations. A 15-ply control panel was processed and cured with each autoclave load.

Ultrasonic C-scans were made of the entire area of each panel and microscopic cross sections were removed at selected locations. The first lot of panels produced contained excessive porosity. These panels were produced from lot 1585 during July 1980 and were rejected as unsuitable for specimen details. After conducting numerous processing tests on lot 1585 and lot 1643, some in conjunction with Hercules, a new lot of material (lot 1699) was obtained in the latter part of October 1980. Laminates produced from this lot (1699) were satisfactory for fabrication of specimen details as evidenced by C-scans and microscopic cross-sections. Microscopic cross sections typical for each laminate configuration are shown in Figures 3, 4, and 5. The density, resin content, and thickness per ply for each of the laminates are given in Table 3. For each autoclave load longitudinal flexure and horizontal shear tests were conducted on specimens removed from the control panels. In addition, tensile specimens were removed from one of the 24-ply panels of each autoclave load. The results of these tests are presented in Table 4.

The specimen layout for each laminate configuration is shown in Figures 6 and 7. The number shown for each specimen area was marked on the panel prior to cutting the specimen from the panel.

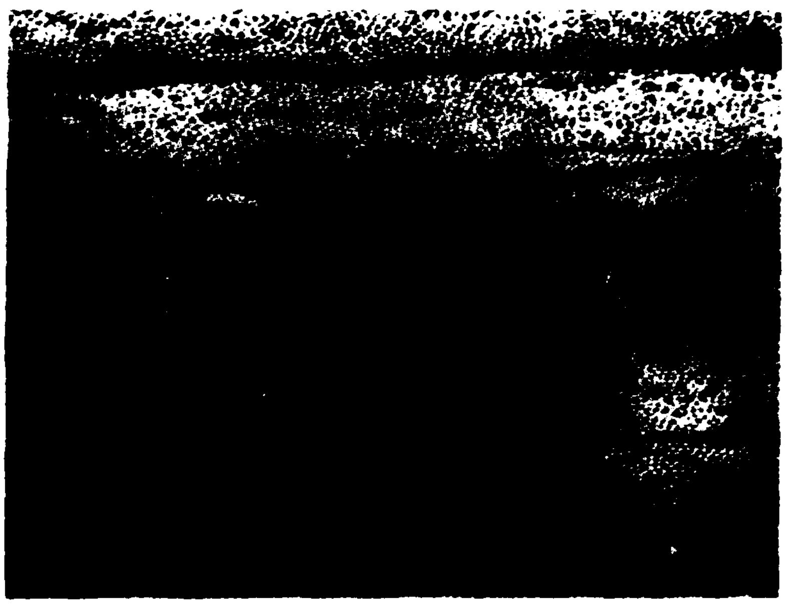


Figure 3. Microscopic Cross Section of Laminate A

Figure 4. Microscopic Cross Section of Laiminate B

Figure 5. Microscopic Cross Section of Laminate C

TABLE 3

SUMMARY OF PHYSICAL PROPERTIES FOR EACH LAMINATE CONFIGURATION

LAMINATE CONFIGURATION	DENSITY	BY WT. RESIN CONTENT	THICKNESS PER PLY (INCHES)
A	1.61	31.58	0.00558
B	1.60	32.69	0.00575
C	1.61	30.66	0.00554

TABLE 4

SUMMARY OF CONTROL TEST VALUES

AUTOCLAVE LOAD LAMINATE PANEL	15 PLY PROCESS CONTROL PANEL LONGITUDINAL FLEXURE KSI	$E \times 10^6$ PSI	HORIZONTAL SHEAR KSI	24 PLY BASIC PANEL TENSILE STRENGTH KSI	$E \times 10^6$ PSI
A	248	18.1	15.3	150	10.8
B	249	18.2	15.2	149	10.7
C	255	18.7	16.1	93	7.3

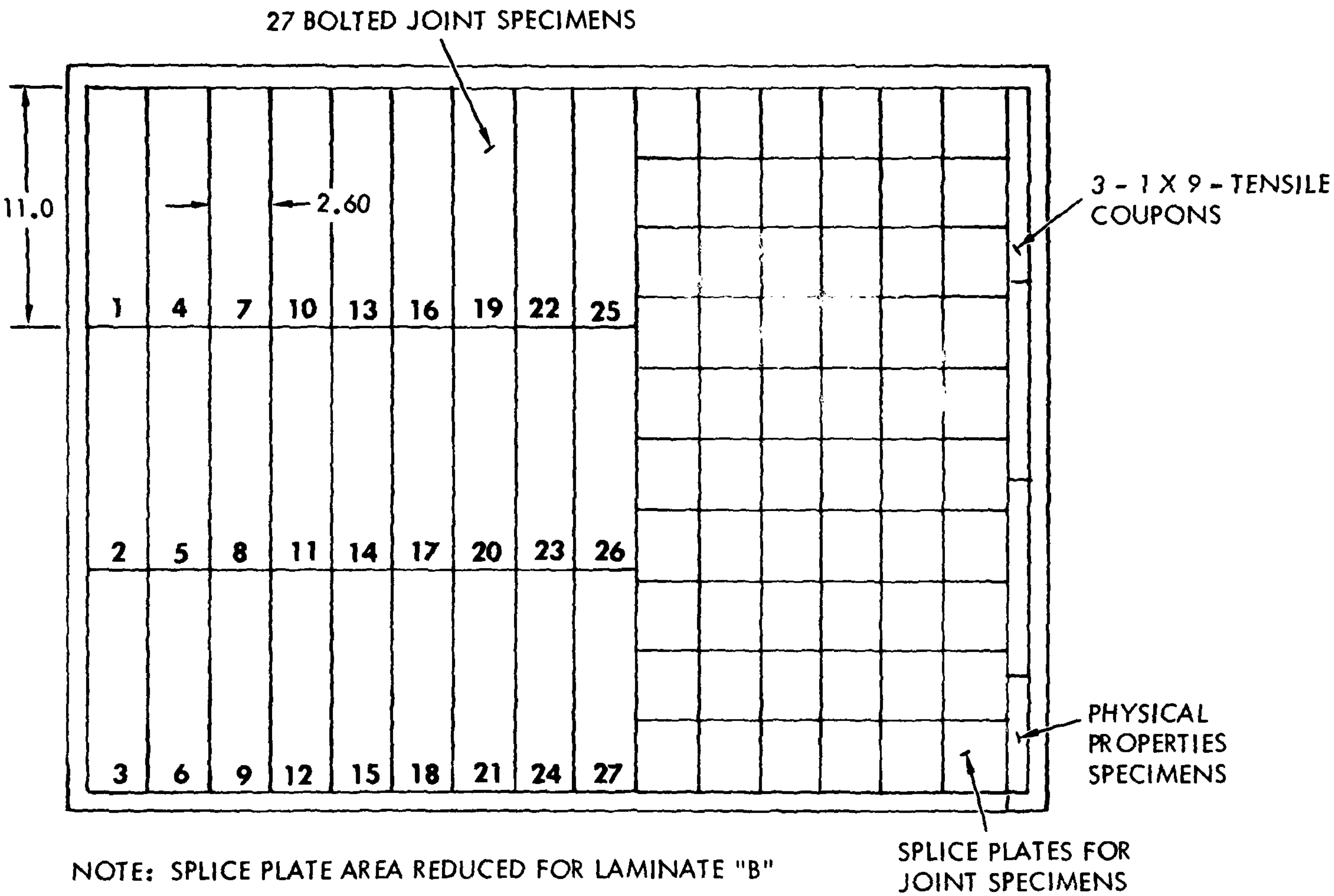
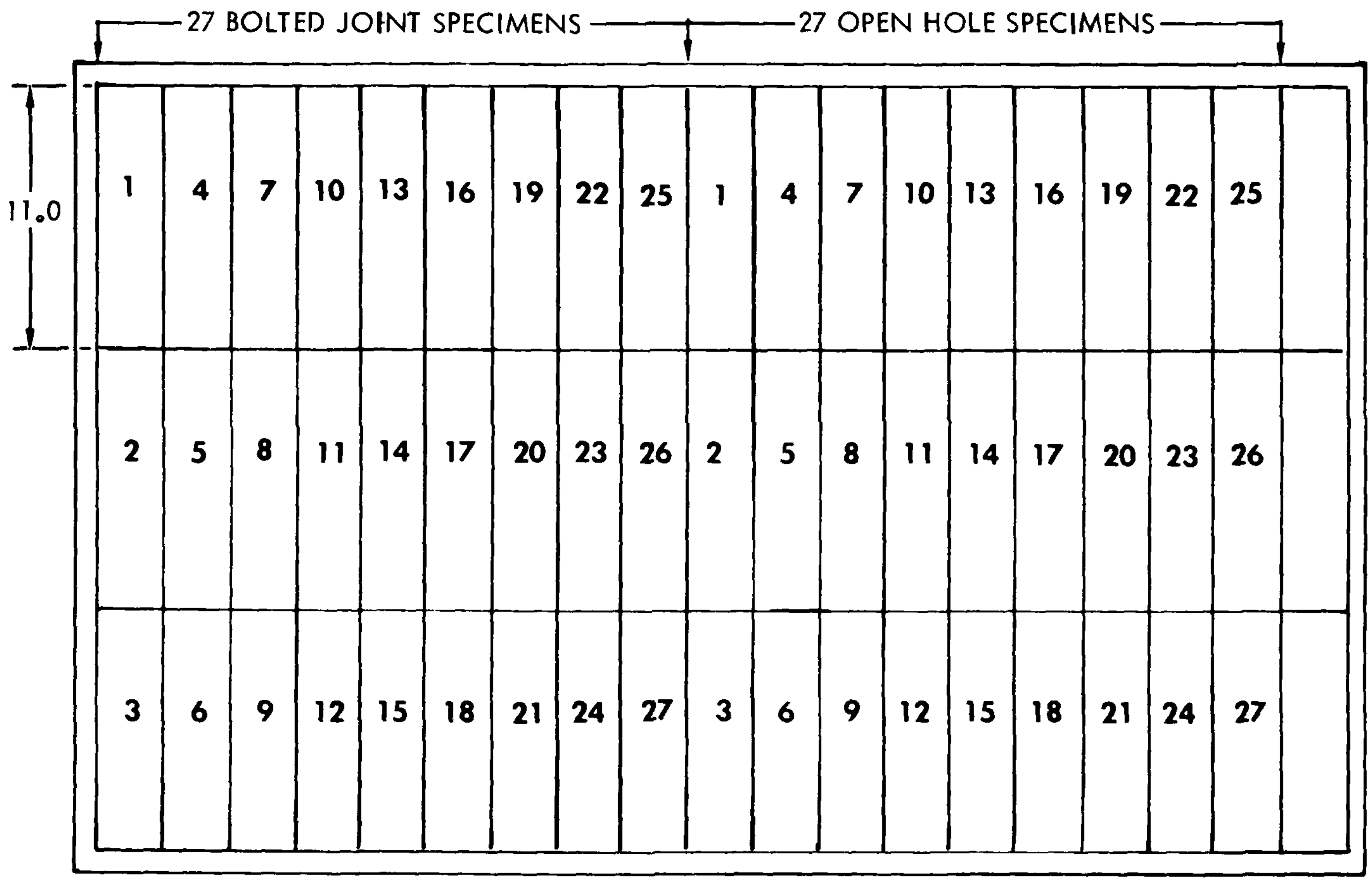


Figure 6. **Specimen Layout for Panel 1 of Each Laminate Configuration**



NOTE: PANEL SIZE REDUCED FOR LAMINATE "B"

Figure 7. Specimen Layout for Panel 2 of Each Laminate Configuration

(B) Specimen Configuration

The specimen configurations for this program were open hole and mechanically fastened joints. The open hole specimens are designated Type I and a sketch of this specimen is shown in Figure 1. The mechanically fastened joint specimens are designated as Type IIA for specimens with an edge distance ratio of 2 and Type IIB for specimens with an edge distance ratio of 3. Figure 2 shows a sketch of a typical bolted joint specimen. Examples of typical specimen identification are as follows:

```
I-A-27                              IIA-B-6
| | |__ SPECIMEN NUMBER             | | |__ SPECIMEN NUMBER
| |____ LAMINATE CONFIGURATION      | |____ LAMINATE CONFIGURATION
|______ SPECIMEN TYPE               |______ SPECIMEN TYPE
```

(C) Machining and Drilling of Specimen Details

The detail parts for each test specimen were cut from the laminate panels with a diamond-edged saw revolving at 3500 revolutions per minute. A drill fixture containing drill bushings was used for each type of specimen to ensure quality and uniformity of hole locations. A carbide gun drill bit mounted in a Quackenbush drill motor was used to drill the holes. The gun drill bit contains a hole through the bit for introduction of a coolant to the cutting surface which also provides a continuous flushing of the graphite-epoxy particles through a straight slot on the exterior section of the bit. The drilling residue is removed with a vacuum system. A gun drill bit is shown in Figure 8. The average hole diameter was 0.2504 inch.

(D) Quality of Specimen Details

All specimen details were inspected using the tetrabromoethane (TBE) enhanced x-ray radiography technique. The test area of each detail was immersed in TBE for 30 minutes, removed from the soak container, and the TBE removed from the laminate surface. The details were stored in plastic bags and x-rayed within

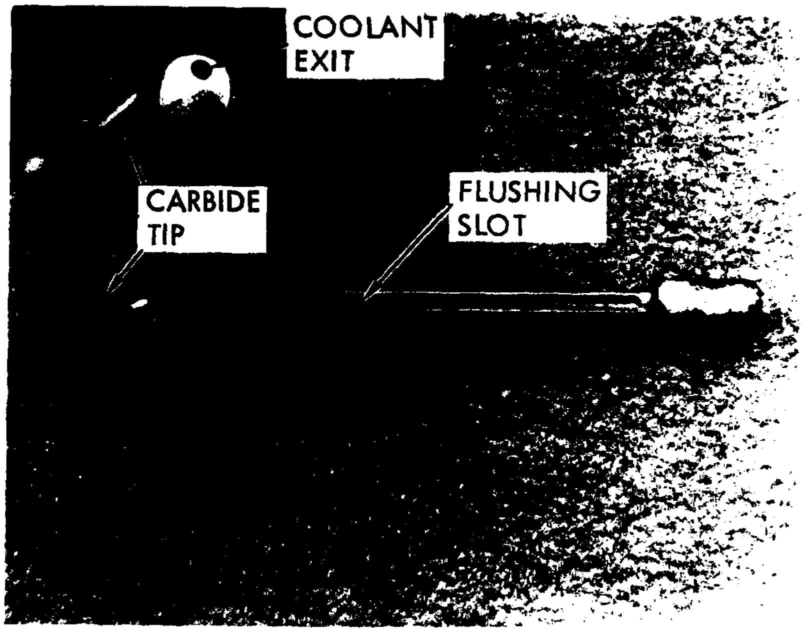


Figure 8. Gun Drill Bit

3 hours. Some of the Type IIA laminate B (IIA-B) strap details showed signs of damage adjacent to the bolt holes. These details were reversed, and the new holes that were drilled showed no signs of damage when inspected using TBE enhanced x-ray radiography.

Two specimens for each type and laminate configuration were selected at random and inspected for fabrication-induced fiber fractures using the deplying technique. The laminae of the Type I specimens showed no signs of damage. The details for the Type II specimens selected for deply inspection were inadvertently assembled along with the other joint specimens. They were disassembled and subjected to the deply inspection procedure. Although these specimens had not been loaded, there was evidence of fiber fracture in some specimens in the two or three laminae adjacent to the fastener head. This fiber fracture was caused by fastener installation and/or removal. Typical views of the damage observed on these laminae are shown in Figure 9.

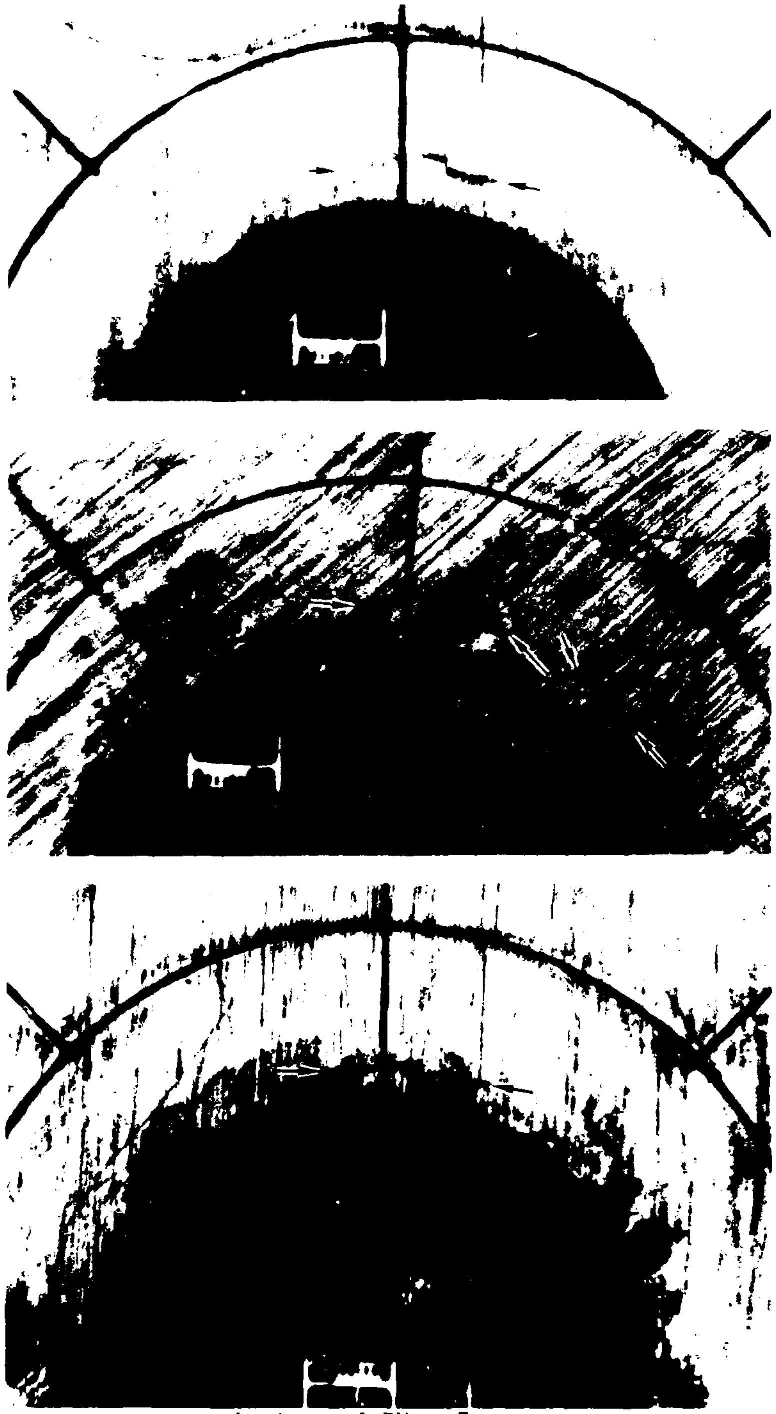


Figure 9. Typical Views of Fiber Fracture
Caused by Fastener Installation and or Removal

Note: Outer Circle of Overlay Corresponds
to the Periphery of the Fastener Head.

(E) Specimen Assembly

The Type IIA and Type IIB specimen details were assembled with HI LOK 18-8-5 fasteners torqued to 70 inch pounds. The average diameter of these fasteners was 0.2487 inch, thus providing a nominal clearance of 0.0017 inch between the fastener and the walls of the holes in the details. An assembled joint specimen is shown in Figure 10.

2. TASK II - INTRODUCTION OF LOAD INDUCED DAMAGE

(A) Specimen Selection for Tests

From each of the eight sets of specimens five replicate specimens were randomly selected for ultimate tests and each of the four load levels.

Figure 10. Typical Assembled Joint Specimen

(B) Specimen Loading

All open hole and joint tests were conducted in the same MTS 880 electro-hydraulic servo-controlled test system using the 20,000-pound and 50,000-pound load ranges. All specimens were loaded and unloaded through hydraulic grips at 5000 pounds per minute and were controlled with a computerized program. A view of the loading equipment and the acoustic emission equipment is shown in Figure 11, and a close up view of the test specimen in the loading fixture is shown in Figure 12.

(C) **Acoustic Emission Monitoring Procedure and Rationale**

The acoustic emission data were obtained with a commercial 32-channel AE flaw location system (Dunegan/Endevco, Model 1032D, Source Location and Analysis System) and recorded on the system's floppy disc recording unit, Figure 13. Only two channels of the system were required to acquire the data from the two

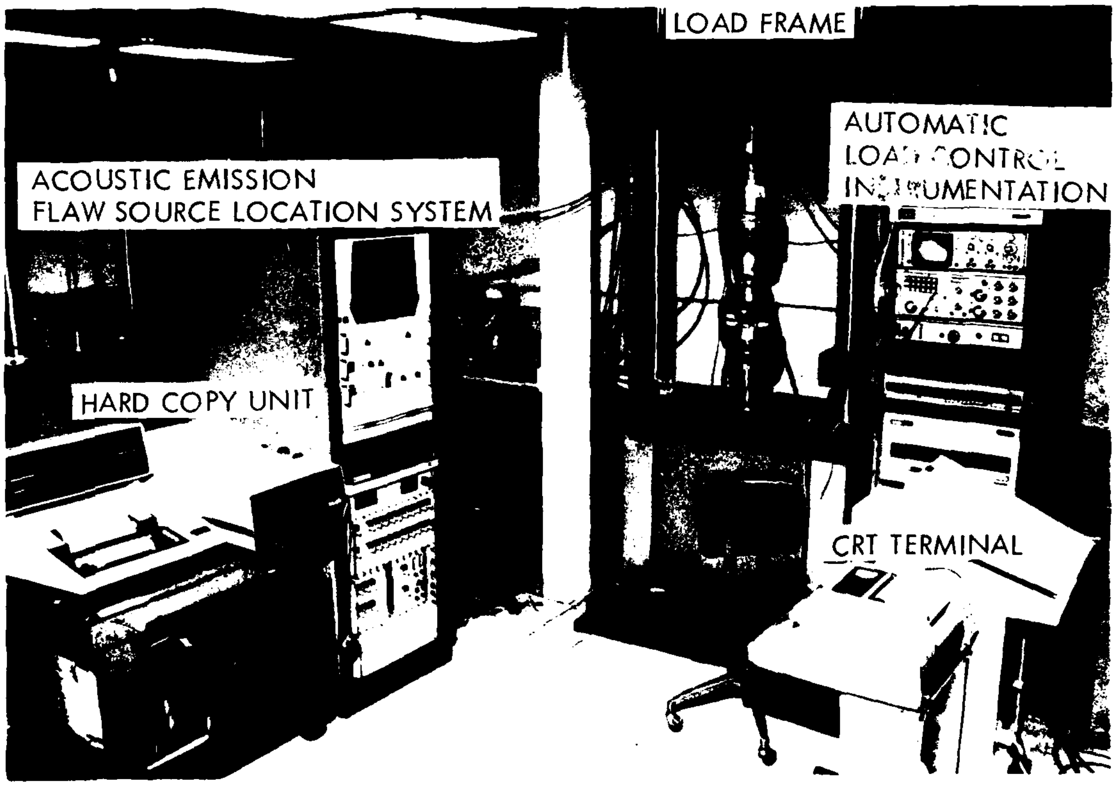


Figure 11. Test Setup for Loading Specimens and AE Monitoring

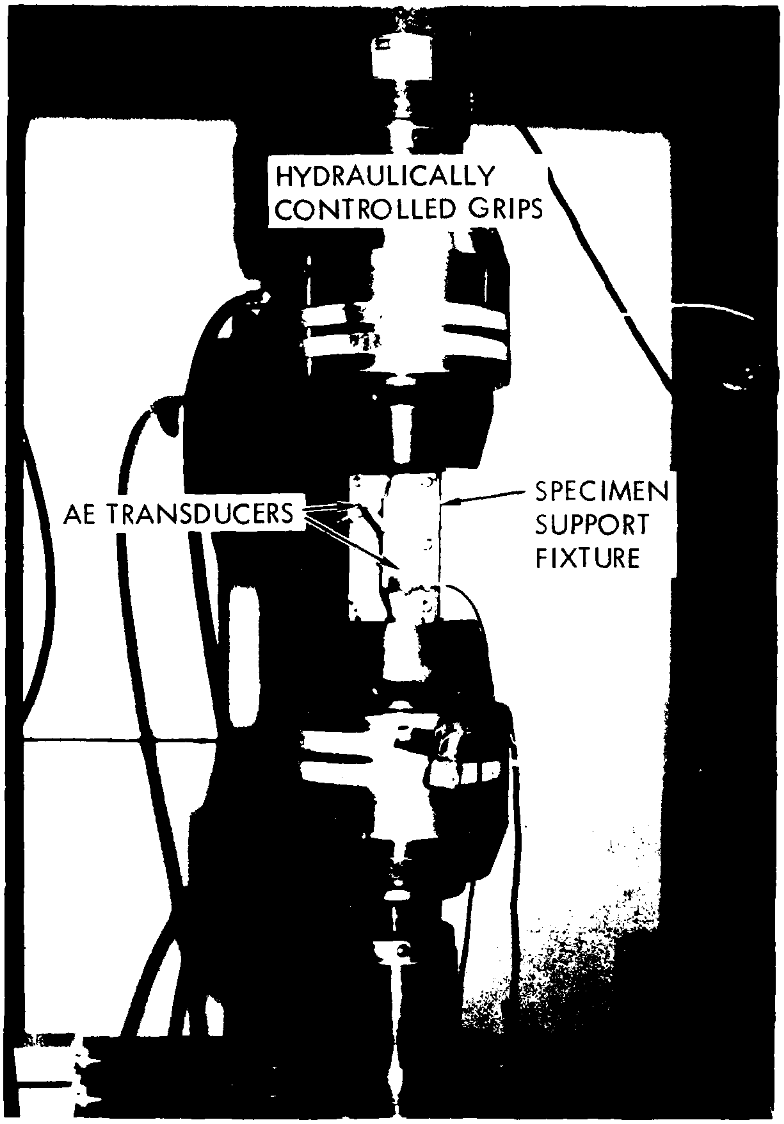


Figure 12. Test Specimen in Loading Fixture

types of specimens, since only a 2-transducer array was applicable. Two piezoelectric transducers (Dunegan/Endevco S750B) and wideband preamplifiers were used to detect and amplify the AE signals. The transducers contacted the specimens through holes drilled 3.5 inches apart in the specimen support fixture and were held in place by screw-loaded cantilever arms. A jell type of acoustic couplant was used at the contact interface.

Along with the AE signal data, a load signal from the MTS 880 load controller was also input to the AE flaw locator system and recorded simultaneously with each AE event. The data includes event number, location x-coordinates, delta-time of arrival at the second transducer to be hit, machine time, and the corresponding load value at which the AE event was produced. The system software has provisions for analytical display of the following plots: x-location, cumulative events versus load signal, cumulative counts (number of threshold crossings of the event ringdown signal) versus load signal, and counts versus events. Prior to running the tests a calibration of applied load versus the MTS controller load signal as received at the AE system console was obtained, showing agreement within 1 to 3 percent.

The AE equipment was "calibrated" for AE signal reception and processing by simulating acoustic emission in the specimen. This was done by breaking a No. 2 graphite lead, 0.5mm in diameter and about 2-3mm long, on the surface of the specimen near the holes and observing the system response. AE system controls were then adjusted to obtain desirable response parameters. This resulted in, for one thing, an average reference level for AE signal intensity (counts of ringdown threshold crossings for each AE event), which was used later in the data analysis.

Factors which strongly influenced the reception, processing and analysis of AE data in this program include the following:

(1) The transducers were installed diagonally across the specimen, enclosing the bolt holes and joint (Type II specimen) between them.

(2) When an AE signal hits one transducer, further AE events are ignored by the processor for a preset "dead-time" (12-15 milliseconds in this case) after which the system is reset to await the next event.

(3) Events processed by the system are those whose amplitudes exceed a preset threshold, and all event counts are relative to this threshold. Most AE events having relatively low counts are considered "noise," while most of the higher count events are produced by significant load-induced damage.

(4) A reference level for counts is obtained on each specimen type by breaking a No. 2, 0.5mm diameter graphite lead filament on the surface of the specimen to simulate AE.

(5) The count reference level is used to select accept/reject levels to improve the signal-to-noise ratio for purposes of analysis.

Relating the AE data to the actual damage is an activity that has few established guidelines and is based heavily on experience with similar specimens and/or feedback from damage analysis of the present specimens. We have found at Lockheed that the average reference level of simulated AE is the approximate level that separates significant damage from noise and the less important damage. Most AE signals above this count level will be related to some type of significant matrix or fiber damage and most below that level will be due to insignificant matrix damage and irrelevant origins. Hence, the reference level determines the filter parameters that are set up to "purify" the data. Factors concerned with the relationship of AE signals to fiber and/or matrix damage in the specimen in this program include:

(1) Damage observed in the deplied specimens is revealed-only damage (total damage may include some undetected damage).

(2) Damage observed in deplied specimens is final damage and does not necessarily reflect how incremental damage accrued during loading.

(3) AE signals from similar types and increments of damage are not uniform, but occur over a range of values, resulting in some good signals being rejected by the filters; also, a fiber bundle fracture and a significant delamination or matrix crack may produce equivalent AE signals.

(4) Due to the AE system "dead-time," signals from some significant damage may be lost.

(5) In general, the greater the total number of AE events received from a specimen, the lower the relative loads at which significant damage began to occur and the greater the damage observed.

(6) The relationships between cumulative AE and damage in composites can best be assessed on a statistical level rather than a one-to-one basis.

(D) Ultimate Tests and Selection of Load Levels for Type II Specimens

Five specimens for each of the five sets of joint specimens were loaded to failure. The average load at which AE monitoring indicated the first significant damage and the average and minimum failure loads are presented in Table 5.

TABLE 5

SUMMARY OF ULTIMATE TESTS FOR TYPE II SPECIMENS

	POUNDS LOAD				
	IIA-A	IIA-B	IIA-C	IIB-A	IIB-C
AVERAGE ULTIMATE	8240	5274	9645	7797	9012
MIN. IND. VALUE	7821	5158	9399	7582	8061
AVG. AE LOAD	4928	3060	5970	4836	6820

The four load levels selected for producing progressive amounts of damage in each set of the joint specimens are presented in Table 6.

(E) Ultimate Tests and Selection of Load Levels for Type I Specimens

Five specimens for each of the three sets of open hole specimens were loaded to failure. The average load at which AE monitoring indicated the first significant damage and the average and minimum failure loads are presented in Table 7.

TABLE 6

SUMMARY OF TEST LOADS SELECTED FOR EACH

SET OF TYPE II SPECIMENS

LOAD LEVEL	POUNDS LOAD				
	IIA-A	IIA-B	IIA-C	IIB-A	IIB-C
A	5000	3100	6000	5000	6850
C	5686	3639	6819	5614	7000
D	6345	4166	7658	6238	7149
B	7038	4642	8459	6824	7255

TABLE 7

SUMMARY OF ULTIMATE TESTS FOR TYPE I SPECIMENS

	POUNDS LOAD		
	I-A	I-B	I-C
AVERAGE ULTIMATE	24,079	35,065	15,844
MIN. IND. VALUE	23,473	33,634	15,486
AVG. AE LOAD	21,890	14,025	14,624

For the specimens of laminates A and C the average load at which AE monitoring indicated the first significant damage was somewhat larger than 90% of the minimum ultimate load. AE monitoring for the specimens of laminate B indicated the first significant damage to occur at approximately 40% of average ultimate. Accordingly the test load levels for the Type I-B specimens were selected using the same criteria as for the Type II specimens. The calculated load for failure to initiate in the laminate A specimens was 11,095 pounds based on a theoretical K_t of 3.48 (anisotropic homogeneous and linear). Since laminates A and B were both 50 percent $\pm 45^{\circ}$ laminae and 50% 0° laminae, the lowest load level (A) selected for laminate B was likewise used for laminate A. In the case of laminate C the calculated load for failure to initiate was 9,201 pounds based on a K_t of 3.0. The lowest load level (A) for laminate C was arbitrarily selected at 60% of average ultimate although the calculated load for failure to initiate was 58% of average ultimate. The highest load level (B) and the intermediate load levels (C and D) were selected using the same criteria as for the Type II specimens. The four load levels selected for producing progressive amounts of damage in each set of the open hole specimens are presented in Table 8.

TABLE 8

SUMMARY OF TEST LOADS SELECTED FOR EACH SET OF TYPE I SPECIMENS

LOAD LEVEL	POUNDS LOAD I-A	I-B	I-C
A	14,500	14,500	9,538
C	16,703	19,757	11,640
D	18,917	24,000	13,742
B	21,125	30,270	13,937

3. TASK III-DAMAGE ASSESSMENT BY X-RAY RADIOGRAPHY AND DEPLY TECHNIQUE

The test specimens were inspected using TBE enhanced x-ray radiography to determine the extent of fiber fracture, delaminations, and matrix cracking. In addition, a stereo x-ray pair was obtained for the specimen with the most apparent damage in each load level for each set of specimens. Following radiography a segment of each specimen containing the test area was removed for destructive inspection (ref. 3) to determine the lamina location of fiber bundle fracture and matrix cracking and the interlaminar location and configuration of delaminations.

(A) X-Ray Radiography

1. **Conventional radiography.** The Type II specimens were disassembled and the test area of both straps of each specimen and the test area of each Type I specimen were soaked in TBE for a minimum of 30 minutes. Upon completion of the soak interval the specimens were removed from the soak container and the TBE removed from the surface of the specimen. Each batch of specimens was transported to the x-ray laboratory in plastic bags and were removed just prior to radiography. Radiography was accomplished within 3 hours of removal from the soak. The specimens were radiographed at 25 KV using a NORELCO MG 150 with a beryllium window tube.

2. **Stereo radiography.** The tilt table device shown in Figure 13 was used for making the stereo radiographs. The shots were made with the specimen and film holder tilted plus and minus 15 degrees from the vertical direction of the x-ray beam.

(B) Deply Technique

1. **Specimen sizing.** Segments of suitable size, containing the test area, were removed from each specimen. The configuration and size of these segments are shown in Figure 14. In the case of the Type IIA and IIB specimens the deply segment was removed from the strap that contained the most damage as indicated by the enhanced radiographs. Any residual TBE was removed from the segments by warming them at 150°F for 1 hour while subjected to a vacuum of not less than 28 inches of mercury.

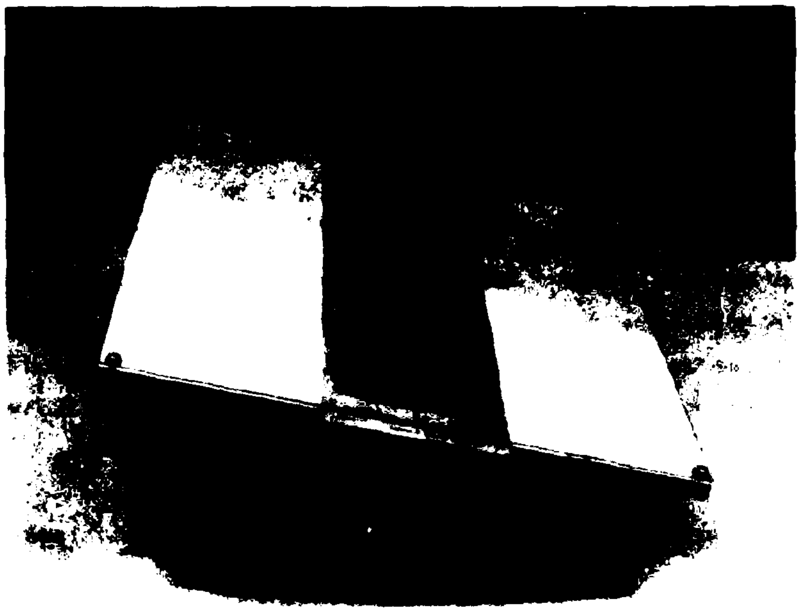


Figure 13. Tilt Table for Making Stereo-radiographs

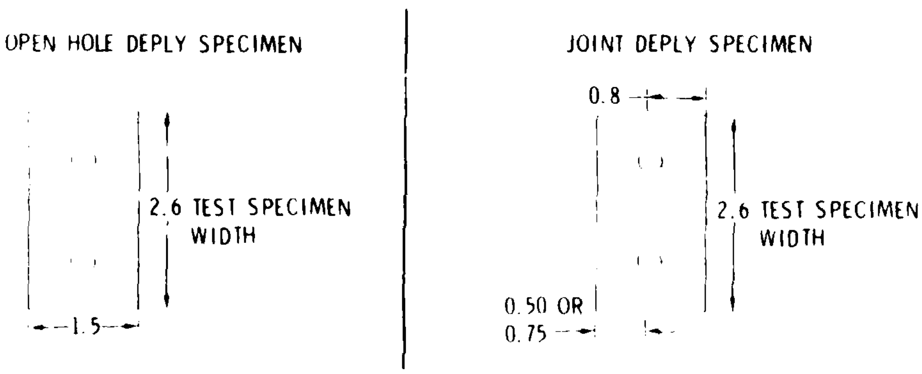


Figure 14. Specimen Segments for Deply

2. **Application of gold chloride marker solution.** A piece of pressure sensitive mylar tape was applied over the holes on one surface of the deply segment. The segment was then placed on a flat surface with the tape on the bottom. The holes were filled with the gold chloride diethylether solution (0.6% gold by weight) and each hole covered with a small piece of plain mylar. The excess marker solution was removed from the hole for recycling after a minimum of 30 minutes soak. The mylar tape was removed and the segment allowed to air dry. The surfaces of the specimen adjacent to the holes were wiped with acetone moistened cotton to remove marker from the surface. The segment was then heated to approximately 150°F to remove solvent before proceeding with the deplying.

3. **Pyrolysis of segments.** Two segments were placed on a stainless steel wire mesh holder or boat, and the boat containing the segments was inserted into a tube furnace. The boat was placed into a zone of the tube maintained at [illegible]°F to [illegible]°F for [illegible] to [illegible] minutes. Most segments were sufficiently pyrolyzed after [illegible] minutes to be suitable for [illegible]. [illegible] completion of the pyrolysis period the boat containing the segments was removed from the furnace and allowed to cool to room temperature. A photograph of a segment [illegible] is shown in Figure 15.

Figure 15. Typical Specimen Segment After Pyrolysis

4. **Unstacking laminae.** The segments with the partially pyrolyzed resin matrix were carefully removed from the boat, and the individual laminae of each unstacked. Each lamina was reinforced with transparent tape (Scotch 650) and lifted from the segment. A piece of double-coated tape (Scotch 665) was placed along one edge of each lamina to attach it to a work sheet to facilitate handling for microscopic study and photography.

5. **Examination of the laminae for fiber fracture, delaminations, and matrix cracks.** Each lamina was examined with a stereo microscope with a magnification range of 8X to 50X. For fiber fracture examination the laminae were examined using light from a fluorescent lamp impinged at 90° to the fiber direction. Some of the more subtle and smaller fractures required probing at 30 to 50X to distinguish them from pyrolysis artifacts. Delamination and matrix cracks marked by the gold chloride required impingement of a high-intensity light source on the lamina surface parallel to the fiber direction.

6. **Method for charting fiber fracture and matrix damage indications.** Fiber fractures and indications of delaminations and matrix cracks as observed during the microscopic examination were recorded on Lamina Damage Characterization Charts (LDCC). A chart was prepared for each specimen and contained a pictorial sketch, with fiber orientations shown, for each lamina of the deply area. At the time of charting the depictions for holes and fastener head periphery were actual size so that the damage could be charted close to actual size. Some of the charts were reduced in size during the reproduction process. To gain improved understanding of the LDCC for open hole specimens, examples of actual size charting of damage for some of the laminae of specimen I-B-6 (Figure B-51) are presented in Figure 16. Also included in this figure is an identification of the symbols used to indicate different types of damage, and a photomacrograph showing delaminations and fiber fracture adjacent to an open hole. Unfortunately, the gold color of the delamination appears as a shade of grey in this black-and-white reproduction.

During charting of damage for the bolted-joint specimens, two types of transparent overlays were used to provide a reference line for the Periphery of the Fastener Head (PFH), and thus to aid in accurately charting Matrix Crack Indications (MCI), Delamination Indications (DI), and fiber fractures.

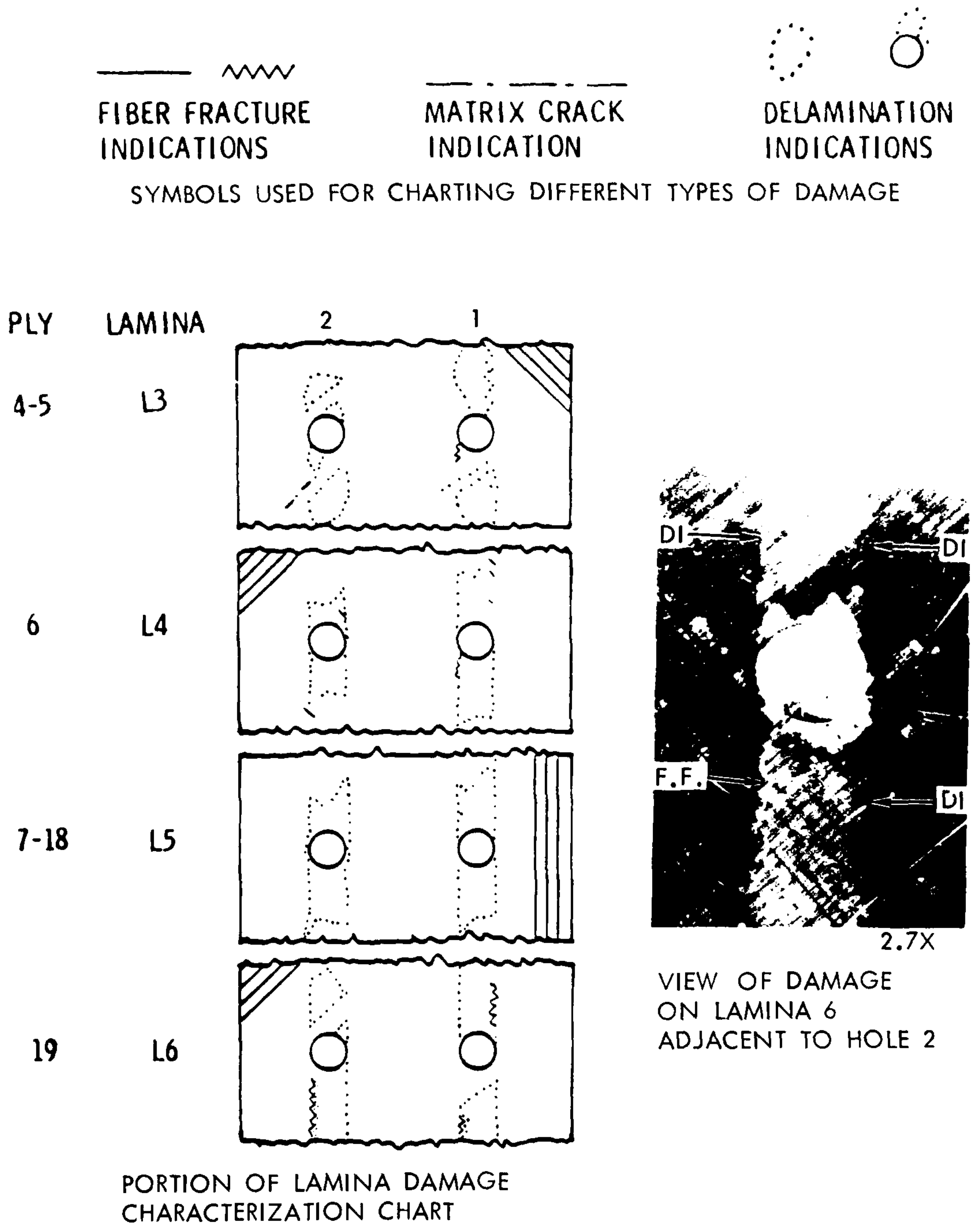


Figure 16. Example of Charting Techniques for Damage on the Lamina of an Open Hole Specimen

A film-positive overlay was used for fiber fracture observations while the lighting conditions required for MCI and DI made a glass-plate overlay necessary to avoid reflections. Examples of actual size charting of damage for some of the laminae of specimen II A-C-2 (LDCC F-60) are presented in Figure 17 along with the symbols used to indicate the different types of damage. An example of the view observed when lighting a lamina surface for DI is shown in Figure 18. In this figure, the lighting technique required for seeing the delamination indication causes the lamina surface to appear black with the DI highlighted in gold. When this view is reproduced in a black-and-white photomacrograph, the gold appears as a shade of grey. An example of the view observed when lighting a lamina surface for fiber fracture is shown in Figure 19.

4. TASK IV - INSPECTION RESULTS

A. Introduction and Summary of Reporting Methods

A summary and discussion of the inspection results is presented in this section of the report while the detail results of the inspections are presented in the appendices.

The detailed results of the inspections are presented in the form of figures. These figures include the following information for each specimen:

> Specimen type; laminate stacking sequence; load level; pounds load; percent of ultimate and, in the case of the open hole specimens, the expected number of fiber bundle fractures based on acoustic emission monitoring; prints of the penetrant-enhanced x-ray radiographs before and after loading; and lamina damage characterization charts.

In addition for each load level of each set of specimens the following information is included in the figures.

> Prints of a stereo x-ray pair for the specimen that contained the most damage and AE plots of accumulative events vs load for the bolted joint specimens with the minimum and maximum amount of AE response.

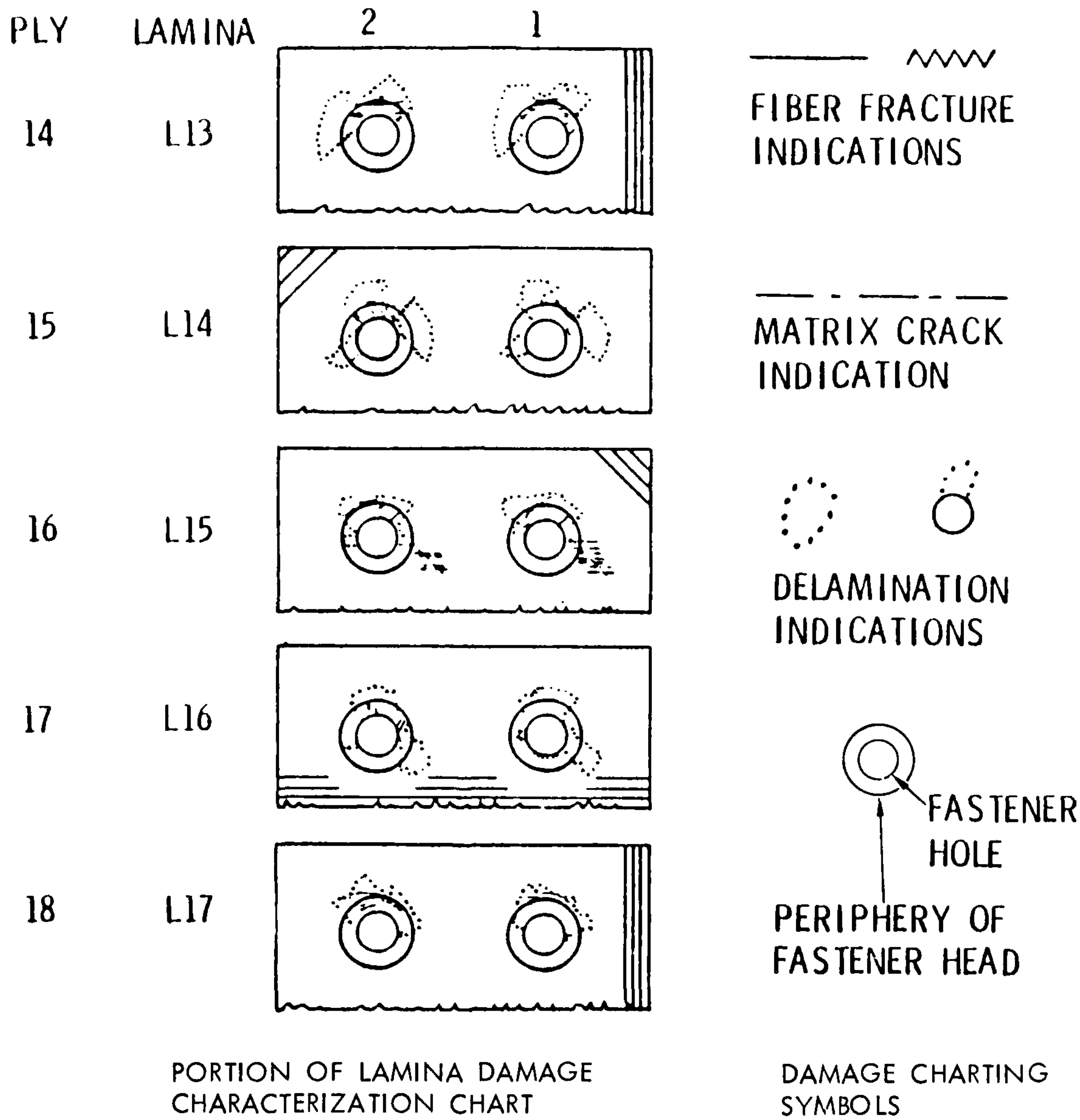
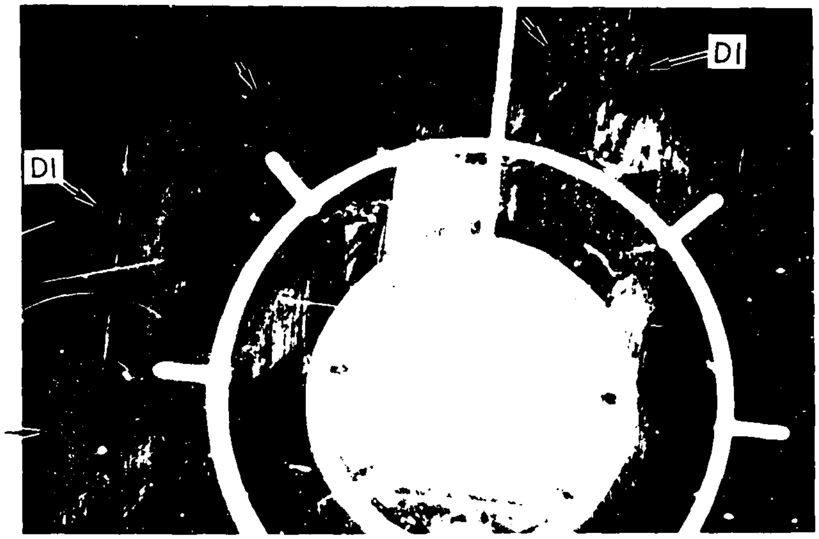


Figure 17. Example of Charting Techniques for Damage on the Lamina of a Strap Segment of a Bolted Joint Specimen



REFER TO FIGURE 17 FOR CHARTED DAMAGE

Figure 18. Lamina 13 Hole 2 Illuminated for Delaminations Marked with Gold Chloride

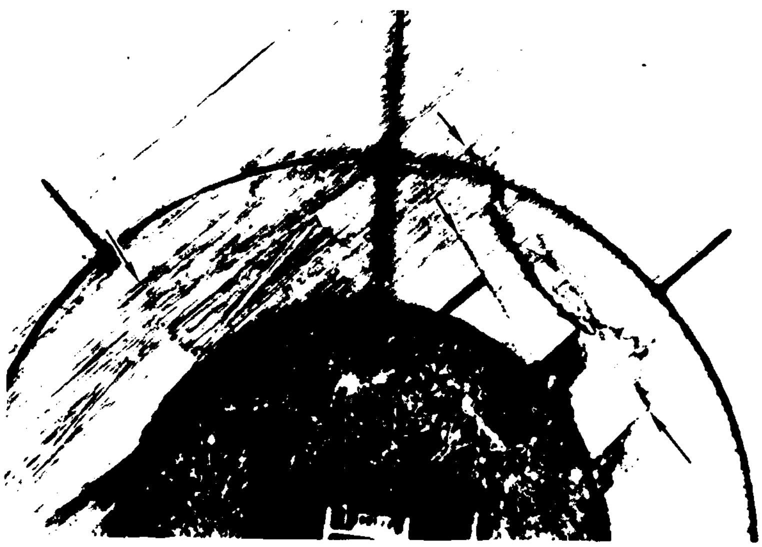


Figure 19. Lamina 14 Hole 2 Illuminated for Fiber Fracture Observations

AE plots of accumulative events vs load are presented for the ultimate specimens of each set of open hole specimens. All figures for each set of specimens are combined into separate appendices.

B. Summary of Results for Type I Specimens

1. AE results vs deply inspection. To observe the significance of the AE data in estimating the number of fiber bundle fractures, refer to Table 9 and the Lamina Damage Characterization Charts (LDCC) for the open hole specimens and compare these two sets of independent data. Comparison shows rather close agreement between the two data sets as follows:

(a) Type I-A specimens. Neither data set indicates fiber bundle fracture for any load level.

(b) Type I-B specimens. Neither data set indicates fiber bundle fractures for load levels A and C. The AE data indicate numerous fiber bundle fractures for the five specimens of load level B and the deply damage analysis agrees quite well for at least four of the specimens. Both data sets report minor fiber damage for most of the specimens of load level D, again in quite close agreement on number of fractures.

(c) Type I-C specimens. Neither data set indicates fiber bundle fractures for load levels A and C. The AE data estimates minor fiber damage for one specimen in each of load levels D and B. The deply damage analysis reports no fiber damage for load levels D and B.

It should be noted that there is no method available to completely separate AE events caused by fiber bundle fractures and those caused by major matrix cracks and ply delaminations. Therefore, it must be presumed that the AE data given in Table 9 possibly represent both types of damage.

The AE data in Table 9 were extracted from the raw AE data (recorded on disk storage) through application of two basic assumptions:

TABLE 9.
EXPECTED NUMBER OF FIBER BUNDLE FRACTURES (FBF) ACCORDING TO AE FOR OPEN HOLE SPECIMENS

LAMINATE CONFIGURATION	LOAD LEVEL	SPECIMEN NUMBER	NO. FBF (MAX.)
A	A	ALL	NONE
	C	ALL	NONE
	D	ALL	NONE
	B	ALL	NONE
B	A	ALL	NONE
	C	ALL	NONE
	D	7	1
	D	20	2
	D	17	NONE
	D	2	2
	D	4	3
	B	6	12
	B	14	27
	B	18	13
	B	24	8
	B	27	8
C	A	ALL	NONE
	C	ALL	NONE
	D	2	2
	D	REMAINING	NONE
	B	27	1
	B	REMAINING	NONE

(a) Fiber bundle fractures result, in most cases, in AE events having counts (intensity) at or above the simulated reference level as determined for each laminate using the fracture of a No. 2 pencil lead.

(b) Fiber bundle fracture begins at a threshold load somewhat below the ultimate load and this threshold can be estimated from plots of AE events versus load for the specimens of each laminate loaded to failure.

Making use of these assumptions, a software filter was set up to refine the signal-to-noise ratio of the recorded AE data and to select those events whose counts exceeded the reference level. Further analysis on these selected events using assumption (2) resulted in the AE data in Table 9.

2. **Enhanced radiography indications versus deply inspection.**

(a) Type I-A specimens. Radiographs of these specimens indicated small matrix cracks and delaminations. Matrix Crack Indications (MCI) were first present in load level "C" and increased in length somewhat with each higher load level. These crack indications were in the 0° laminae and extended in both directions on each side of the holes. Figures A-42 and A-66 illustrate the more pronounced MCI in the 0° laminae. Delamination Indications (DI) were present in specimens of load levels "D" and "B" and were very faint.

There were no MCI on the surfaces of the deplied laminae. This absence of MCI leads one to believe the cracks were probably contained within the four 0° plies which comprised the center lamina. The DI on the deplied laminae were for the most part very small. These indications were marked in the appropriate locations on the LDCC. If one refers to the LDCC of appendix A, the extent of damage found by deply can be readily viewed for each of the load levels. Thus some of the very small DI shown on the LDCC's would be very difficult to interpret on the enhanced radiographs. A photograph of a DI on a lamina of a load level "A" specimen is shown in Figure 20. No fiber bundle fracture was found on any of the laminae of these specimens.

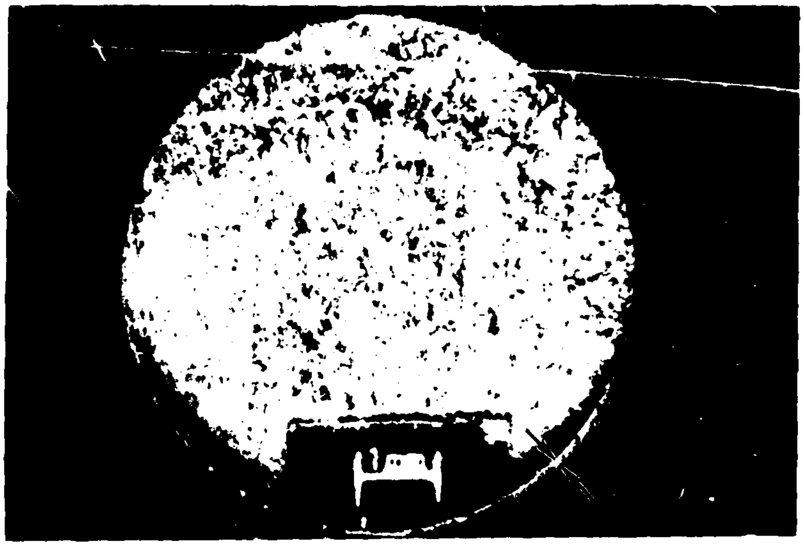


Figure 20. Typical Delamination Indication on a "I-A" Load Level "A" Lamina

(b) Type I-B specimens. Radiographs of these specimens indicated fiber fracture, matrix cracks and delaminations. MCI appeared in load level "A" in the 0° direction and extended in both directions on each side of the holes as shown in Figures B-2 and B-3. These 0° MCI increased with each increase in load and were very pronounced. MCI in the $\pm 45^{\circ}$ laminae were evident in the load level "C" radiographs and increased in intensity with the higher loads. DI were larger in the radiographs of the lower load levels (A and C) than for specimens of types I-A and I-C. Deply inspection revealed these DI were confined mainly to the interface of lamina 5 and lamina 6.

Radiographs of load level "D" specimens showed the area of the DI increased significantly and fiber fracture occurred in three of the five sepcimens. Deply inspection of the laminae revealed the fiber fracture occurred in lamina 4 of two specimens and lamina 6 of one specimen. The stair-step or saw-tooth fiber fracture configuration found in lamina 4 of specimen I-B-20 (LDCC B-39) can also be seen in the radiograph of this specimen. In most cases, fiber fractures of this configuration are quite easy to identify in radiographs, although one may have to use a pocket magnifier to see the saw tooth effect. At load level "B," 90% of the minimum ultimate load, the radiographs showed a marked increase in the area of DI, the number of

MCI and fiber fracture. The deplied laminae likewise confirmed this increase in fiber fracture and delaminations. The matrix crack indications were not found on the surface of the laminae in the same quantity as shown in the radiographs.

(c) Type I-C specimens. Radiographs indicated small matrix cracks in the 90° laminae. The number and intensity of these cracks increased with increasing load. Magnification was required for the lower load level radiographs to view these indications. DI indications were not visible on the radiographs. In the deply inspection of the individual laminae MCI were not present on the surface of the laminae. The DI found on the laminae were very small and can best be understood by reviewing LDCC in appendix C. No fiber fracture was found on the laminae of any of the type I-C specimens.

A tabular summary of the damage observed on the deplied laminae of the type I specimens was prepared. In compiling this table a lamina was counted as containing fiber fracture or delamination even if evidence of this damage was adjacent to only one hole. No size restriction was applied to either of these types of damage. This summarized data is presented in Table 10.

C. **Summary of Results for Type II Specimens**

1. **Discussion of acoustic emission results versus damage for the Type II specimens.** The plots of AE versus applied load presented in the Appendices (D through H) for the bolted joint specimens include only those plots in which AE indicated the most and the least damage for each laminate type at each load level. It is important to note that the AE was generated in the entire specimen, i.e., at the four fastener holes, the joint interfaces and the three sepaprate members of the specimen. The AE, therefore, may contain responses from progressive failures in three primary components: the epoxy matrix, the fiber bundles, and the joint interface. It is believed that displacements at the faying surfaces of the joint produce mostly AE signals having low intensities (counts). Eliminating the low-count AE events, therefore, improves the signal-to-noise ratio of the remaining data and provides

TABLE 10

SUMMARY OF DAMAGE OBSERVED ON THE INDIVIDUAL LAMINAE OF TYPE I SPECIMENS

	LAMINATE A			LAMINATE B			LAMINATE C		
LOAD LEVEL	LOAD	FIBER FRACT.	DELAM	LOAD	FIBER FRACT.	DELAM	LOAD	FIBER FRACT.	DELAM
	% OF AVG.ULT.	%(1)	% (2)	% OF AVG.ULT.	%(1)	% (2)	% OF AVG.ULT.	%(1)	%(2)
A	60	0	32	41	0	56	60	0	21
C	69	0	21	56	0	58	73	0	45
D	79	0	36	68	7	76	87	0	52
B	88	0	35	86	22	83	88	0	39

(1) 22 - INDICATES PERCENT OF LAMINAE THAT CONTAINS FIBER FRACTURE

(2) 35 - INDICATES PERCENT OF LAMINAE THAT CONTAINS SOME DELAMINATION

information relating mainly to matrix and fiber damage. It was observed that, in each group of five specimens, the level of AE activity often varied considerably between specimens, with some having very few AE events.

The total AE events, expressed on each plot in the upper left corner, is the total number of raw AE events received, before filtering, for that specimen and its loading condition, and can be regarded as a rough measure of the relative overall damage incurred throughout the specimen.

A software filter was used to eliminate those AE events whose intensities were less than 22 counts, which is about 25 percent of the average reference level of counts established for the bolted joint specimens using the fracture of a No. 2, 0.5mm diameter graphite lead on the specimen surface. The use of this filter resulted in the curves shown in the aforementioned plots, which represent primarily the AE response from matrix and fiber damage.

No attempt was made to correlate the AE data with specific damage identified by deply analysis because of (1) the uncertainty in the AE data arising from the complexity of the specimens, and (2) only a partial (two out of eight hole sites) deply damage analysis was made. The results of such attempts under these circumstances would be questionable. Nevertheless, the AE range in the selected curves show a rough correlation with the total damage revealed in the partial deply damage analysis. The portion of the specimen subjected to deply analysis may or may not have contained an equal proportion of damage in each case, contrasting with the fact that the AE data represents damage in the entire specimen.

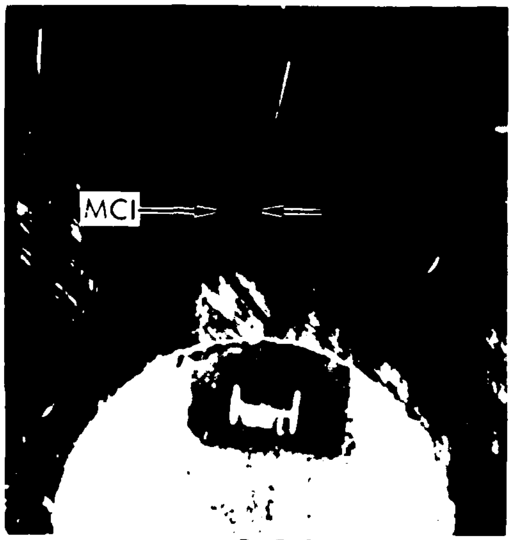
An important observation concerning the bolted joint specimens is that fiber damage occurred at lower loads than with the open hole specimens because the load was transferred through the fasteners in the holes. This fact is observed in the deply analysis results and indicated in the AE versus load curves for those specimens having sufficient AE data.

In both the bolted joint (Type II) and open hole (Type I) types of specimens, acoustic emission data has proved to be a good indicator of significant matrix and fiber damage initiation and total relative damage.

2. **Enhanced radiography indications versus deply inspection.**

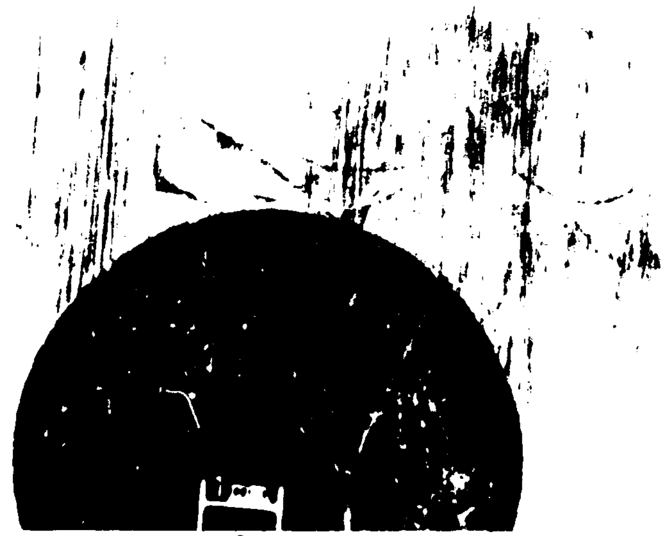
(a) Type IIA-A specimens. Radiographs of these specimens indicated matrix cracks, delaminations and fiber fracture. MCI and DI were present in load level "A" specimens. DI were present in four of the five specimens but did not extend beyond the periphery of the fastener head (PFH). The majority of MCI were in the 0° laminae and extended from the edge of the fastener holes to the butt joint end of the strap detail. A few very faint MCI were present in the 45° laminae. In load level "C" the intensity of the 0° MCI increased and the 45° MCI were more numerous, although they did not extend beyond the PFH. DI extended beyond the PFH for three of the five specimens. MCI for load levels "D" and "B" increased in intensity with increase in load, but those in the 45° lamina did not extend beyond the PFH. The DI for load level "D" extended beyond the PFH for two of the five specimens. Thus, the DI can be considered approximately the same (qualitatively) for load levels "C," "D," and "B" when using the criteria of being contained within the PFH or extending beyond the PFH.

Observations of the deplied laminae for MCI, DI, and fiber bundle fracture revealed the first appearance of MCI in load level "C" on lamina 14 of two specimens. A photomacrograph of MCI is shown in Figure 21. These indications increased with increasing load and were present on six lamina locations in load level "B." DI were present in all load levels and increased in quantity and size with increasing load. Fiber bundle fractures were present in laminae 15 thorugh 17 in all four load levels in varying degrees. Based on the findings of deply inspection for initial quality of specimen details, a portion of the fiber bundle fracture in these three laminae (15, 16, 17) can be attributed to fastener installation. In load levels "D" and "B," fiber fracture occurred in numerous lamina locations other than 15 through 17. Figure 22 shows fiber fractures on Lamina 6 of Specimen IIA-A (also see LDCC D-48). A summary of the average number of fiber bundle fractures per lamina at each load level is presented in Table 11 for these specimens (Type IIA-A). A summary of the delaminations



HOLE-1

Figure 21. View of Matrix Crack Indications on Lamina 14 of Specimen IIA-A-20



HOLE-2

Figure 22. Fiber Fractures on Lamina 6 of Specimen IIA-A-28

TABLE 11

SUMMARY OF FIBER FRACTURE DAMAGE IN TYPE IIA SPECIMENS FROM LAMINATE "A"

LAMINA NO.	ORIENT.	AVERAGE NUMBER OF FIBER FRACTURES PER LAMINA AT EACH LOAD LEVEL			
		A	C	D	B
1	+45	0	0	0.4*	0.4*
2	-45	0	0	0.6	2.4
3	0_2	0	0	2.0	4.4
4	-45	0	0	1.0	2.4
5	+45	0	0	0.6	2.8
6	0_2	0	0.2*	3.8	6.4
7	+45	0	0	0	1.6
8	-45	0	0	0	1.8
9	0_4	0	0	0.4	2.2
10	-45	0	0	0	1.0
11	+45	0	0	0.2*	0.6
12	0_2	0	0	0	0.2*
13	+45	0	0	0	0.2*
14	-45	0	0	0	0
15	0_2	1.4	3.0	1.2	0.8
16	-45	2.8	5.8	3.2	4.0
17	+45	4.4	6.6	5.4	5.2

*PRACTICALLY NO DAMAGE IN THESE SPECIMENS
THESE RECORDINGS ARE POSSIBLE DUE TO THE SENSITIVITY OF THE TECHNIQUE FOR FINDING VERY SMALL DAMAGE

and fiber bundle fractures observed on the individual laminae is presented on a load level basis in Table 12. This table shows the percentage of laminae containing these two types of damage. A visualization of the damage observed on the laminae of these specimens can best be obtained by referring to the LDCC of appendix D.

(b) Type IIA-B specimens. Radiographs of these specimens indicated matrix cracks, delaminations and fiber fractures. The DI extended beyond the PFH for all load levels. MCI for the 0° lamina were very pronounced in all load levels. In most specimens they extended in both directions from the bolt holes as can be seen in the figures of radiograph prints in appendix E. MCI for the 45° laminae were very faint and did not show well in the prints. Some fiber fracture indications could be mistaken for 45° MCI until verified by deply inspection.

Deply inspection of the individual laminae revealed MCI in the 0° direction. The 0° MCI on lamina 4 was present on one specimen in load level "A" and increased in numbers with increases in load level. The 0° MCI on lamina 5 were first present on one specimen in load level D and all specimens in load level "B". DI were present in all load levels, although not on all laminae. The largest DI were present on lamina 7 and represents the degree of delamination between lamina 7 and lamina 8. A typical view of these DI is shown in Figure 23 (also see LDCC E-39). In general, fiber bundle fracture was present in laminae 8 and 9 of all specimens. As in the case of the Type IIA-A specimens, at least a portion of these fractures can be attributed to fastener installation. A summary of the average number of fiber bundle fractures per lamina at each load level is presented in Table 13 for these specimens (Type IIA-B). A summary of the delaminations and fiber bundle fractures observed on the individual laminae is presented on a load-level basis in Table 12 The LDCC of appendix E show at a glance the damage observed in the individual laminae of these specimens.

HOLE-1

Figure 23. Delamination Indications on Lamina 7 of Specimen II A-B-13

(c) Type IIA-C specimens. Radiographs of these specimens indicated matrix cracks, delaminations and fiber fracture. DI were present in the specimens of all load levels and extended beyond the PFH. MCI were present in the 90° laminae of the specimens of all load levels and extended beyond the PFH. MCI were present in the 45° laminae of the specimens of all load levels. In load level "A" they were contained within the PFH, while in load levels "C," "D," and "B" they extended beyond the PFH. Fiber fracture indications were present in all load levels. Experience gained from previous deply inspections of fiber fracture made identification of laminae orientations containing fractures possible. Some of the fiber fracture indications on the radiographs which were caused by fastener installation could be mistaken for 45° MCI until verified by deply inspection.

TABLE 12.
SUMMARY OF DAMAGE OBSERVED ON THE INDIVIDUAL LAMINAE OF TYPE IIA SPECIMENS

	LAMINATE A					LAMINATE B					LAMINATE C				
	LOAD		FIBER FRACT.		DELAM	LOAD		FIBER FRACT.		DELAM	LOAD		FIBER FRACT.		DELAM
LOAD LEVEL	POUNDS	% OF AVG. ULT.	%(1)	PER (2) LAMINA	%(3)	POUNDS	% OF AVG. ULT.	%(1)	PER (2) LAMINA	%(3)	POUNDS	% OF AVG. ULT.	%(1)	PER (2) LAMINA	%(3)
A	5000	61	14	0.51	38	3100	59	22	0.64	82(31)	6000	62	37 (2)	1.15	66 (22)
C	5686	69	18	0.92	39(5)	3639	69	18	0.69	69(31)	6819	71	32 (3)	1.33	92 (22)
D	6345	77	42	1.11	48(13)	4166	79	22(2)	0.98	76(33)	7658	79	58 (12)	3.79	94 (36)
B	7038	85	62(1)	2.14	68(39)	4642	88	18	0.89	84(56)	8459	88	92 (36)	8.59	100 (72)

(1) 55(10) - 55 INDICATES PERCENT OF LAMINAE THAT CONTAINS FIBER FRACTURE
- (10) INDICATES PERCENT OF LAMINAE THAT CONTAINS FIBER FRACTURE THAT EXTENDS BEYOND THE PERIPHERY OF FASTENER HEAD.

(2) 0.92 - AVERAGE NUMBER OF FIBER FRACTURE PER LAMINA (TOTAL NUMBER OF FIBER FRACTURES COUNTED ON ALL LAMINAE DIVIDED BY THE TOTAL NUMBER OF LAMINAE)

(3) 82 (31) - INDICATES PERCENT OF LAMINAE THAT CONTAINS SOME DELAMINATION (31) INDICATES PERCENT OF LAMINAE THAT CONTAINS AT LEAST ONE DELAMINATION THAT EXTENDS BEYOND PERIPHERY OF FASTENER HEAD.

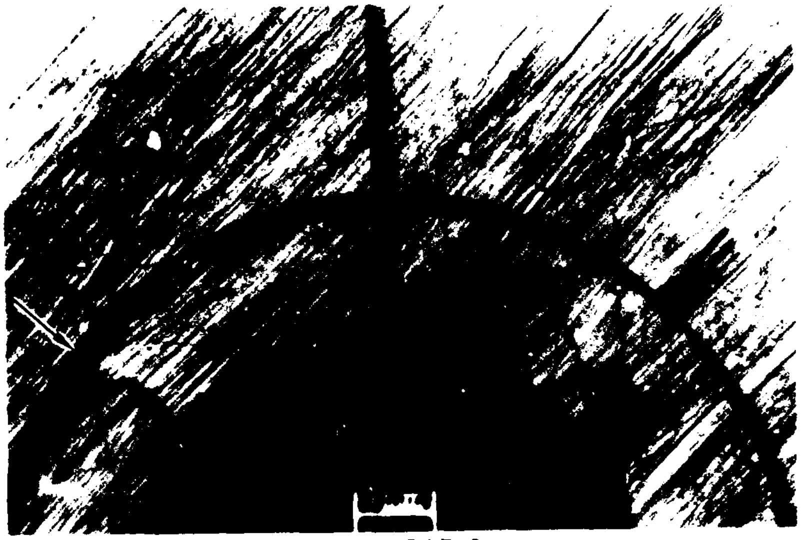
TABLE 13.

SUMMARY OF FIBER FRACTURE DAMAGE ON TYPE IIA SPECIMENS FROM LAMINATE "B"

LAMINA NO.	ORIENT.	AVERAGE NUMBER OF FIBER FRACTURES PER LAMINA AT EACH LOAD LEVEL			
		A	C	D	B
1	+45	0	0	0	0
2	-45_2	0	0	0	0
3	$+45_2$	0	0	0	0
4	-45	0	0	0	0
5	0_{12}	0	0	0	0
6	-45	0	0	0	0
7	$+45_2$	0	0	0	0
8	-45_2	2.0	2.4	3.0	2.8
9	+45	3.4	3.8	5.8	5.2

Deply inspection of the individual laminae revealed MCI, DI and fiber bundle fracture in all load levels. MCI were present on lamina 14 of two specimens in load level "A." These indications increased with increasing loads and were present on four lamina locations in load level "C," nine lamina locations in load level "D" and ten lamina locations in load level "B". DI were present on laminae in all load levels and increased in quantity and size with increasing loads. Since area measurements of DI were beyond the scope of this program the best understanding of their magnitude can be obtained by reviewing the LDCC of appendix F. Fiber bundle fractures were present in varying degrees in laminae 21, 22, and 23 of all specimens in all four load levels. A portion of the fractures in these three laminae can be attributed to fastener installation as in the case of the type IIA-A specimens. Fiber fracture also occurred in numerous lamina locations other than 21 through 23. Fiber fractures in lamina 10 of Specimens IIA-C-27 and IIA-C-6 are shown in Figures 24 and 25 (also refer to LDCC F-48 and F-51). A summary of the average number of fiber bundle fractures per lamina for each load level is presented in Table 14. The delaminations and fiber bundle fractures that were observed on the individual laminae are summarized on a load level basis in Table 12.

(d) Type IIB-A Specimens. Radiographs of these specimens indicated matrix cracks, delaminations and fiber fracture. In load level "A," DI were present in three of the five specimens but did not extend beyond the PFH. MCI were visible on only one specimen of the load level. The MCI in the 45° laminae of this one specimen were contained within the PFH, whereas the MCI in the 0° laminae extended from the edge of the fastener holes to the butt joint end of the strap detail. In load level "C," DI were present in only one of the five specimens and did not extend beyond the PFH. MCI were present in four of the five specimens of this load level. The MCI in the 45° laminae were contained within the PFH, while the MCI in the 0° laminae extended beyond the PFH and some to the butt-joint end of the strap detail. In load level "D," specimen detail IIBA-20B showed considerably more damage in the radiograph than the other specimens of this group. DI and MCI were extensive, and the deply inspection confirmed this condition. In other specimens in this group the DI were contained within the PFH. MCI in the 0° laminae extended beyond the PFH, and most extended from the fastener hole to the butt joint end of the strap detail. In load level "B," specimen detail IIB-A-27B showed considerably more damage in the radiograph than the other specimens of this group. For the other specimens of this load level, the DI were contained within the PFH. MCI in the 45° laminae were contained within the PFH while the majority of those in the 0° laminae extended from the fastener hole to the butt joint end of the strap detail. Fiber fracture indications were present in all load levels. The fiber fracture indications for the heavily damaged



F-48

HOLE-2

Figure 24. Fiber Fractures on Lamina 10 of Specimen II A-C-27

F-51

HOLE-1

Figure 25. Fiber Fractures on Lamina 10 of Specimen II A-C-6

NOTE: THIS VIEW IS REVERSED FROM THE NORMAL VIEW.

TABLE 14.

SUMMARY OF FIBER FRACTURE DAMAGE IN TYPE IIA
SPECIMENS FROM LAMINATE "C"

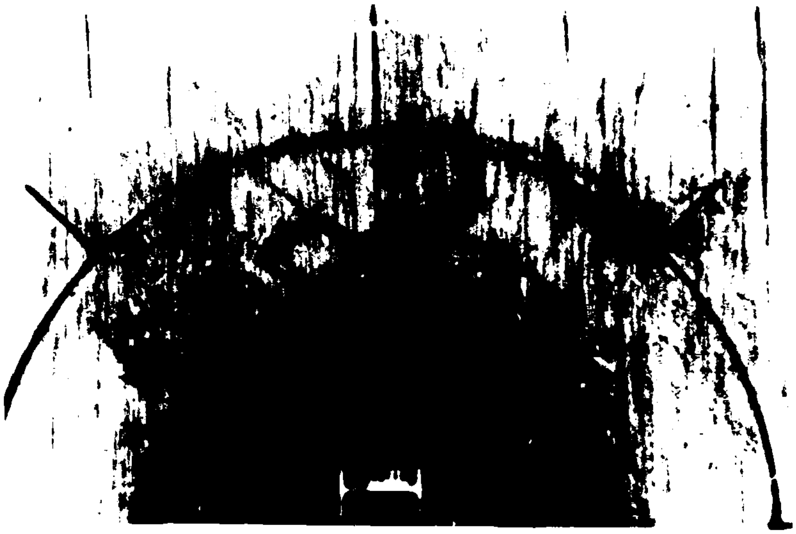
LAMINA NO.	ORIENT.	AVERAGE NUMBER OF FIBER FRACTURES PER LAMINA AT EACH LOAD LEVEL			
		A	C	D	B
1	+45	0.8	0	1.8	3.8
2	-45	1.8	0.8	3.6	7.2
3	0	2.0	2.4	4.4	9.8
4	90	0	0.2*	0	2.5
5	-45	2.8	1.8	11.0	14.0
6	+45	1.8	1.2	10.0	14.0
7	0	2.8	3.8	13.4	16.2
8	90	[illegible]	0	0.4*	6.2
9	+45	0.8	2.0	8.4	16.2
10	-45	2.0	1.4	5.2	13.2
11	0	1.0	1.4	5.0	14.8
12	90_2	0	0	0	0.8
13	0	0.2*	0	0.4*	7.8
14	-45	0	0	1.0	7.8
15	+45	0	0	1.0	6.8
16	90	0	0	0	1.5
17	0	0.5	0	0.8	7.5
18	+45	0	0	0	10.2
19	-45	0	0	0	6.2
20	90	0	0	1.0	3.2
21	0	2.2	3.0	4.0	11.2
22	-45	5.5	7.8	7.0	12.2
23	+45	5.0	4.8	6.6	6.8

*PRACTICALLY NO DAMAGE IN THESE SPECIMENS. THESE RECORDINGS ARE POSSIBLE DUE TO THE SENSITIVITY OF THE TECHNIQUE FOR FINDING VERY SMALL DAMAGE.

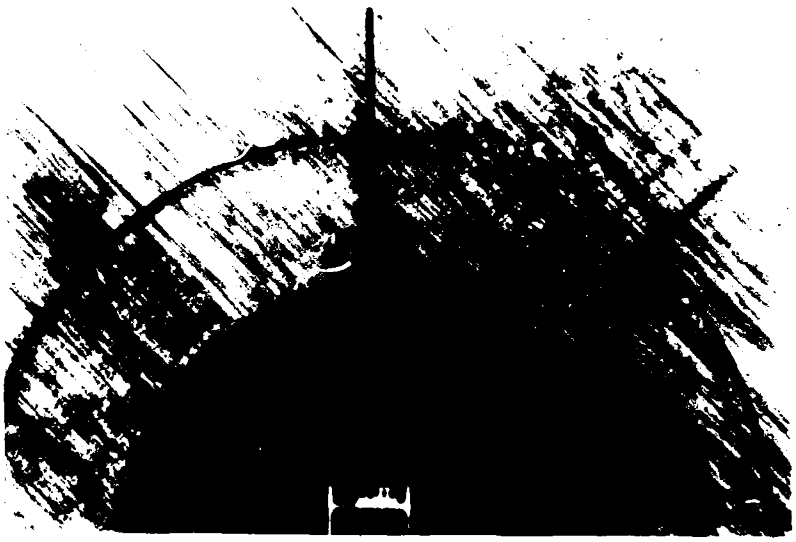
specimens in load levels "D" and "B" were very distinct, while some of the other indications require experience, gained from deply inspections, to interpret them. Radiographic indications of fiber fracture induced by fastener installation were not as evident in this specimen set (IIB-A) as in other specimen sets.

Deply inspection of the individual laminae revealed MCI in load levels "D" and "B". All load levels contained DI and fiber fracture. Fiber fractures in two laminae of Specimen IIB-A-27 are shown in Figure 26 (also refer to LDCC G-60). Fiber fracture was present to some extent in laminae 15, 16, and 17 in all load levels and as in the case of the type IIA-A specimens, a portion of the fracture in these three laminae can be attributed to fastener installation. Fiber fracture also occurred in numerous lamina locations other than 15 through 17. In load levels "D" and "B" one specimen contained significantly more damage than the other four specimens. A summary of the average number of fiber bundle fractures per lamina for each load level is presented in Table 15. Delaminations and fiber bundle fractures observed on the individual laminae are summarized on a load-level basis in Table 16. The exact details of these conditions can be seen in the LDCC of Appendix G.

(e) Type IIB-C Specimens, Indications of matrix cracks, delaminations and fiber fracture were present in the radiographs of these specimens. In load level "A", very faint DI were present in all specimens. Likewise MCI were present in all specimens of this load level and in three of the specimens they extended beyond the PFH in the 45° and 90° laminae. Apparent fiber fracture indications extended beyond the PFH in three of the specimens. Specimen detail IIB-C-3B showed considerable more damage in the radiograph than the other specimens of load level "A". In load level "C", the DI were very faint for four of the specimens and were contained within the PFH. In all specimens the MCI in the 45° and 90° laminae extended beyond the PFH. Apparent fiber fracture indications were present in all specimens and in two of the specimens these indications extended beyond the PFH with very distinct saw tooth features. Specimen detail IIB-C-24A



LAMINA 6 HOLE 2



LAMINA 13 HOLE 1

Figure 26. Fiber Fractures in Two Laminae of Specimen IIB-A-27

TABLE 15
SUMMARY OF FIBER FRACTURE DAMAGE IN TYPE IIB
SPECIMENS FROM LAMINATE A

LAMINA NO.	ORIENT.	AVERAGE NUMBER OF FIBER FRACTURES PER LAMINA AT EACH LOAD LEVEL			
		A	C	D (1)	B
1	+45	0	0	1.0 (0.3)	1.4 (1.3)
2	-45	0	0.2	1.0 (0.8)	2.6 (2.8)
3	0_2	0.8	1.0	4.4 (4.8)	5.8 (5.0)
4	-45	0.2	0.8	2.0 (1.5)	2.4 (2.3)
5	+45	0	0.6	1.0 (0.5)	4.6 (2.8)
6	0_2	0.6	2.4	4.4 (3.3)	10.0 (7.8)
7	+45	0	0	1.2 (0.5)	3.4 (1.3)
8	-45	0	0.8	1.4 (0.8)	5.2 (2.8)
9	0_2	0	0	1.8 (0.8)	2.8 (2.3)
10	-45	0	0	0.8 (0)	2.6 (1.5)
11	+45	0	.2	1.0 (0)	0.8 (0.3)
12	0_2	0	0.6	1.8 (0.5)	0.6 (0)
13	+45	0	0	0.6 (0)	0.4 (0)
14	-45	0	0	1.0 (0)	0.8 (0.3)
15	0_2	1.8	1.6	2.0 (1.5)	2.0 (2.0)
16	-45	3.6	2.2	2.5 (2.8)	3.2 (2.8)
17	+45	3.6	4.2	2.2 (2.0)	4.2 (4.3)

(1) 1.0 (0.3) NUMBER NOT CONTAINED IN PARENTHESES INDICATES AVERAGE NUMBER OF FIBER FRACTURES PER LAMINA BASED ON FIVE SPECIMENS. NUMBER IN PARENTHESES INDICATES AVERAGE NUMBER OF FIBER FRACTURES PER LAMINA BASED ON FOUR SPECIMENS.

TABLE 16.

SUMMARY OF DAMAGE OBSERVED ON THE
INDIVIDUAL LAMINA OF TYPE IIB SPECIMENS

	LAMINATE "A"					LAMINATE "C"				
	LOAD		FIBER FRACT.		DELAM	LOAD		FIBER FRACT.		DELAM
LOAD LEVEL	POUNDS	% OF AUG.ULT.	%(1)	PER(2) LAMINA	% (3)	POUNDS	% OF AVG.ULT.	%(1)	PER (2) LAMINA	% (3)
A	5000	64	19	0.58	48	6850	76	50	2.1	73(3)
C	5614	72	29	0.85	73 (4)	7000	78	45	1.48	100(7)
D	6238	80	53 (7)	1.79	59 (14)	7149	79	38	1.43	91(10)
B	6824	88	71 (13)	3.13	76 (20)	7255	81	58	2.48	98(14)

(1) 71(13) - 71 INDICATES PERCENT OF LAMINAE THAT CONTAINS FIBER FRACTURE
- (13) INDICATES PERCENT OF LAMINAE THAT CONTAINS FIBER FRACTURE THAT EXTENDS BEYOND THE PERIPHERY OF FASTENER HEAD.

(2) 0.79 - AVERAGE NUMBER OF FIBER FRACTURE PER LAMINA (TOTAL NUMBER OF FIBER FRACTURES COUNTED ON ALL LAMINAE DIVIDED BY THE TOTAL NUMBER OF LAMINAE)

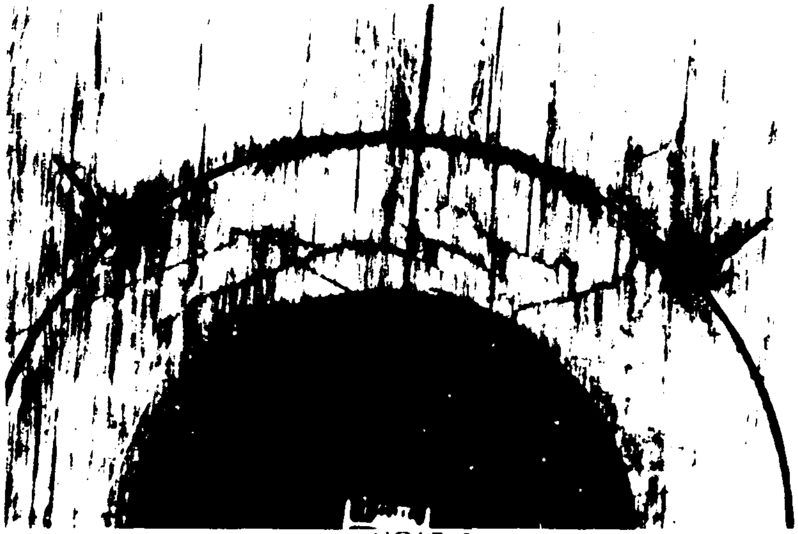
(3) 76 (20) - INDICATES PERCENT OF LAMINAE THAT CONTAINS SOME DELAMINATION (20) INDICATES PERCENT OF LAMINAE THAT CONTAINS AT LEAST ONE DELAMINATION THAT EXTENDS BEYOND PERIPHERY OF FASTENER HEAD.

showed considerably more damage in the radiograph than the other specimens of load level "C". In load level "D", the DI were very pronounced for four of the specimens and extended beyond the PFH. The MCI in the 45^{o} and 90^{o} laminae extended beyond the PFH in all specimens whereas the MCI for the 0^{o} laminae were present in the radiographs of only two specimens. Apparent fiber fracture indications were present in all specimens with two of the specimens having saw tooth indications in the 0^{o} direction. The radiograph of specimen IIB-C-1B indicated more damage than the radiographs of the other specimens of load level "D". In load level "B", DI and MCI extended beyond the PFH of all specimens with the MCI for the 45^{o} and 90^{o} laminae being more distinct than for the 0^{o} laminae. The radiographs of all specimens in this load level contained indications of fiber fracture. Four of these specimens had saw tooth indications in the 0^{o} direction that extended beyond the PFH. In this load level, specimen detail II B-C-6B showed more damage in the radiograph than the details of the other specimens. The saw tooth fiber fracture indications in load levels "C", "D" and "B" are quite easy to identify in radiographs although one may have to use a pocket magnifier to see the saw tooth effect.

Deply inspection of the individual laminae revealed MCI on the surface of some of the laminae in load levels "D" and "B". Fiber fractures in lamina 9 of load level "D" specimen IIB-C-1 are shown in Figure 27. Fiber fractures in lamina 11 of load level "B" specimens are shown in Figure 28. The charted damage for these two figures is shown in LDCC H-45 and H-60. All load levels contained DI and fiber fracture. A portion of the fiber fractures in the three laminae adjacent to the fastener head (21, 22 and 23) can be attributed to fastener installation and/or removal. Excluding the lamina adjacent to the fastener head (lamina 23), the largest percentages of fiber fracture occurred in the 5th (-45^{o}) and 7th (0^{o}), laminae in from the faying surface of the joint. In each load level, one specimen contained significantly more fiber fracture than the other four specimens. A summary of the average number of fiber fractures per lamina for each load level is presented in Table 17. Delaminations

HOLE-1

Figure 27. Fiber Fractures on Lamina 9 of Load Level "D" Specimen II B-C-1



HOLE-1

Figure 28. Fiber Fractures on Lamina II of Load Level "B" Specimen II B-C-6

TABLE 17.
SUMMARY OF FIBER FRACTURE DAMAGE IN TYPE IIB SPECIMENS FROM LAMINATE "C"

LAMINA NO.	ORIENT	AVERAGE NUMBER OF FIBER FRACTURES PER LAMINA AT EACH LOAD LEVEL			
		A	C	D	B
1	+45	0.4(0.2)	1.0(0.8)	1.2(0.8)	0.4(0.3)
2	-45	2.2(1.8)	2.2(2.3)	1.6(1.5)	2.2(2.3)
3	0	2.6(2.3)	2.6(2.3)	1.4(1.3)	3.8(3.5)
4	90	0(0)	0(0)	0.2(0)	0.4(0.3)
5	-45	7.4(5.3)	3.0(2.5)	3.8(2.0)	6.6(5.5)
6	+45	5.4(4.0)	3.0(2.3)	2.2(0)	5.8(5.0)
7	0	8.6(7.8)	5.4(4.8)	4.8(3.8)	8.0(7.8)
8	90	0.8(0.5)	0(0)	0(0)	1.2(0.5)
9	+45	4.1(2.8)	3.0(1.8)	1.2(0.3)	3.2(2.0)
10	-45	3.8(3.0)	1.8(1.0)	2.0(0.8)	3.2(2.0)
11	0	2.6(1.8)	2.4(1.3)	0(0)	4.4(2.5)
12	90_2	0(0)	0(0)	0(0)	0(0)
13	0	0.2(0)	0.8(0.5)	0(0.3)	0.6(0.5)
14	-45	0(0)	0.2(0)	0(0)	1.2(0.5)
15	+45	0(0)	0.6(0.5)	0(0)	0.6(0.3)
16	90	0(0)	0(0)	0(0)	0.2(0)
17	0	0(0.5)	1.0(1.0)	0(0.5)	0.2(0)
18	+45	0(0)	0(0)	0(0.8)	0(0)
19	-45	0(0)	0(0)	0(0)	0(0)
20	90	0(0)	0(0)	0(0)	0.6(0)
21	0	0(2.3)	1.0(0.8)	1.4(1.0)	2.2(2.0)
22	-45	3.6(3.3)	(2.3)	5.4(5.0)	4.4(5.0)
23	+45	4.4(4.5)	4.2(4.3)	6.8(7.0)	7.8(8.3)

(1) 1.0 (0.3) NUMBER NOT IN PARENTHESES IS AVERAGE OF FIVE SPECIMENS
NUMBER IN PARENTHESES IS AVERAGE OF FOUR SPECIMENS

(2) 1.0 (0) "0" IN PARENTHESES INDICATES ALL FIBER FRACTURES IN SPECIMEN WITH THE MOST OVERALL DAMAGE

0 (2.3) "0" NOT IN PARENTHESES INDICATES NO FIBER FRACTURES IN SPECIMEN WITH THE MOST OVERALL DAMAGE.

and fiber bundle fractures observed on the individual laminae are summarized on a load-level basis in Table 16. The exact details of damage can best be seen in the LDCC of Appendix H.

REFERENCES

1. J. L. Rose and W. Shelton, "Damage Analysis in Composite Materials," Composite Reliability, ASTM STP 580, p. 215 f.

2. J. P. Mandell, F. J. McGarry, J. I, and V. Meier, "Fiber Orientation, Crack Velocity, and Cyclic Loading Effects on the Mode of Crack Extension in Fiber Reinforced Plastics," Failure Modes in Composites II, May 1974, p. 33.

3. S. M. Freeman, "Characterization of Lamina and Interlaminar Damage in Graphite-Epoxy Composites by the Deply Technique," paper presented at American Society for Testing and Materials Sixth Conference on Materials: Testing and Design, Phoenix, Arizona, May 1981.

APPENDIX A

DETAIL DAMAGE INFORMATION FOR TYPE I SPECIMENS

The detail information for the Type I specimens of Laminate A is presented in this appendix. It is presented in the order of increasing load levels. All specimens of the same load level are grouped together. Three figures are presented for each specimen. The first figure gives specimen type, laminate information, load conditions and expected number of fiber bundle fractures based on Acoustic Emission monitoring. The second figure consists of positive prints of enhanced x-ray radiographs made before and after loading. In addition, prints of a stereo x-ray pair are included for one specimen of each load level. The third figure consists of a Lamina Damage Characterization Chart. This chart contains a pictorial sketch for each lamina with fiber orientations indicated on one side or edge of each sketch. The damage observed on each lamina is recorded on the appropriate sketch in a manner to indicate size and location relative to the open hole.

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - A

POUNDS LOAD - 14,500 PERCENT OF ULTIMATE - 60

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-1. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-1.

BEFORE LOADING AFTER LOADING

FIGURE A-2. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-1.

PRECEDING PAGE BLANK-NOT FILMED

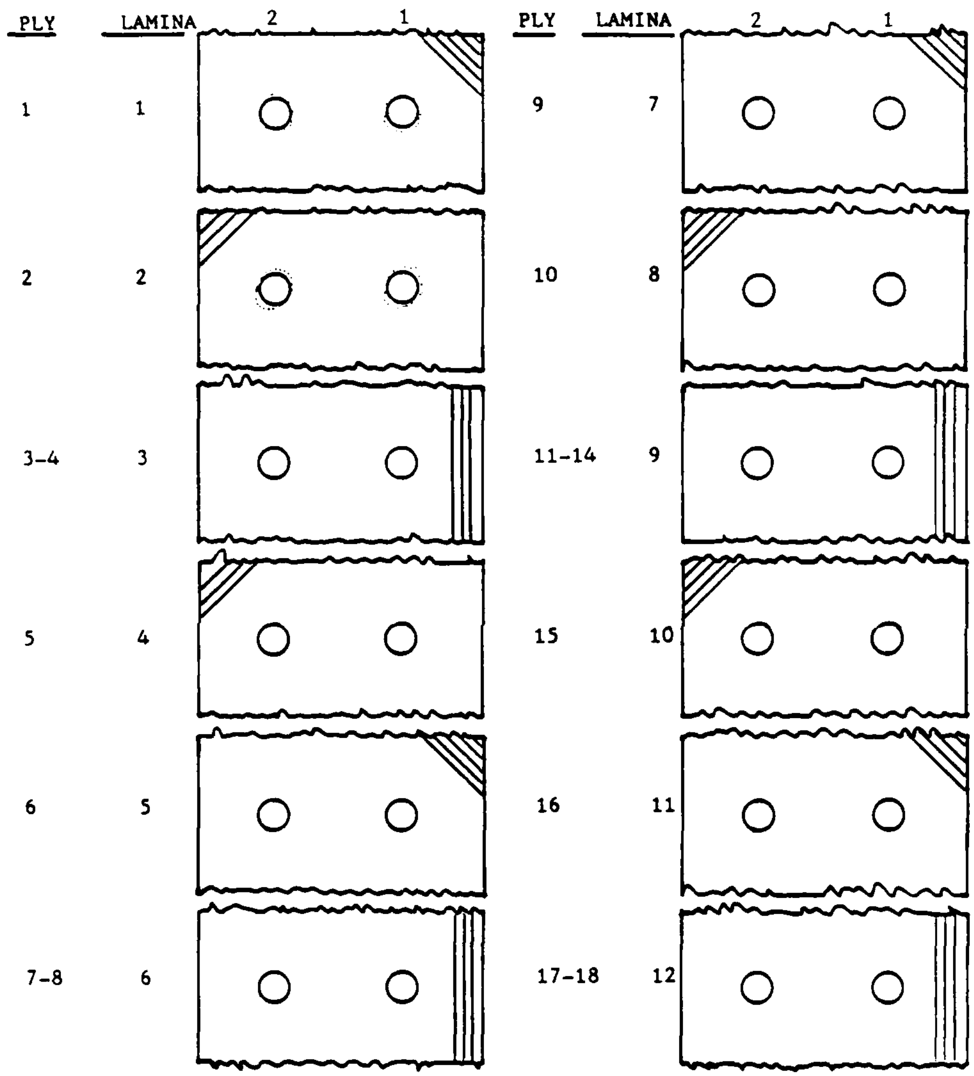


Figure A-3. Lamina Damage Characterization Chart for Specimen I-A-1 Load Level A (Continued)

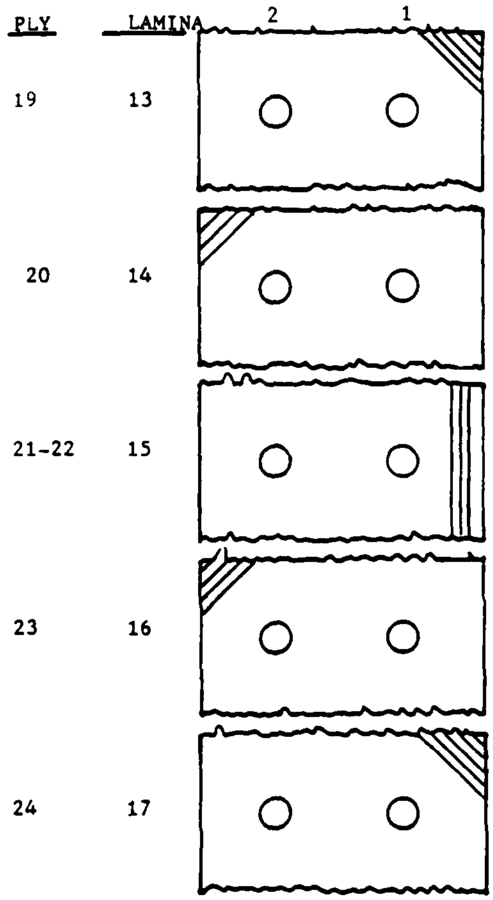


Figure A-3. Lamina Damage Characterization Chart for Specimen I-A-1 Load Level A

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - A

POUNDS LOAD - 14,500 PERCENT OF ULTIMATE - 60

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-4. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-8.

BEFORE LOADING

AFTER LOADING

FIGURE A-5. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-8.

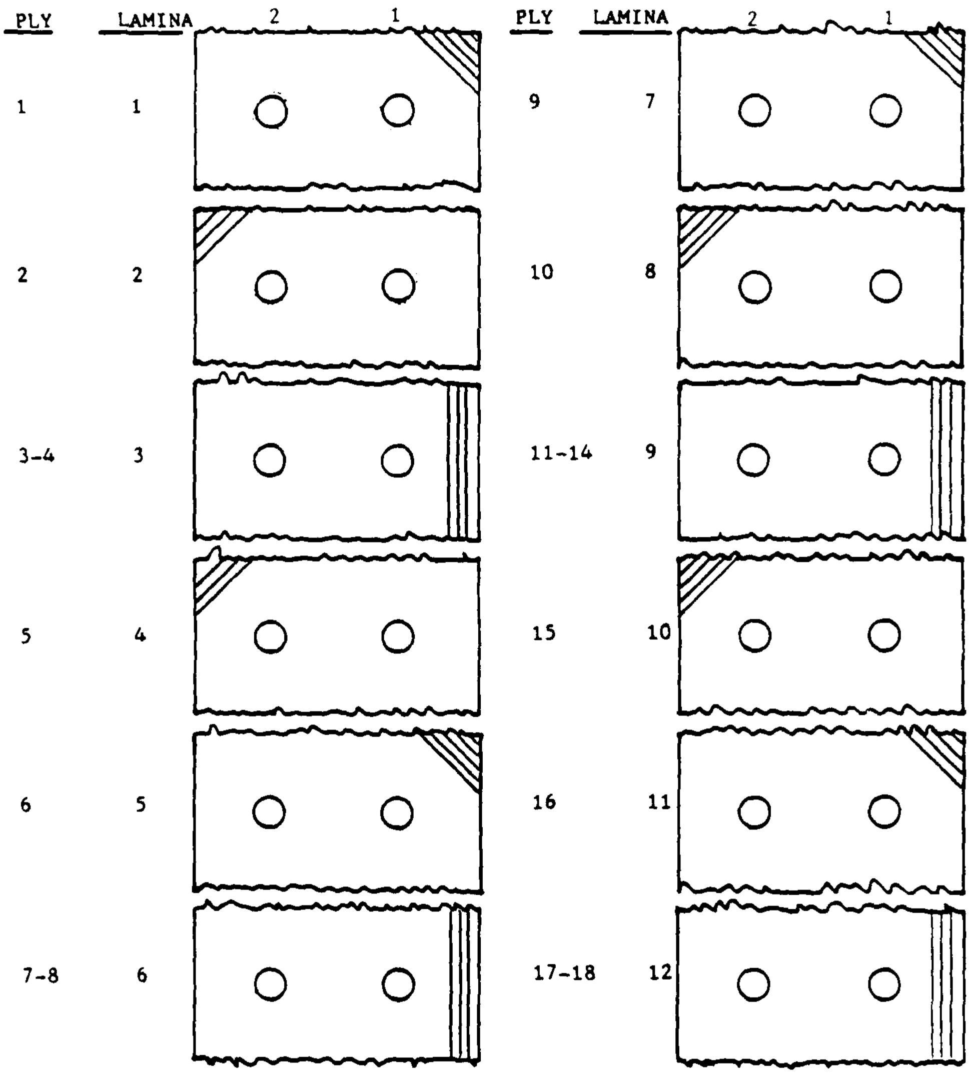


Figure A-6. Lamina Damage Characterization Chart for Specimen
I-A- 8 Load Level A (Continued)

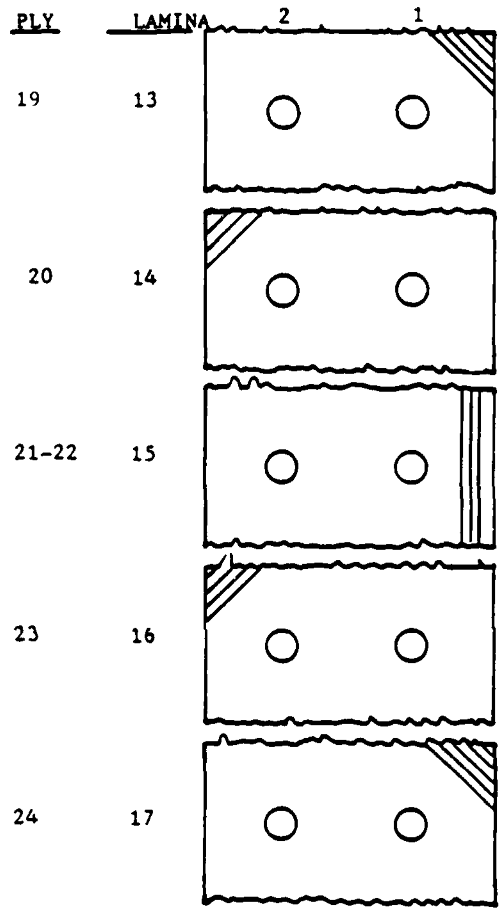


Figure A-6. Lamina Damage Characterization Chart for Specimen I-A-8 Load Level A

SPECIMEN TYPE - I(OPEN HOLE)

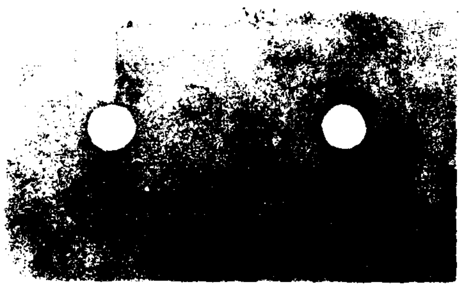
LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - A

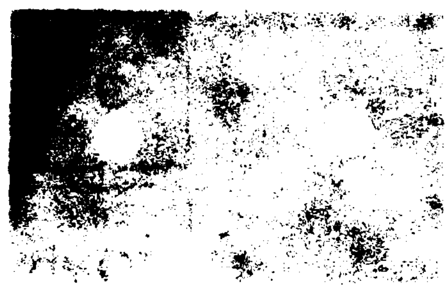
POUNDS LOAD - 14,500 PERCENT OF ULTIMATE - 60

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-7. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-26.



BEFORE LOADING



AFTER LOADING

FIGURE A-8. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-26.

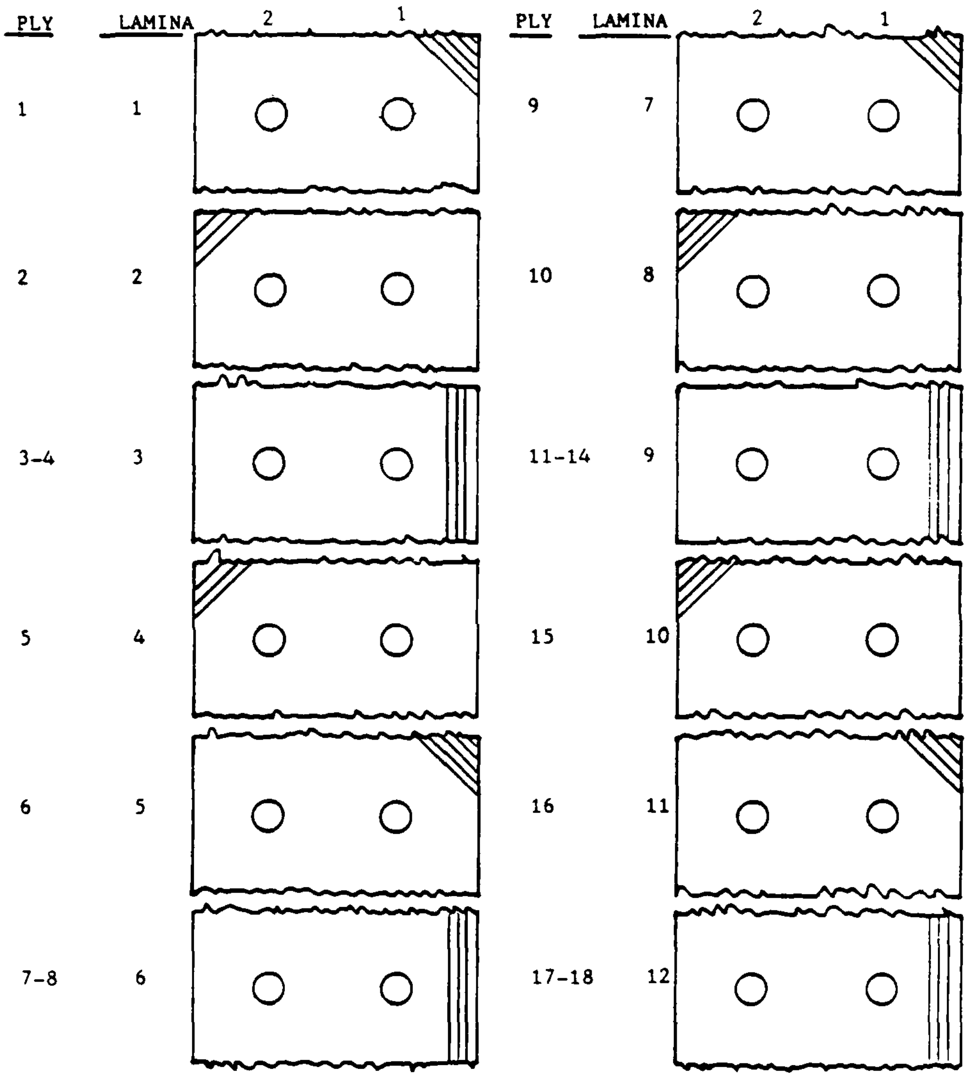


Figure A-9. Lamina Damage Characterization Chart for Specimen I-A- 26 Load Level A (Continued)

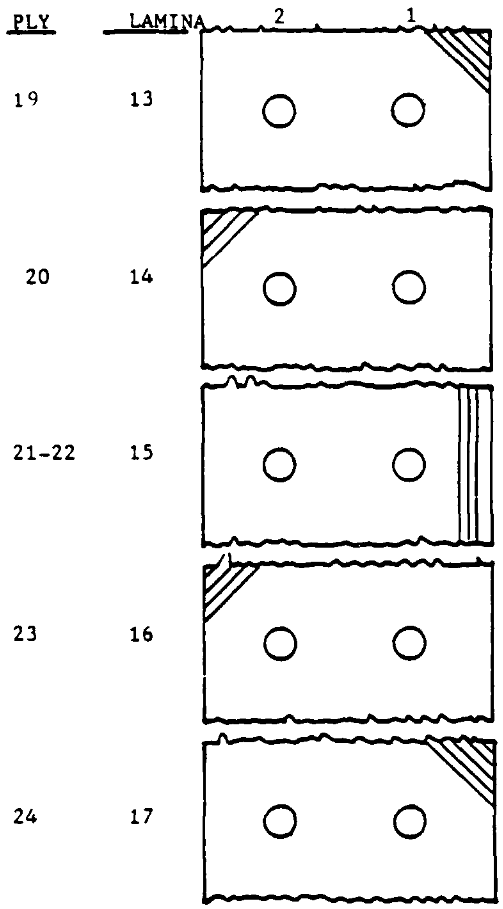


Figure A-9. Lamina Damage Characterization Chart for Specime
I-A-26 Load Level A

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - A($\pm 45^{\circ}$, $0_2{}^{\circ}$, $\mp 45^{\circ}$, $0_2{}^{\circ}$, $\pm 45^{\circ}$, $0_2{}^{\circ}$)s

LOAD LEVEL - A

POUNDS LOAD - 14,500 PERCENT OF ULTIMATE - 60

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-10. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-16.

BEFORE LOADING AFTER LOADING

FIGURE A-11. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-16.

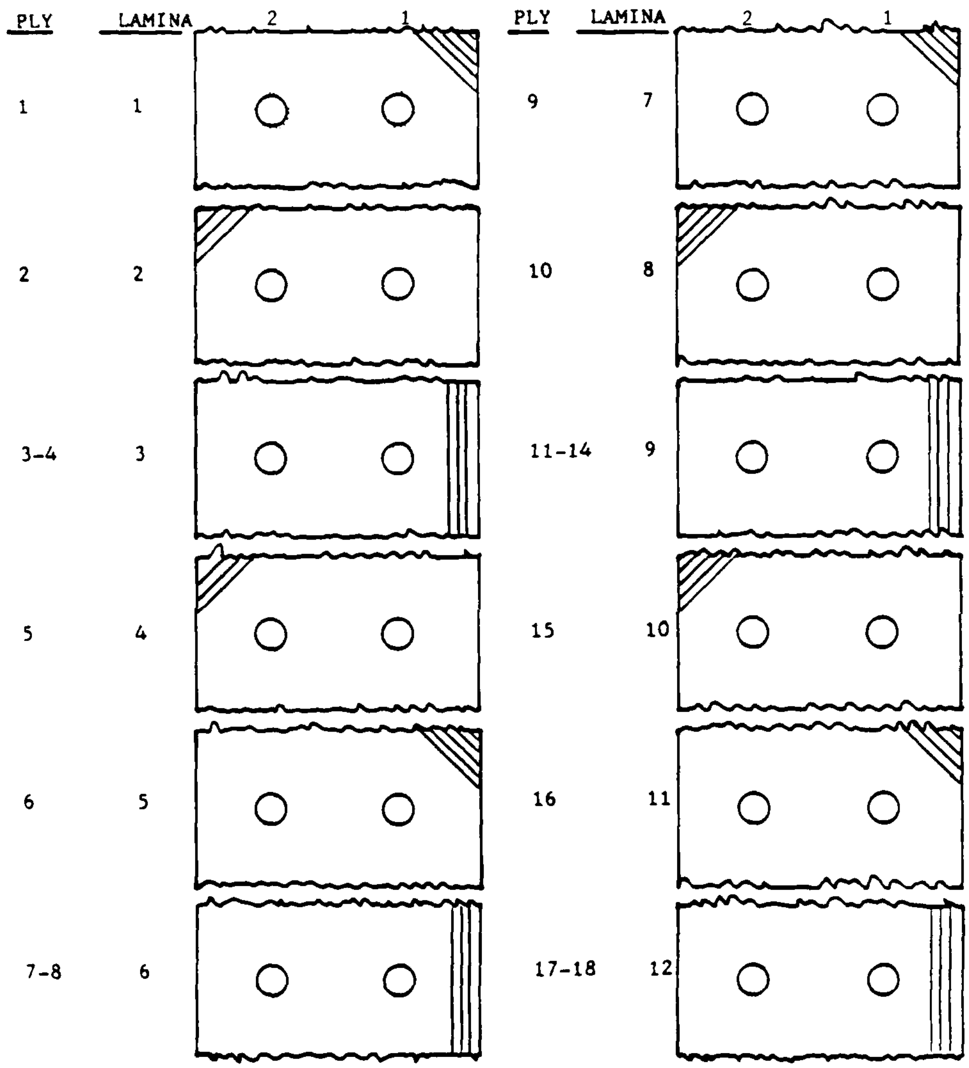


Figure A-12. Lamina Damage Characterization Chart for Specimen I-A- 16 Load Level A (Continued)

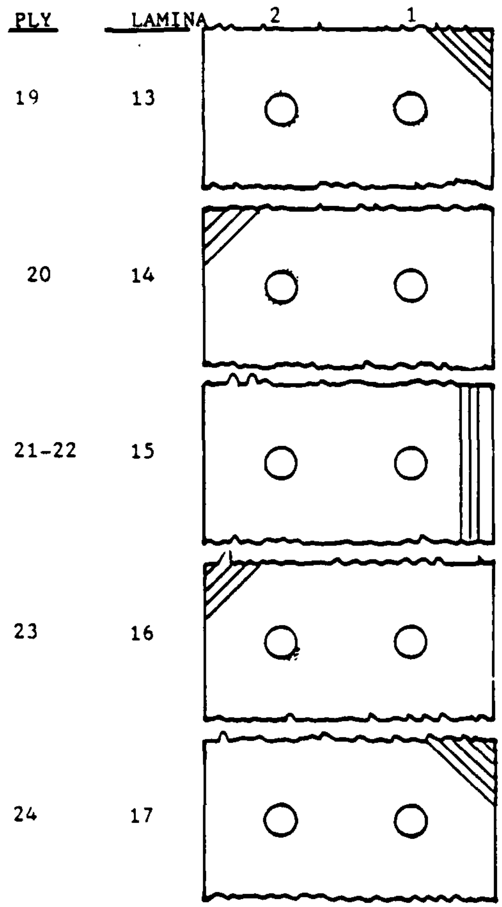


Figure A-12. Lamina Damage Characterization Chart for Specimen I-A- 16 Load Level A

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - A($\pm 45^{\circ}$, $0_2{}^{\circ}$, $\mp 45^{\circ}$, $0_2{}^{\circ}$, $\pm 45^{\circ}$, $0_2{}^{\circ}$)s

LOAD LEVEL - A

POUNDS LOAD - 14,500 PERCENT OF ULTIMATE - 60

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES
BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-13. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-21.

BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE A-14. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-21.

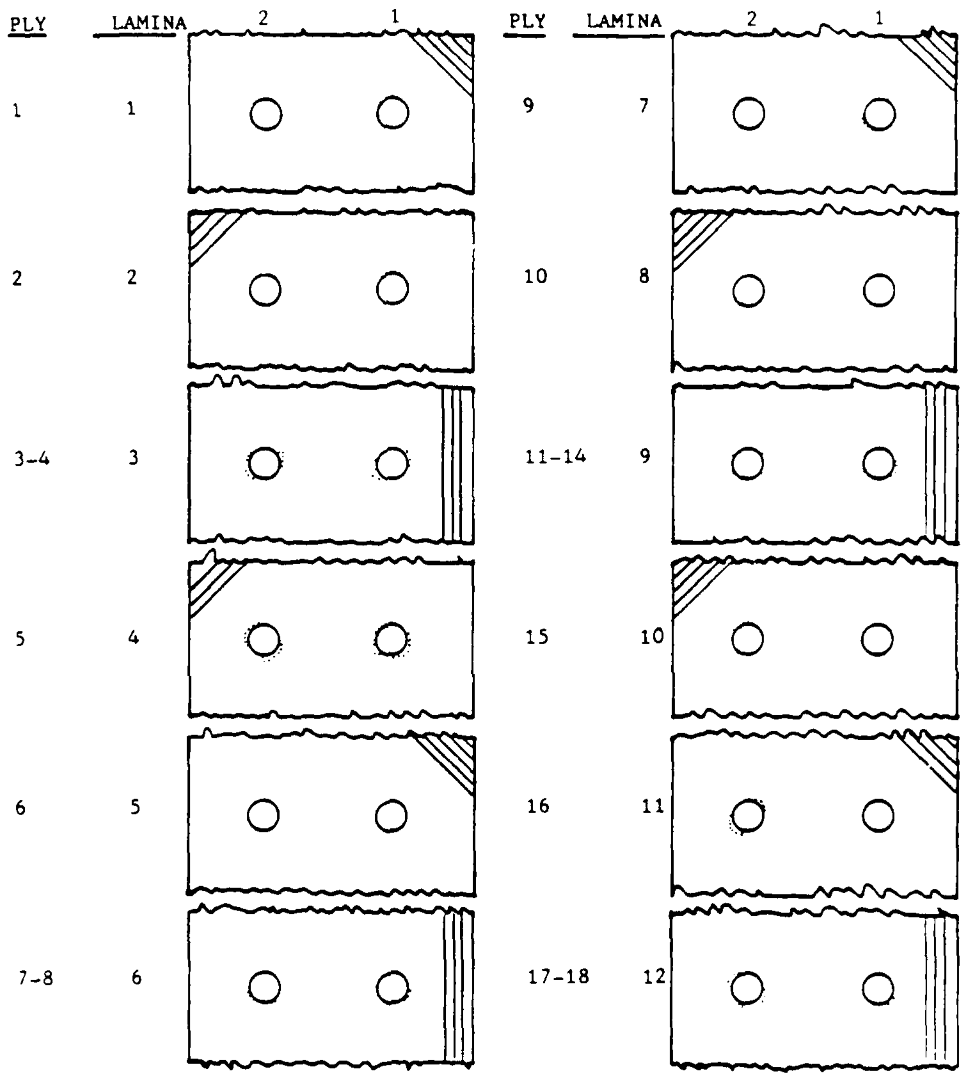


Figure A-15. Lamina Damage Characterization Chart for Specimen I-A- 21 Load Level A (Continued)

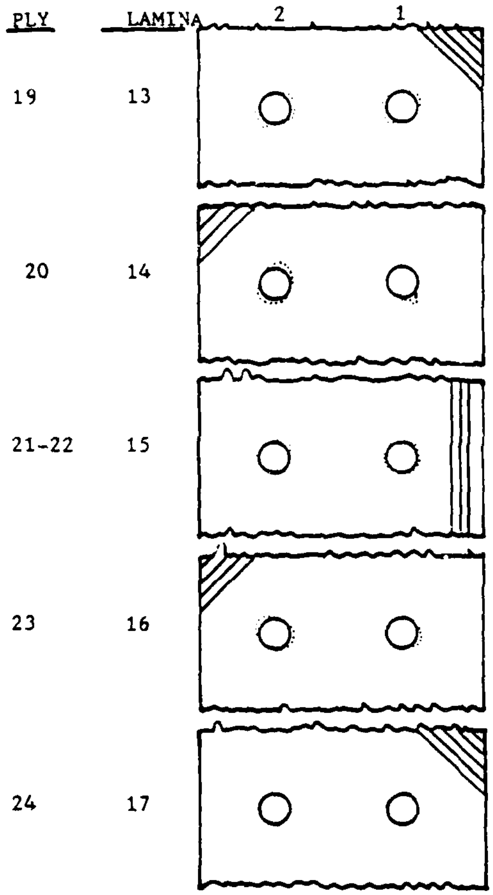


Figure A-15. Lamina Damage Characterization Chart for Specime I-A-21 Load Level A

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - C

POUNDS LOAD - 16,708 PERCENT OF ULTIMATE - 69

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-16. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-3.

BEFORE LOADING AFTER LOADING

FIGURE A-17. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-3.

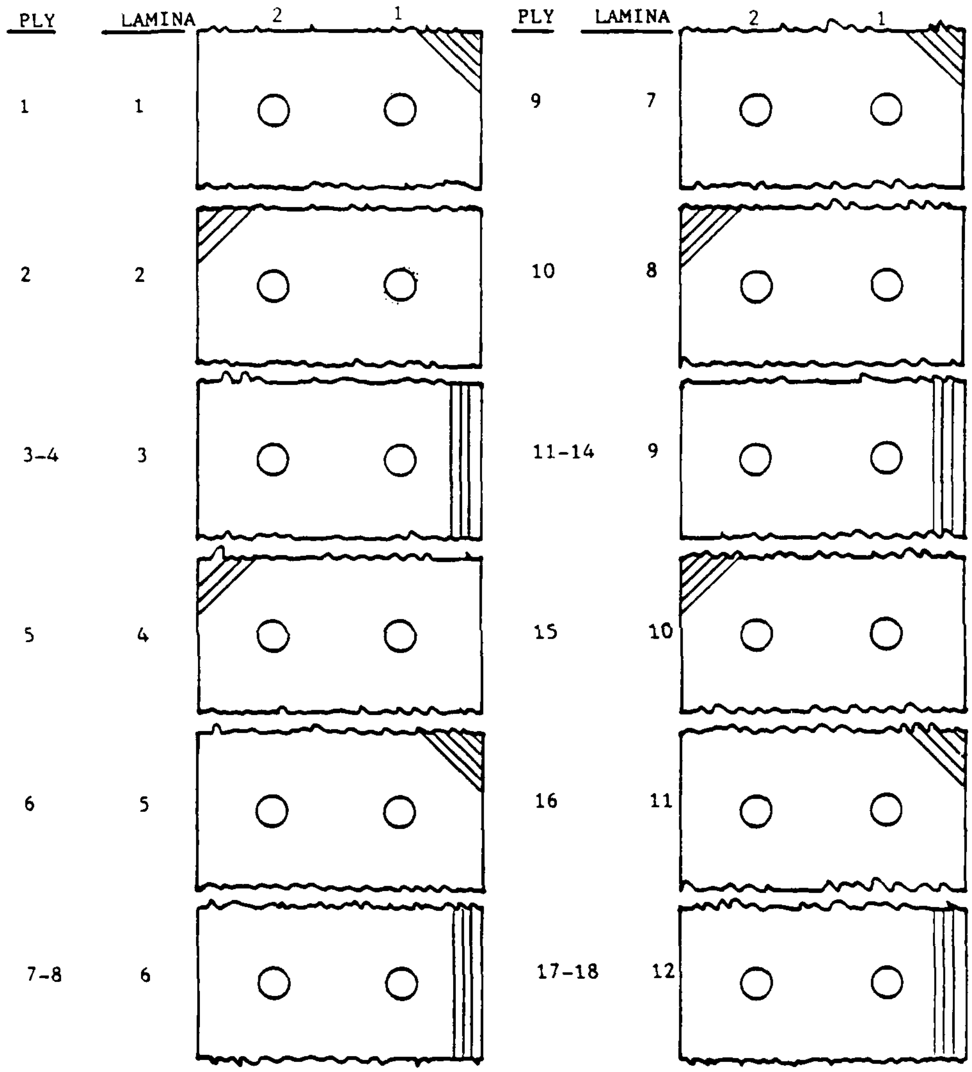


Figure A-18. Lamina Damage Characterization Chart for Specimen
I-A-3 Load Level C (Continued)

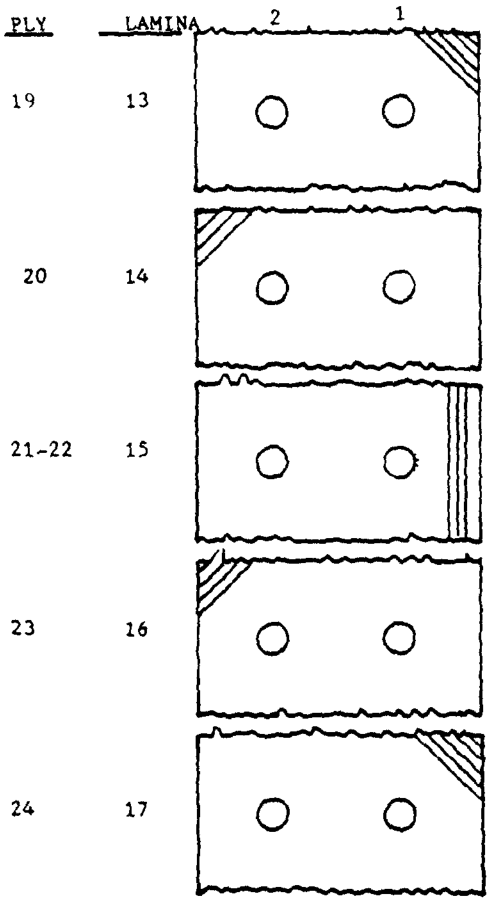


Figure A-18. Lamina Damage Characterization Chart for Specimen I-A-3 Load Level C

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - A($\pm 45^\circ$, $0_2{}^\circ$, $\mp 45^\circ$, $0_2{}^\circ$, $\pm 45^\circ$, $0_2{}^\circ$)s

LOAD LEVEL - C

POUNDS LOAD - 16,708 PERCENT OF ULTIMATE - 69

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-19. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-11.

BEFORE LOADING

AFTER LOADING

FIGURE A-20. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-11.

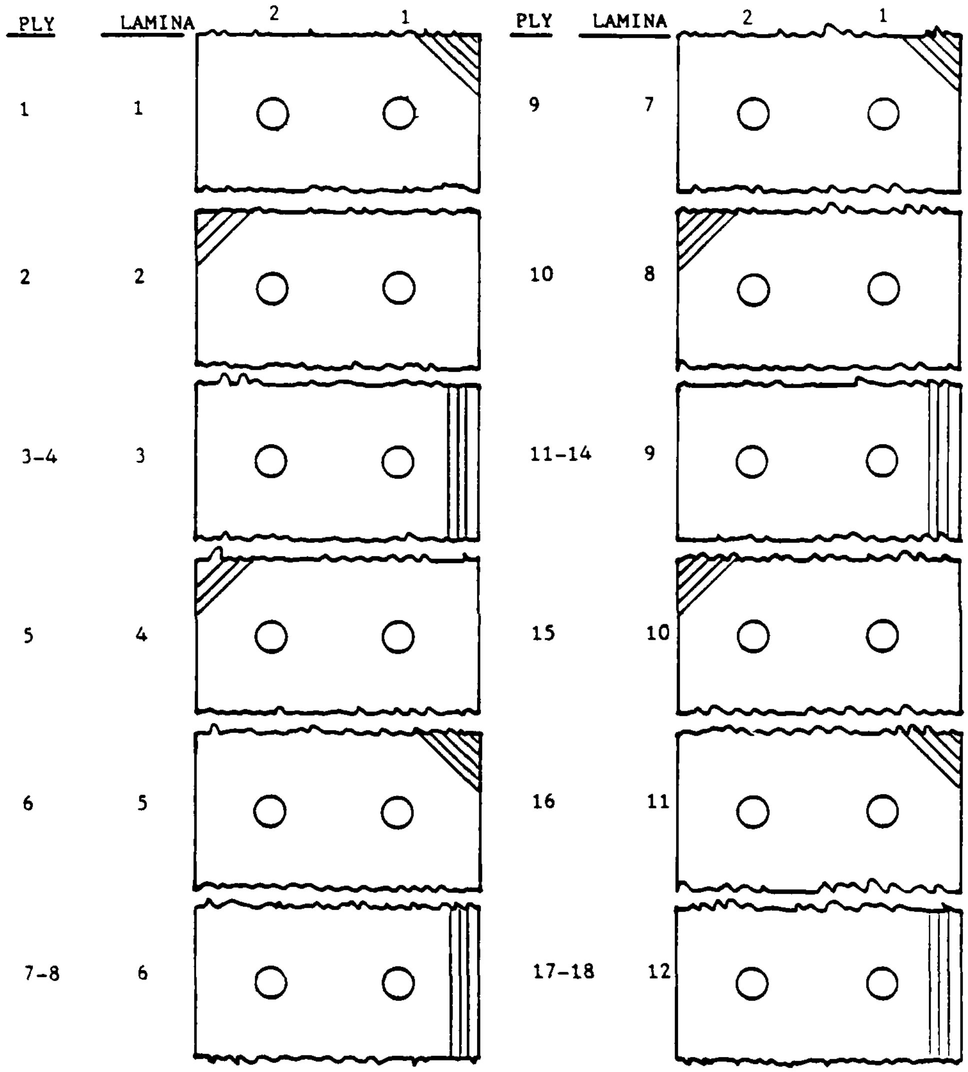


Figure A-21. Lamina Damage Characterization Chart for Specimen I-A-11 Load Level C (Continued)

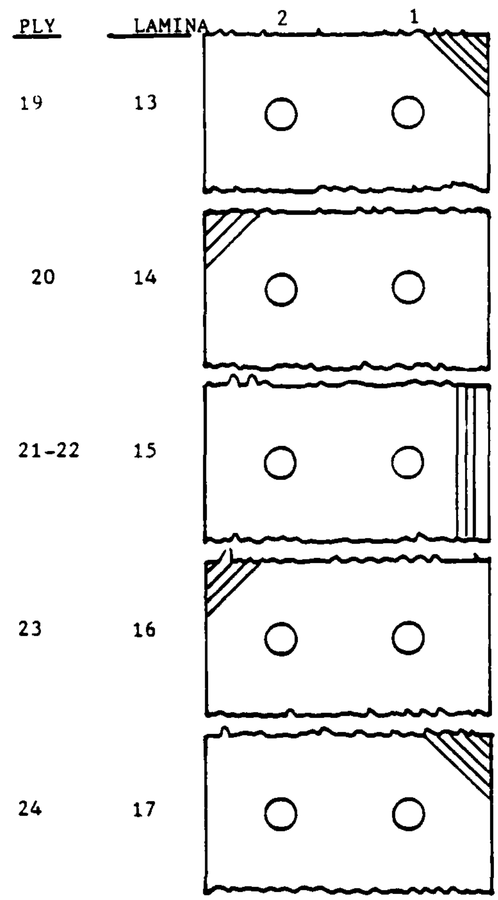


Figure A-21. Lamina Damage Characterization Chart for Specimen I-A-11 Load Level C

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - C

POUNDS LOAD - 16,708 PERCENT OF ULTIMATE - 69

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-22. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-19.

BEFORE LOADING AFTER LOADING

FIGURE A-23. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-19.

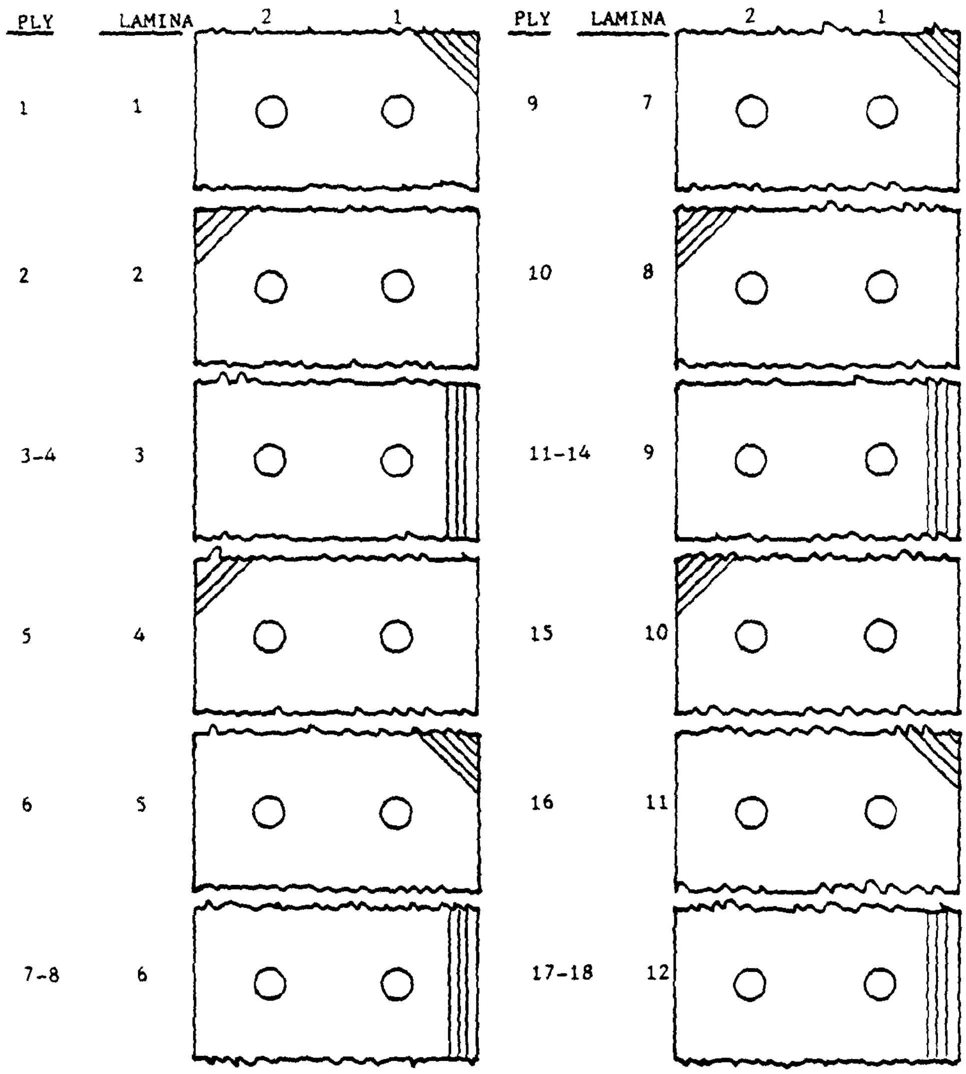


Figure A-24. Lamina Damage Characterization Chart for Specimen I-A-19 Load Level C (Continued)

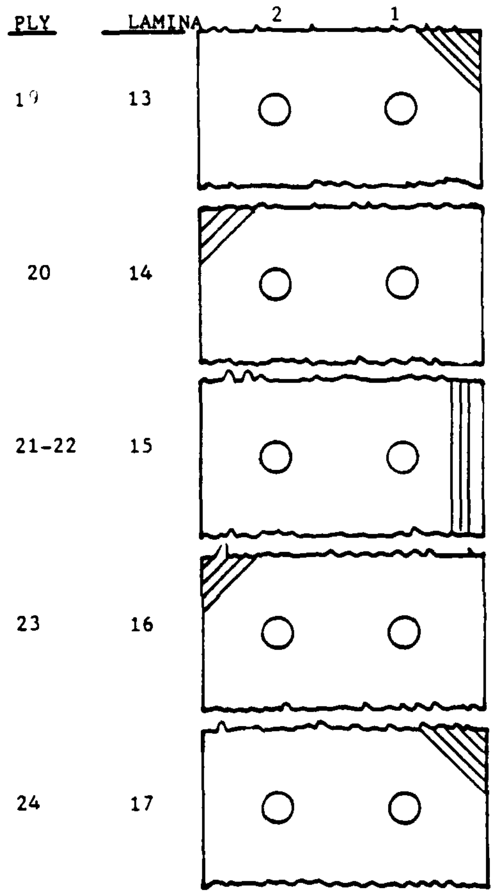


Figure A-24. Lamina Damage Characterization Chart for Specime
I-A-19 Load Level C

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - A($\pm45^\circ$, 0_2°, $\mp45^\circ$, 0_2°, $\pm45^\circ$, 0_2°)s

LOAD LEVEL - C

POUNDS LOAD - 16,708   PERCENT OF ULTIMATE - 69

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-25. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-22.

BEFORE LOADING   AFTER LOADING

FIGURE A-26. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-22.

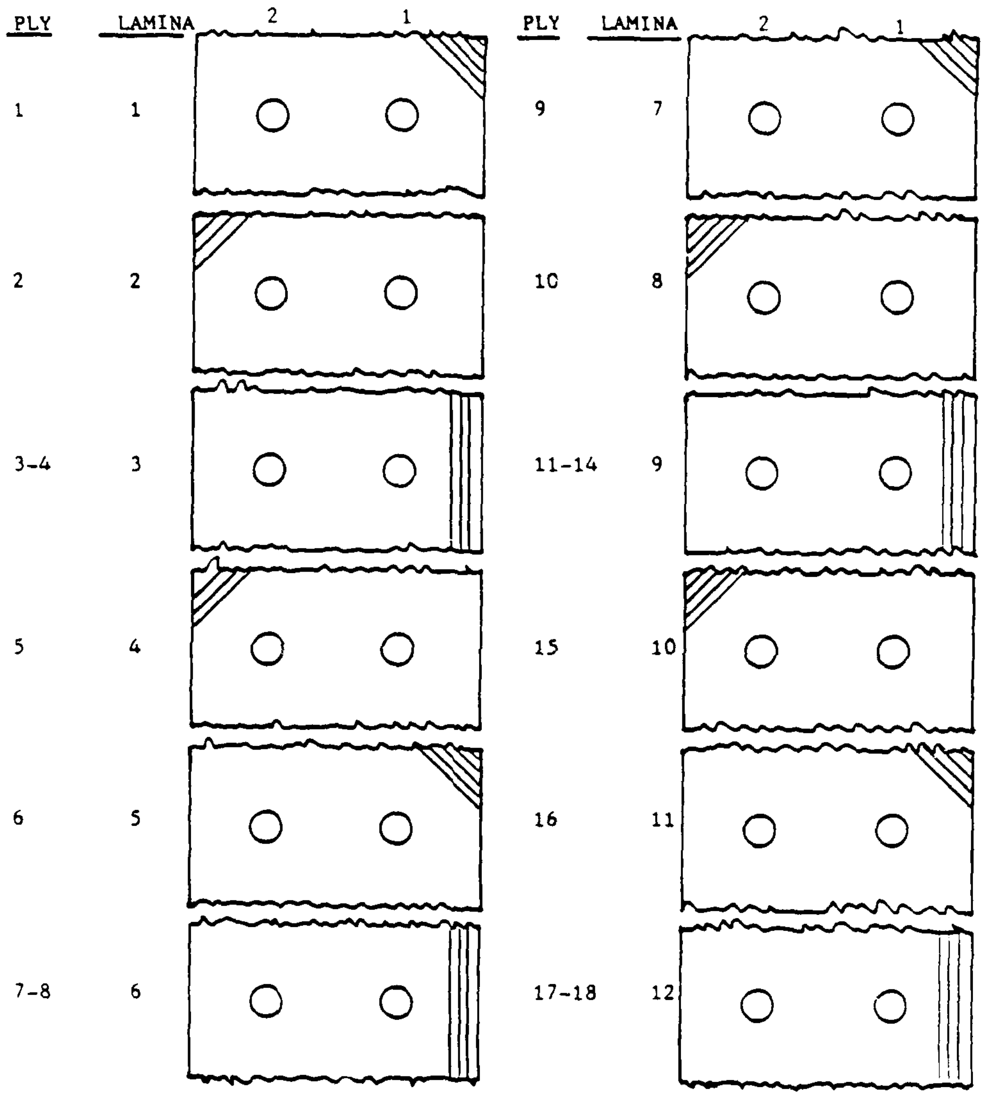


Figure A-27. Lamina Damage Characterization Chart for Specimen I-A-22 Load Level C (Continued)

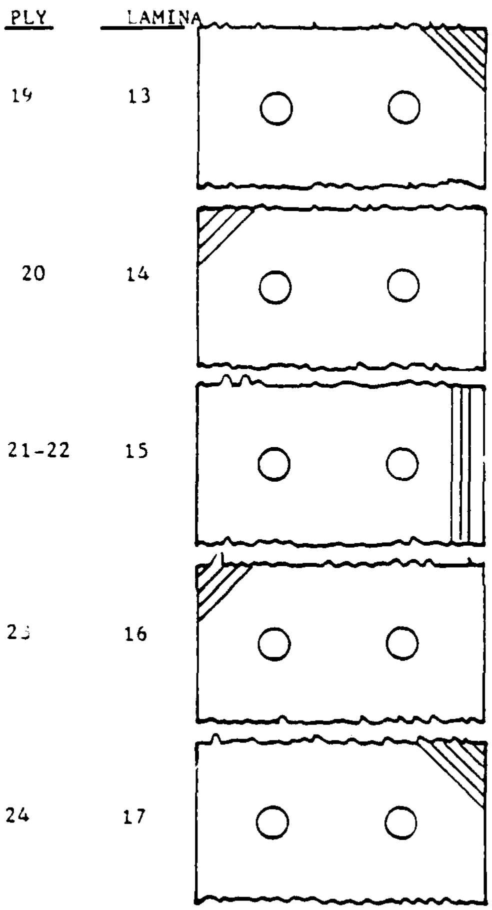


Figure A-27. Lamina Damage Characterization Chart for Specimen I-A-22 Load Level C

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - C

POUNDS LOAD - 16,708 PERCENT OF ULTIMATE - 69

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES
BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-28. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-9.

BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

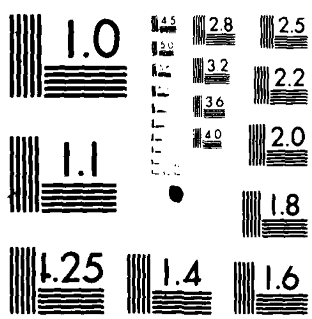
FIGURE A-29. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-9.

AD-A116 120 LOCKHEED-GEORGIA CO MARIETTA F/G 11/4
DAMAGE PROGRESSION IN GRAPHITE-EPOXY BY A DEPLYING TECHNIQUE.(U)
DEC 81 S M FREEMAN F33615-80-C-3224
UNCLASSIFIED LG-81ER0245 AFWAL-TR-81-3157 NL

2 of 6

UNC

116120



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

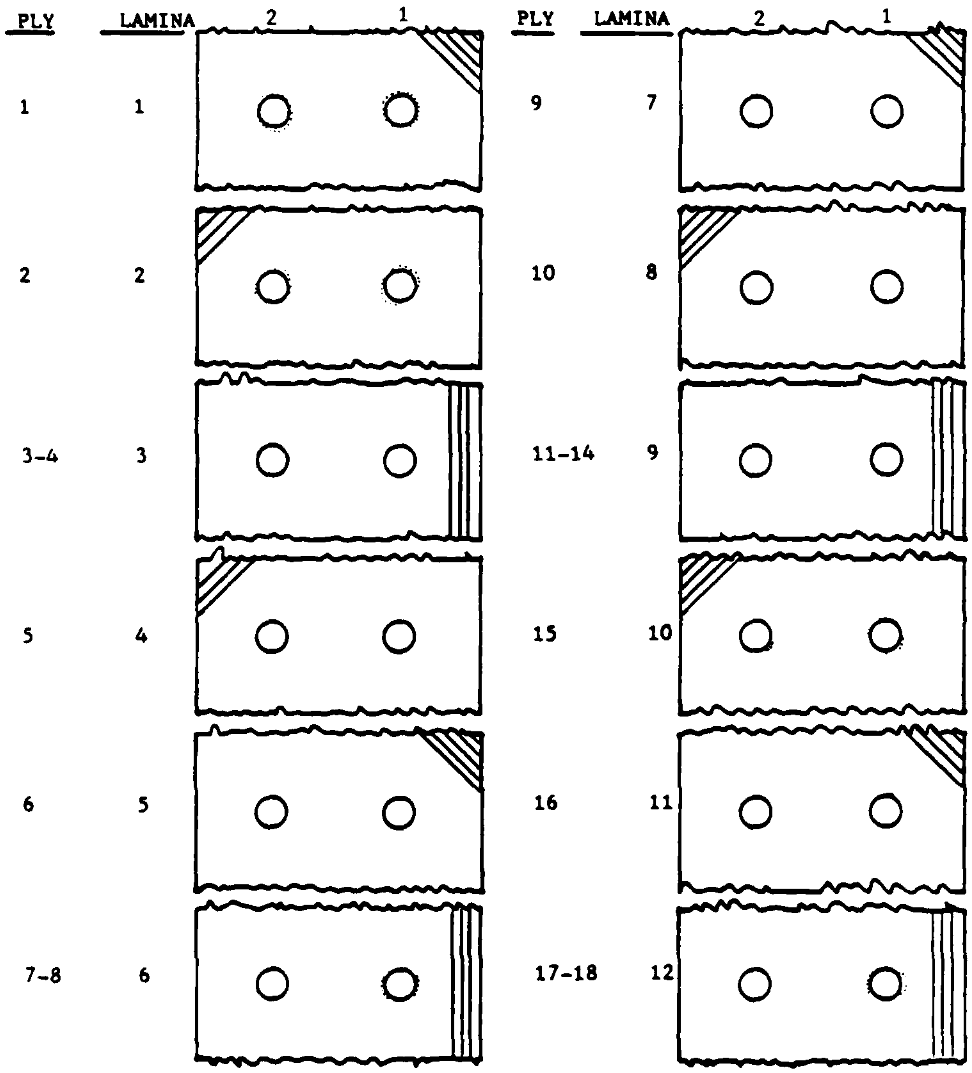


Figure A-30. Lamina Damage Characterization Chart for Specimen I-A- 9 Load Level C (Continued)

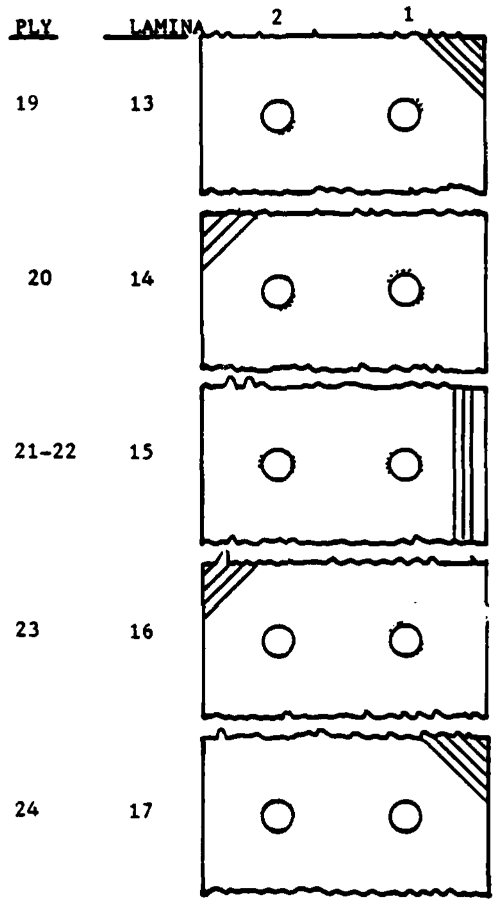


Figure A-30. Lamina Damage Characterization Chart for Specimen
I-A-9 Load Level C

SPECIMEN TYPE - I(OPEN HOLE)

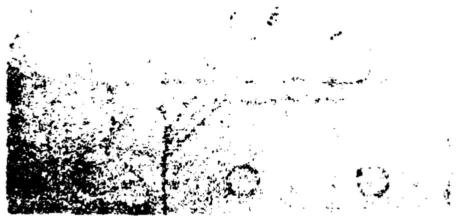
LAMINATE - A($\pm 45^\circ$, 0_2°, $\mp 45^\circ$, 0_2°, $\pm 45^\circ$, 0_2°)s

LOAD LEVEL - D

POUNDS LOAD - 18,917   PERCENT OF ULTIMATE - 79

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-31. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-17.



BEFORE LOADING   AFTER LOADING

FIGURE A-32. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-17.

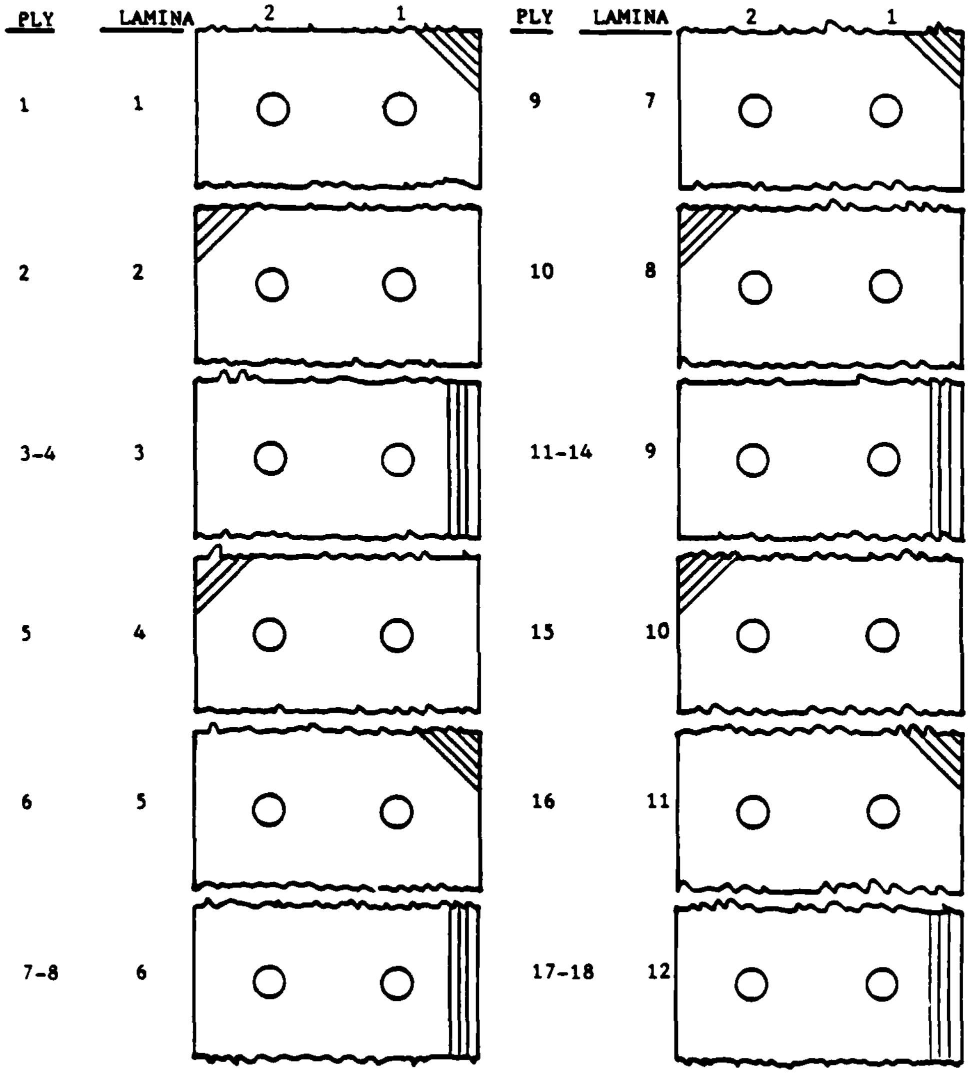


Figure A-33. Lamina Damage Characterization Chart for Specimen I-A- 17 Load Level D (Continued)

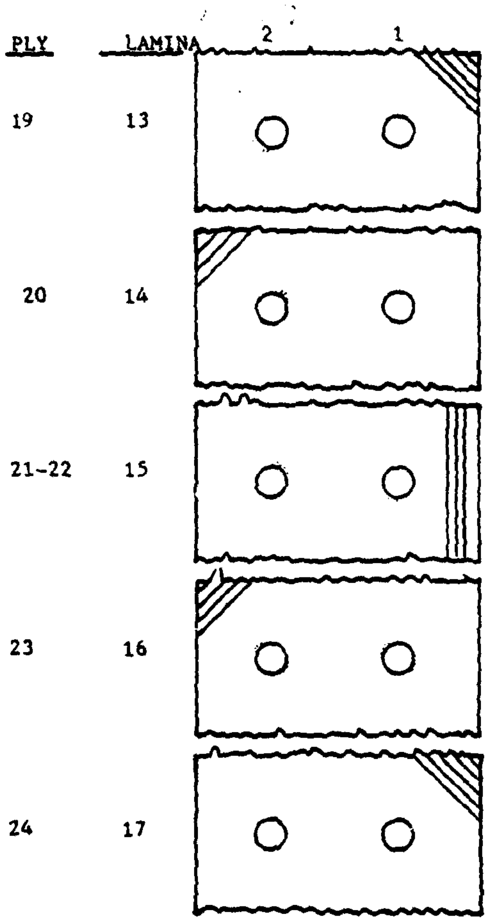


Figure A-33. Lamina Damage Characterization Chart for Specimen I-A-17 Load Level D

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - A($\pm45^\circ$, 0_2°, $\mp45^\circ$, 0_2°, $\pm45^\circ$, 0_2°)s

LOAD LEVEL - D

POUNDS LOAD - 18,917 PERCENT OF ULTIMATE - 79

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-34. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-4.

BEFORE LOADING AFTER LOADING

FIGURE A-35. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-4.

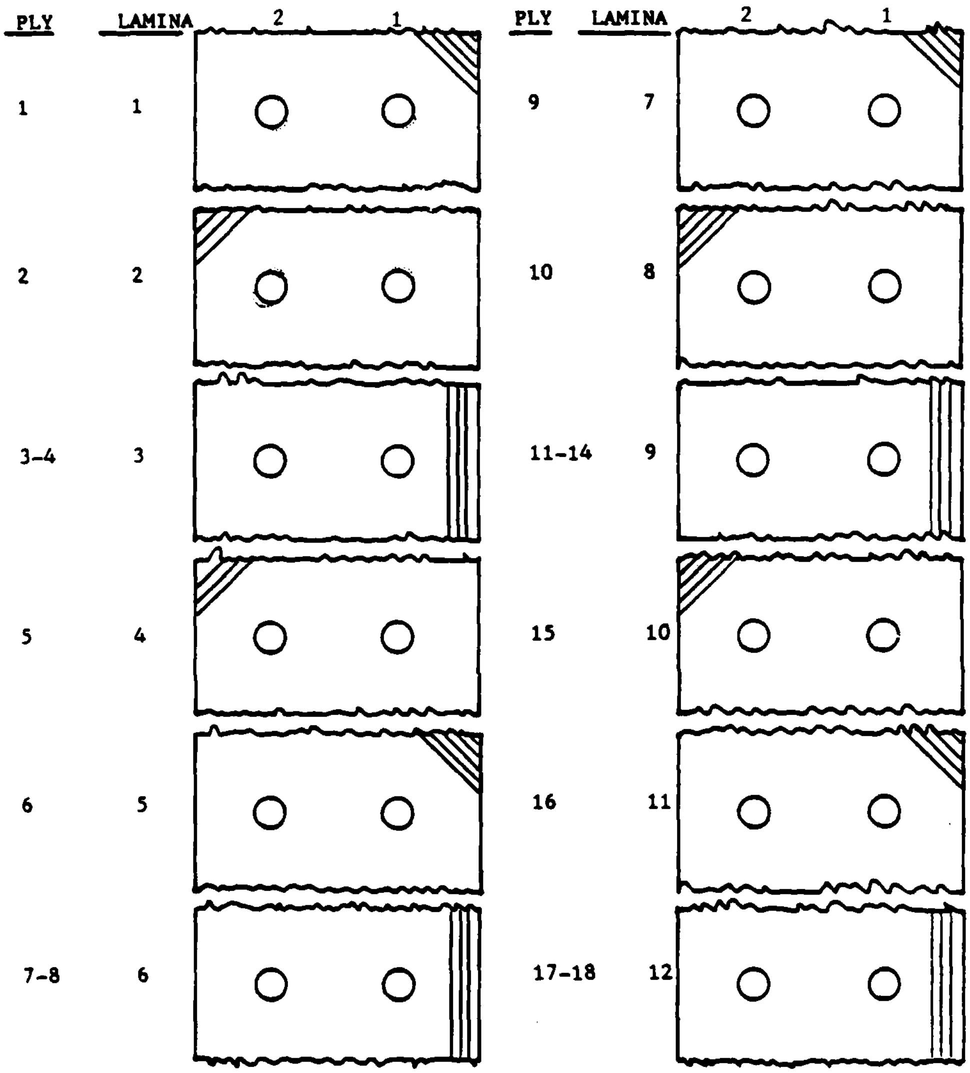


Figure A-36. Lamina Damage Characterization Chart for Specimen I-A-4 Load Level D (Continued)

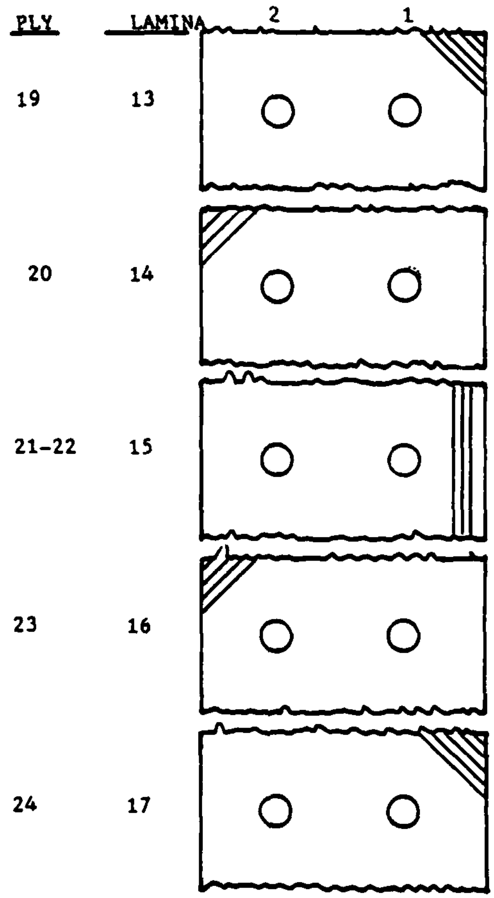


Figure A-36. Lamina Damage Characterization Chart for Specime
I-A-4 Load Level D

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - $A(\pm 45^{\circ}, 0_2^{\circ}, \mp 45^{\circ}, 0_2^{\circ}, \pm 45^{\circ}, 0_2^{\circ})s$

LOAD LEVEL - D

POUNDS LOAD - 18,917 PERCENT OF ULTIMATE - 79

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-37. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-20.

BEFORE LOADING AFTER LOADING

FIGURE A-38. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-20.

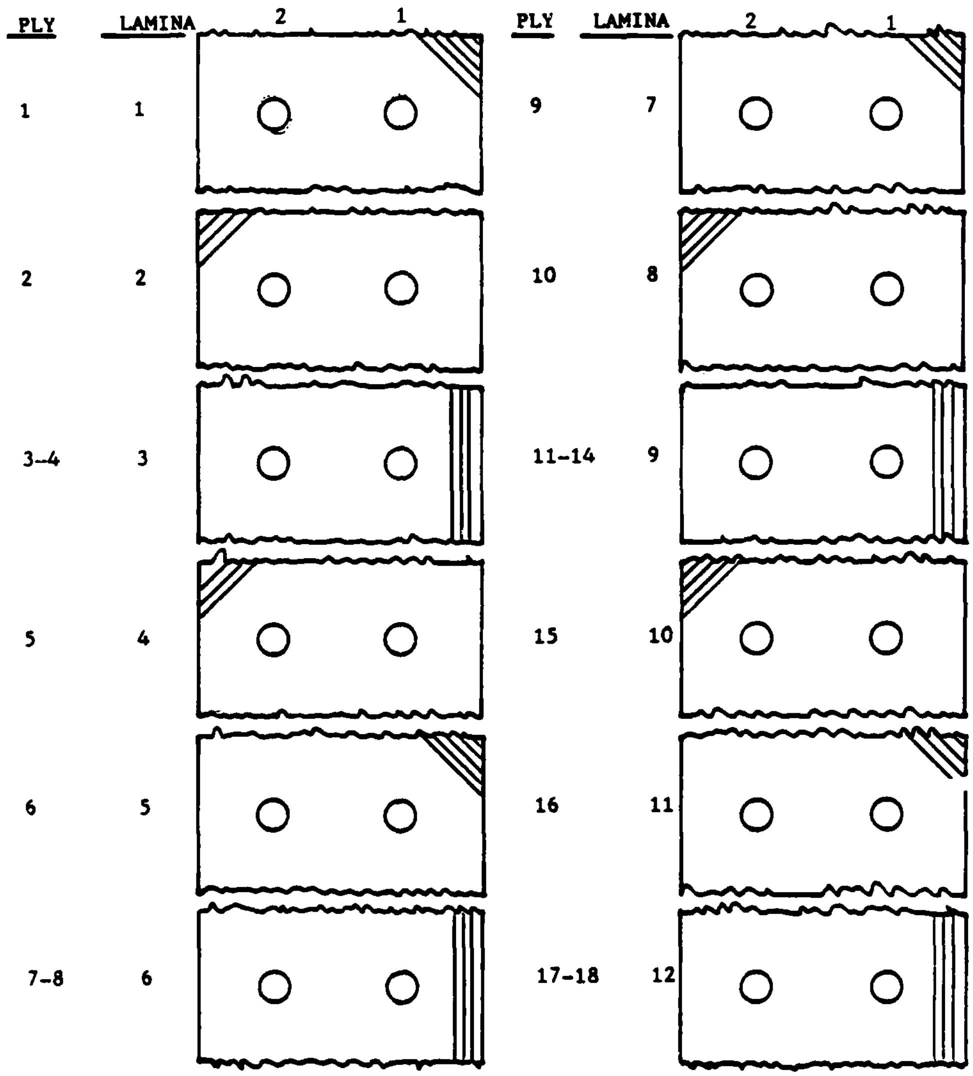


Figure A-39. Lamina Damage Characterization Chart for Specimen
I-A- 20 Load Level D (Continued)

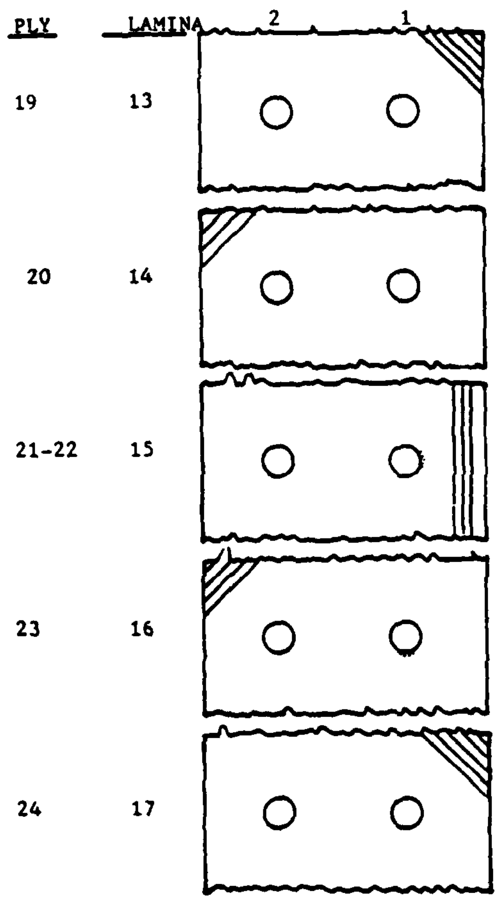


Figure A-39. Lamina Damage Characterization Chart for Specime
I-A- 20 Load Level D

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - D

POUNDS LOAD - 18,917 PERCENT OF ULTIMATE - 79

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-40. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-7.

BEFORE LOADING AFTER LOADING

FIGURE A-41. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-7.

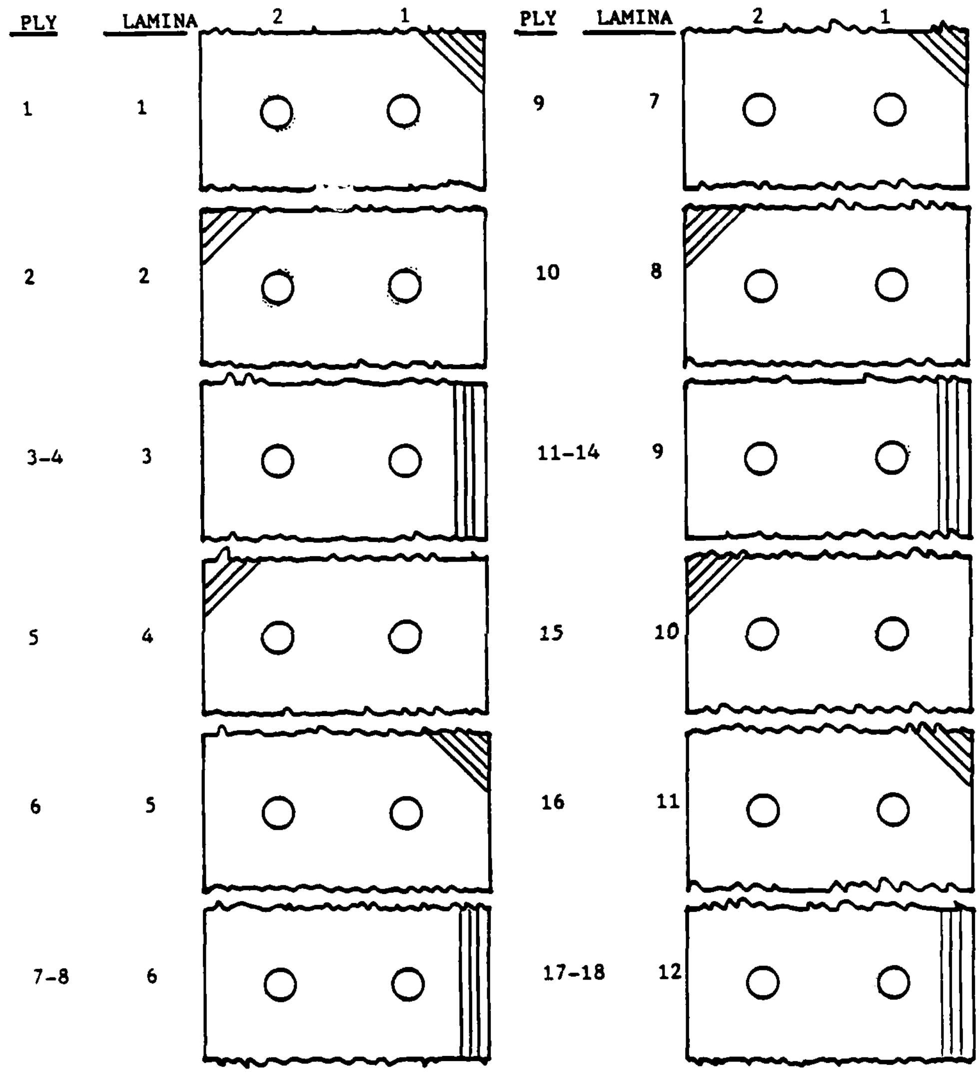


Figure A-42. Lamina Damage Characterization Chart for Specimen I-A- 7 Load Level D (Continued)

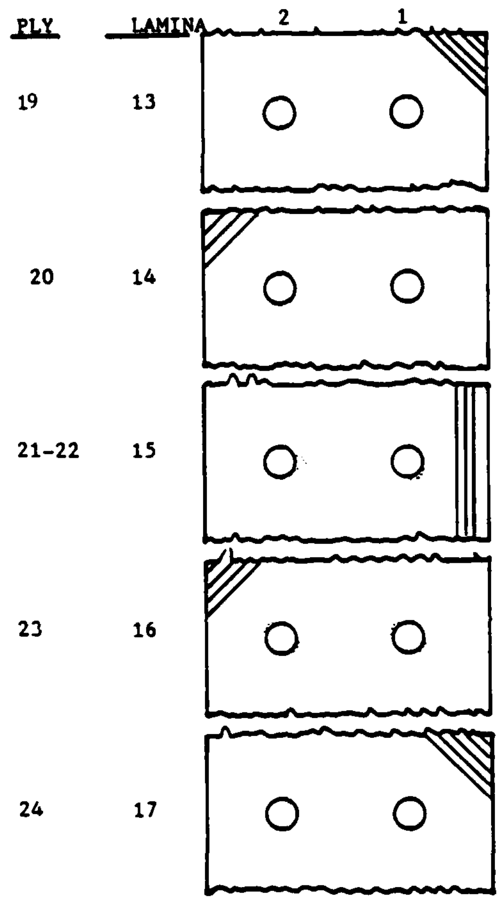


Figure A-42. Lamina Damage Characterization Chart for Specime
I-A-7 Load Level D

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - A($\pm45^{\circ}$, 0_2°, $\mp45^{\circ}$, 0_2°, $\pm45^{\circ}$, 0_2°)s

LOAD LEVEL - D

POUNDS LOAD - 18,917 PERCENT OF ULTIMATE - 79

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES
BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-43. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-2.

BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE A-44. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-2.

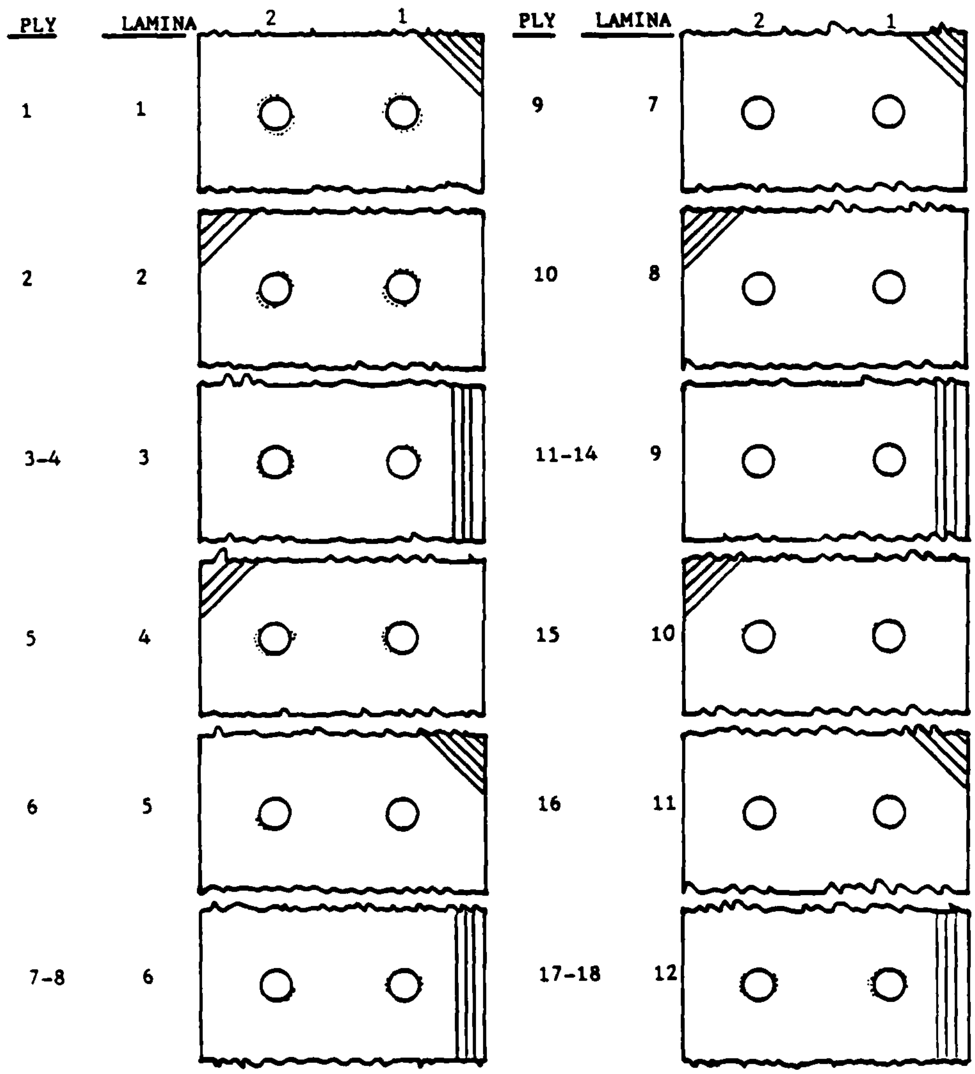


Figure A-45. Lamina Damage Characterization Chart for Specimen I-A-2 Load Level D (Continued)

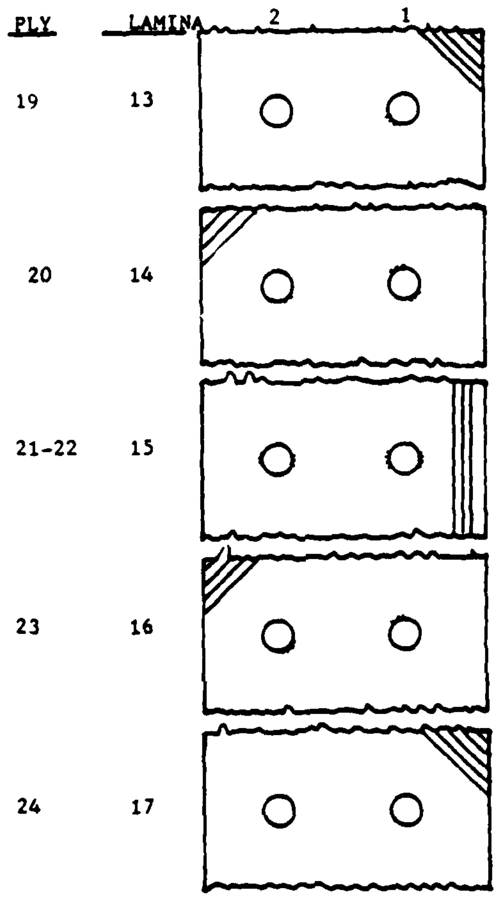


Figure A-45. Lamina Damage Characterization Chart for Specime I-A-2 Load Level D

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - A($\pm45^\circ$, 0_2°, $\mp45^\circ$, 0_2°, $\pm45^\circ$, 0_2°)s

LOAD LEVEL - B

POUNDS LOAD - 21,125 PERCENT OF ULTIMATE - 88

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-46. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-24.

BEFORE LOADING AFTER LOADING

FIGURE A-47. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-24.

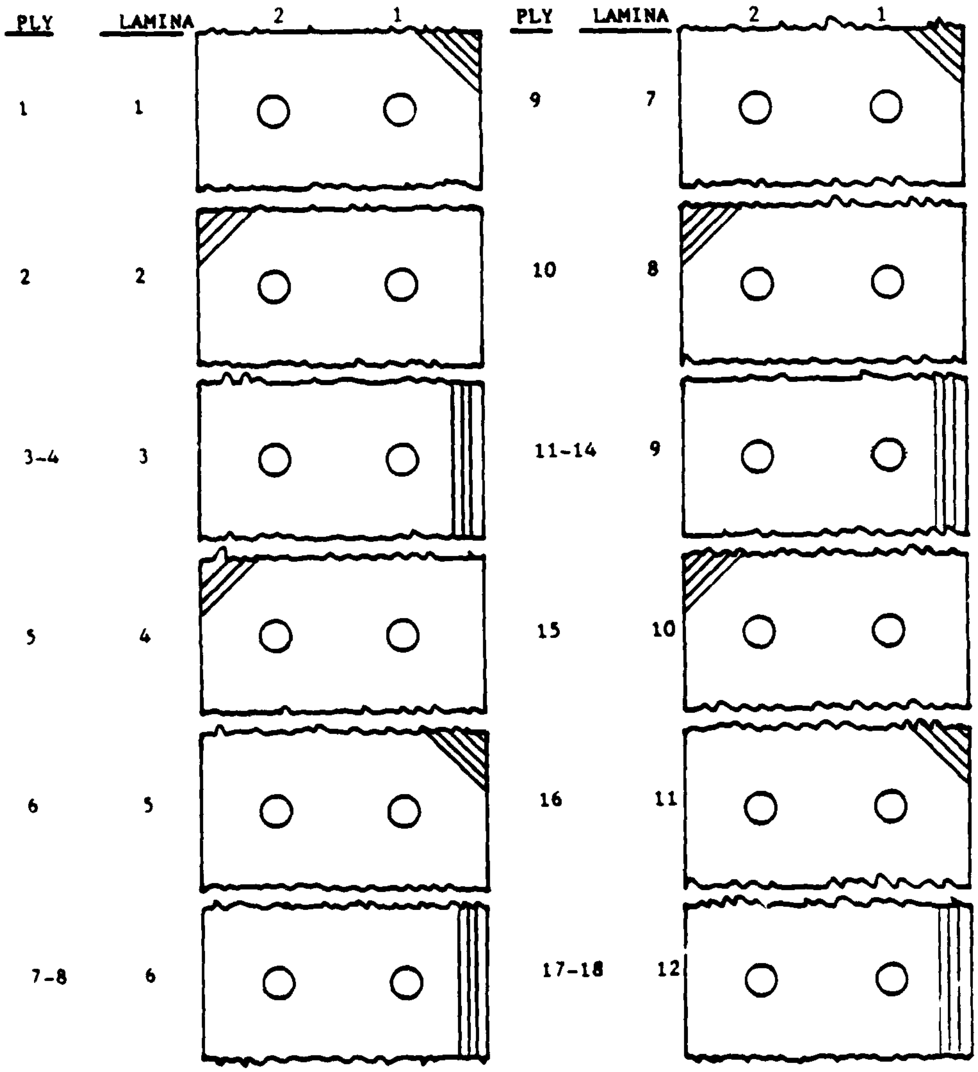


Figure A-48. Lamina Damage Characterization Chart for Specimen I-A-24 Load Level B (Continued)

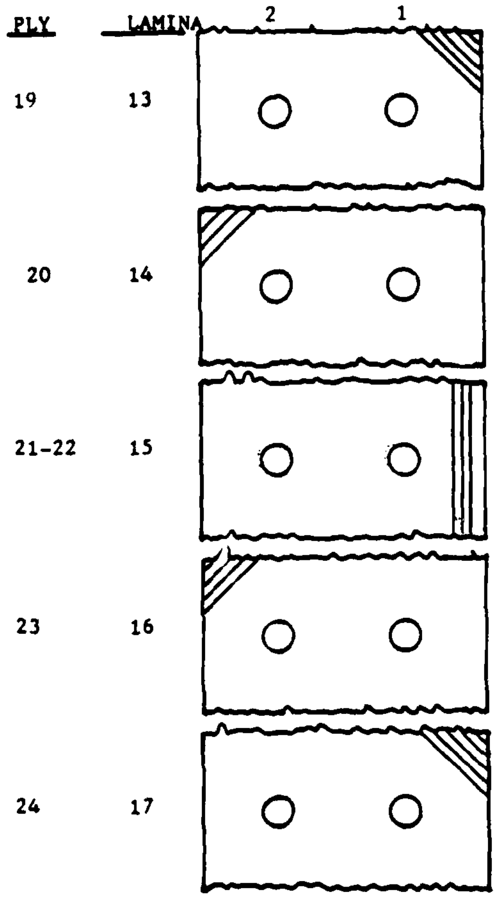


Figure A-48. Lamina Damage Characterization Chart for Specimen I-A- 24 Load Level B

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - A($\pm 45^\circ$, 0_2°, $\mp 45^\circ$, 0_2°, $\pm 45^\circ$, 0_2°)s

LOAD LEVEL - B

POUNDS LOAD - 21,125 PERCENT OF ULTIMATE - 88

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-49. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-18.

BEFORE LOADING AFTER LOADING

FIGURE A-50. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-18.

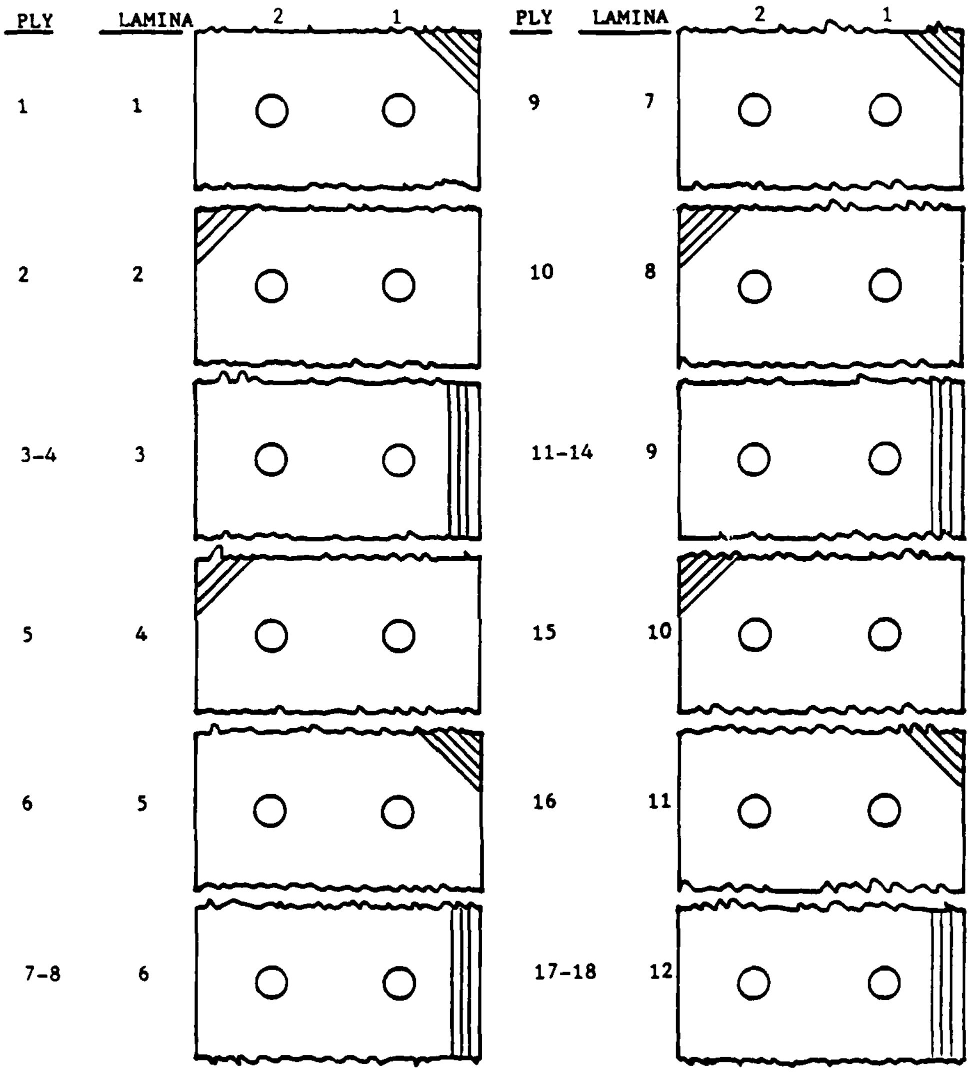


Figure A-51. Lamina Damage Characterization Chart for Specimen I-A-18 Load Level B (Continued)

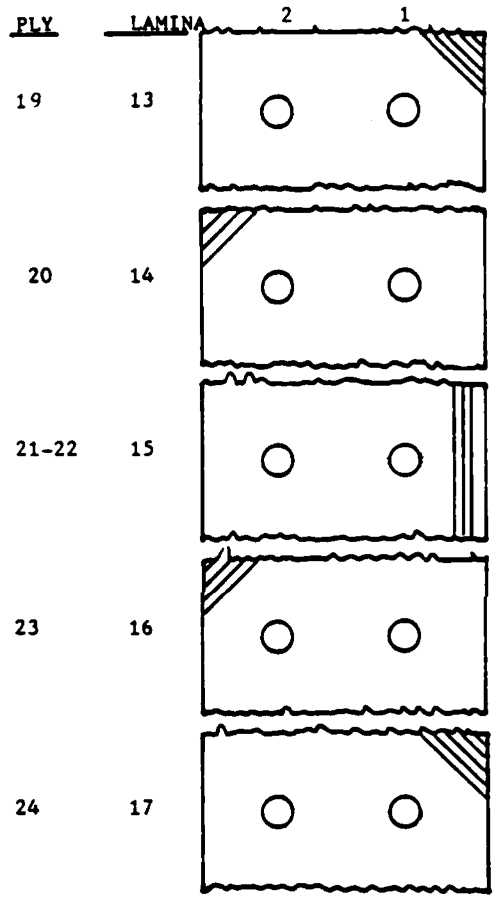


Figure A-51. Lamina Damage Characterization Chart for Specime I-A-18 Load Level B

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - A($\pm 45^\circ$, 0_2°, $\mp 45^\circ$, 0_2°, $\pm 45^\circ$, 0_2°)s

LOAD LEVEL - B

POUNDS LOAD - 21,125 PERCENT OF ULTIMATE - 88

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-52. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-27.

BEFORE LOADING AFTER LOADING

FIGURE A-53. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-27.

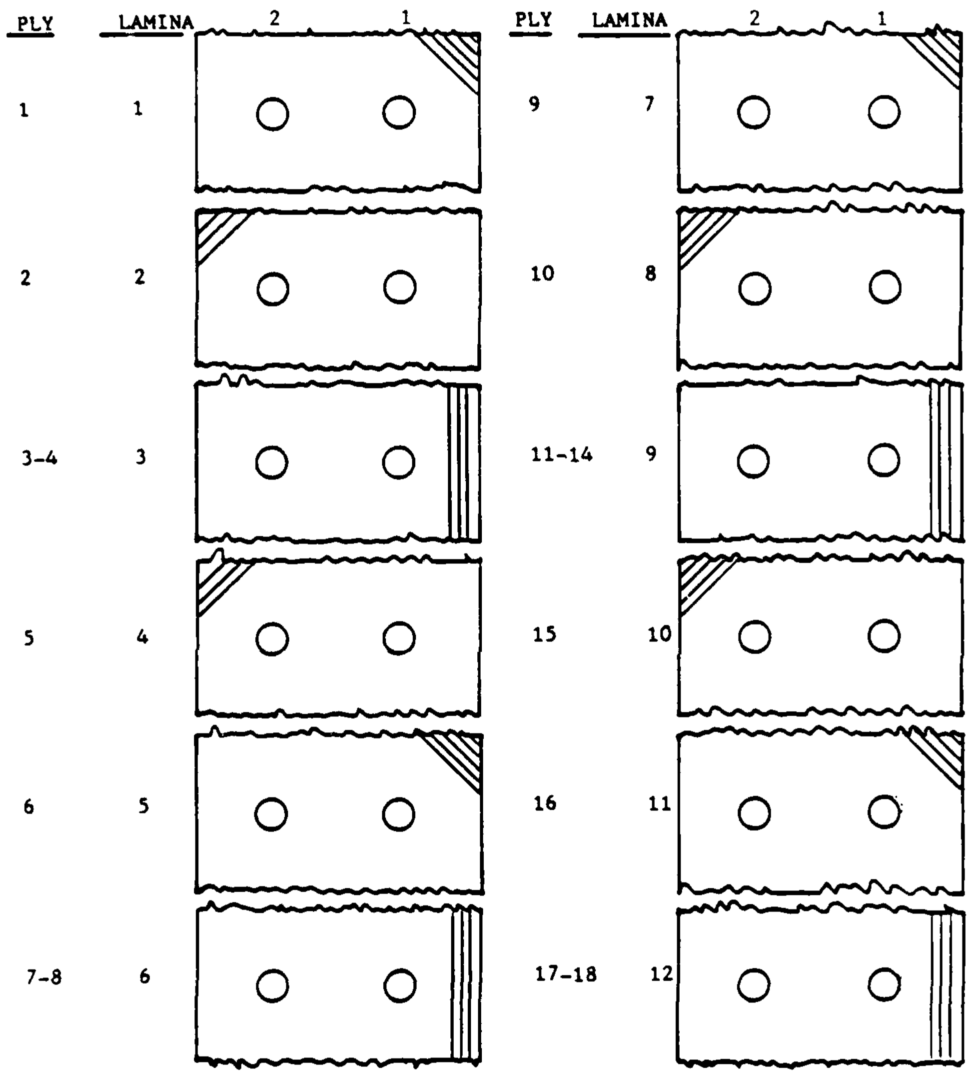


Figure A-54. Lamina Damage Characterization Chart for Specimen I-A-27 Load Level B (Continued)

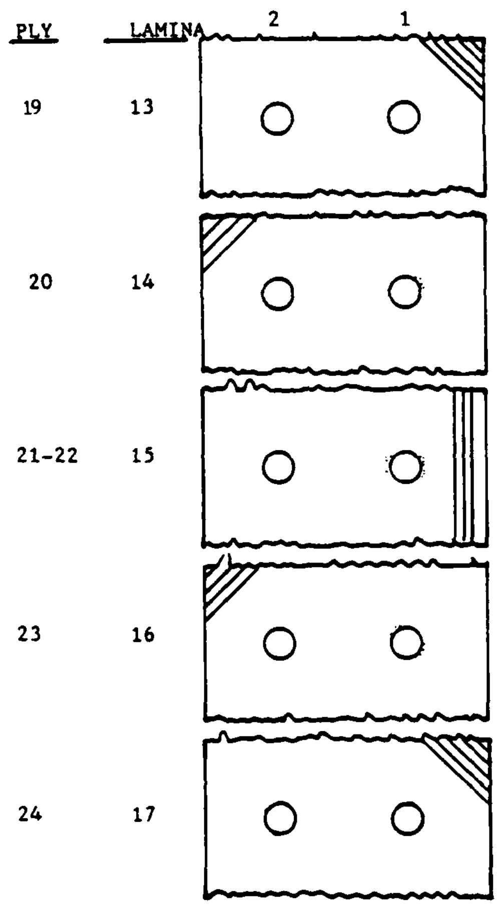


Figure A-54. Lamina Damage Characterization Chart for Specime
I-A- 27 Load Level B

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - A($\pm 45^\circ$, $0_2{}^\circ$, $\mp 45^\circ$, $0_2{}^\circ$, $\pm 45^\circ$, $0_2{}^\circ$)s

LOAD LEVEL - B

POUNDS LOAD - 21,125 PERCENT OF ULTIMATE - 88

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-55. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-6.

BEFORE LOADING AFTER LOADING

FIGURE A-56. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-6.

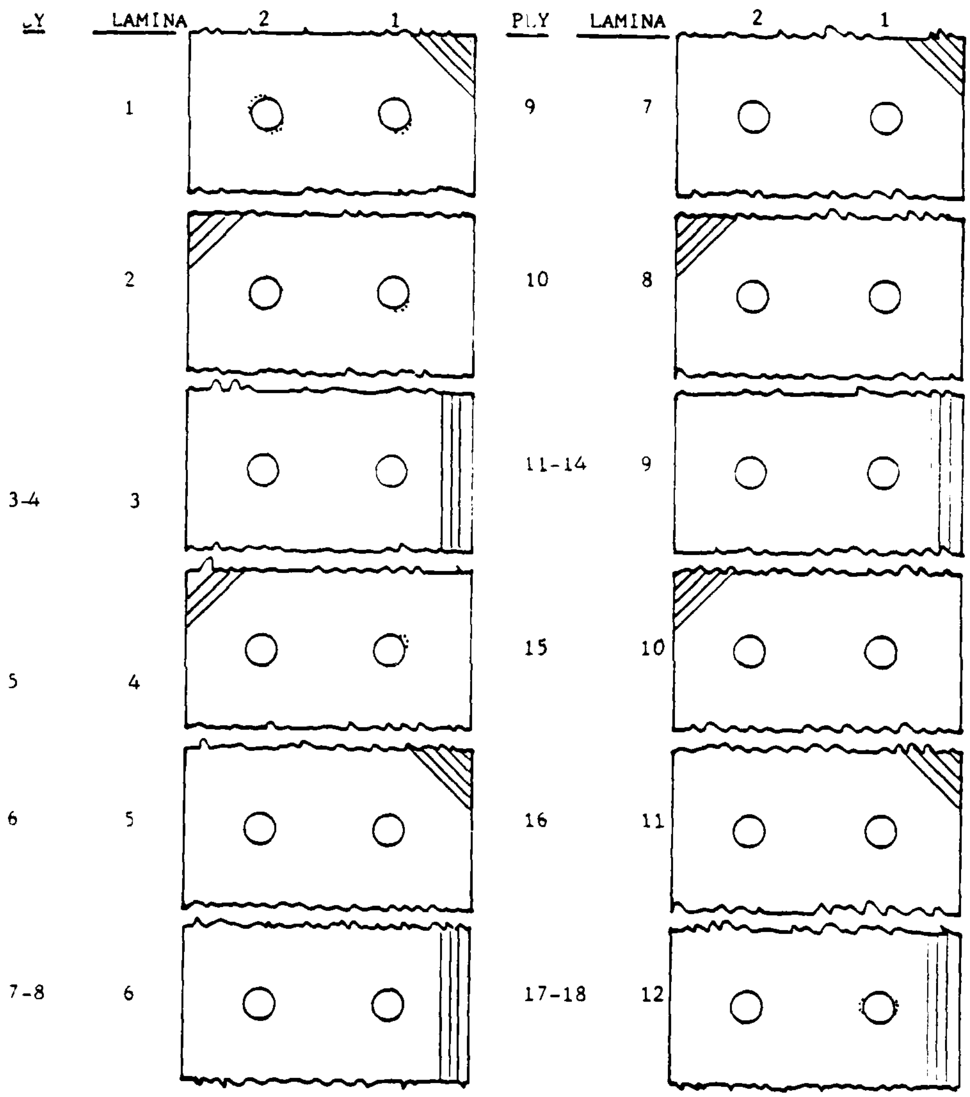


Figure A-57. Lamina Damage Characterization Chart for Specimen
I-A-6 Load Level B (Continued)

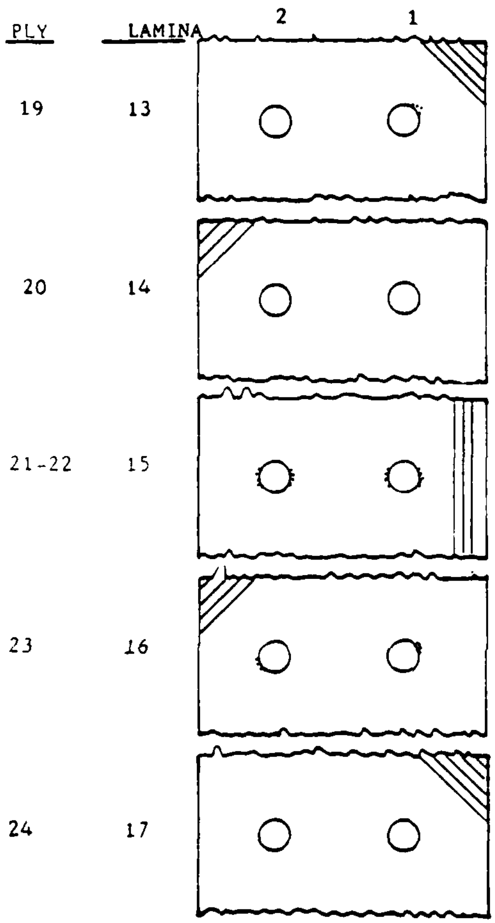


Figure A-57. Lamina Damage Characterization Chart for Specimen I-A-6 Load Level B

SPECIMEN TYPE - I(OPEN HOLE)

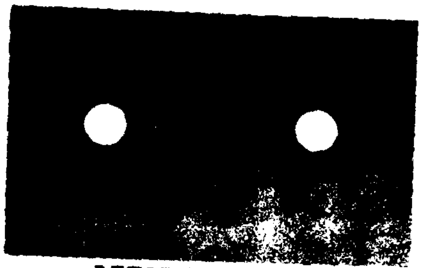
LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - B

POUNDS LOAD - 21,125 PERCENT OF ULTIMATE - 88

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE A-58. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-A-14.



BEFORE LOADING

AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE A-59. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-A-14.

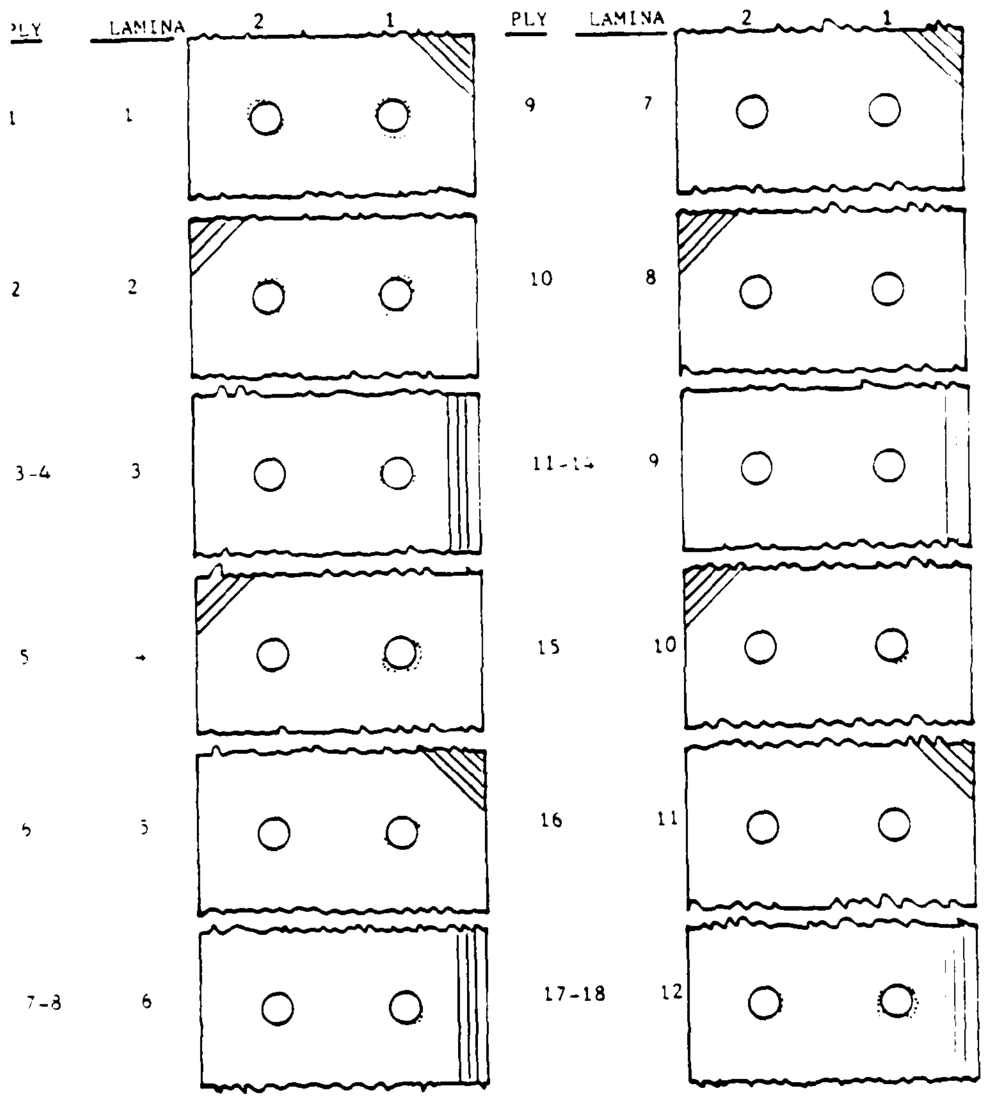


Figure A-60. Lamina Damage Characterization Chart for Specimen
I-A-14 Load Level B (Continued)

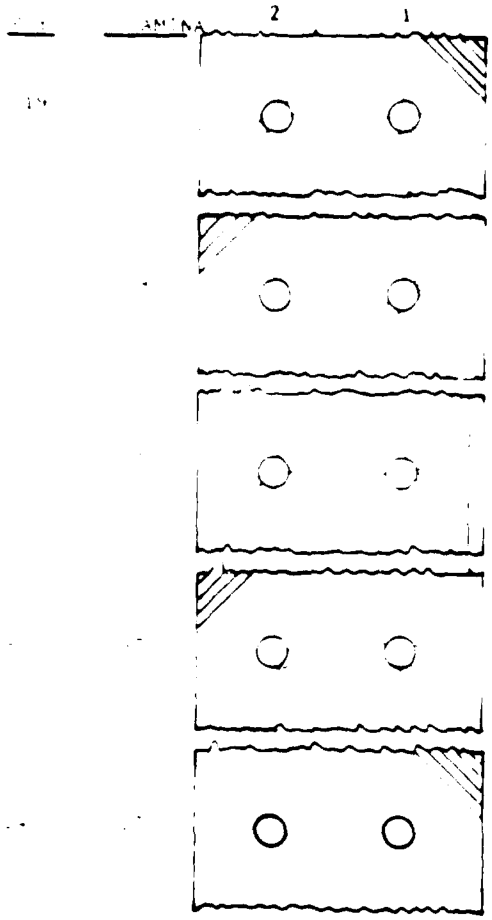


Figure A-60. Lamina Damage Characterization Chart for Specimen
I-A-14 Load Level B

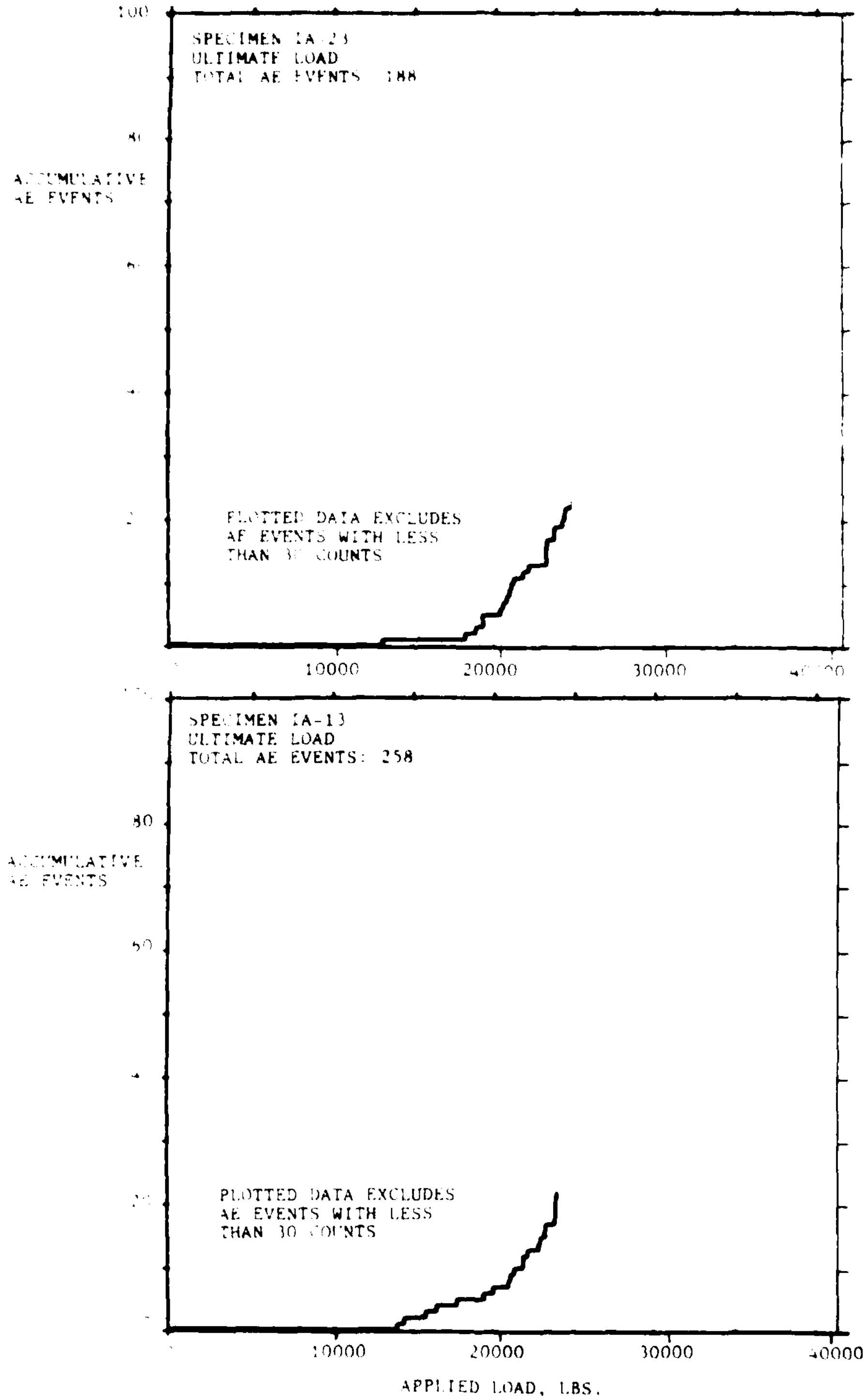
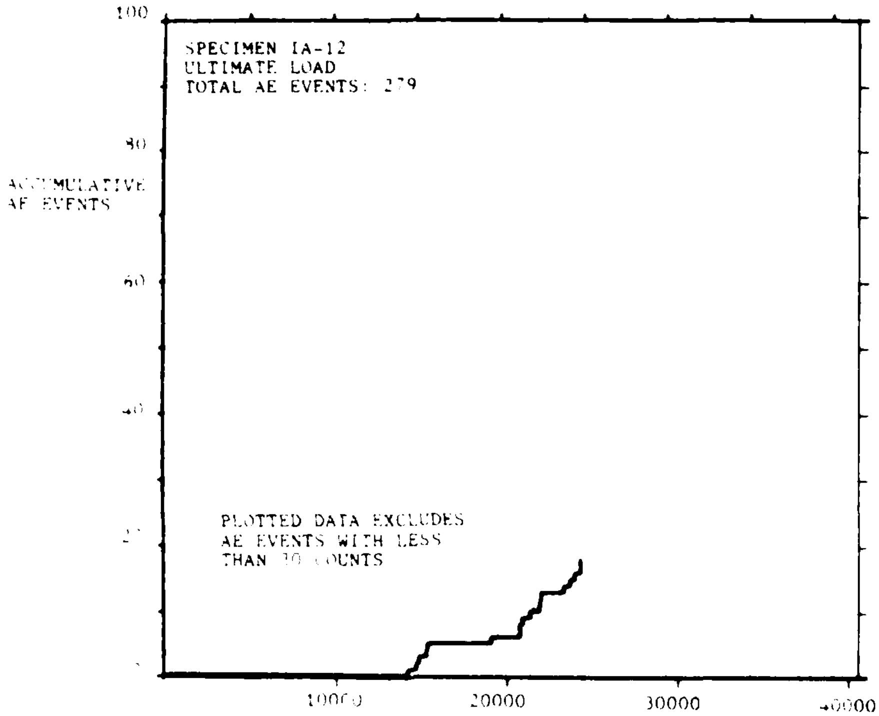


Figure A-61. Plots of Accumulative AE Events vs Applied Load for Type I-A Ultimate Specimens.



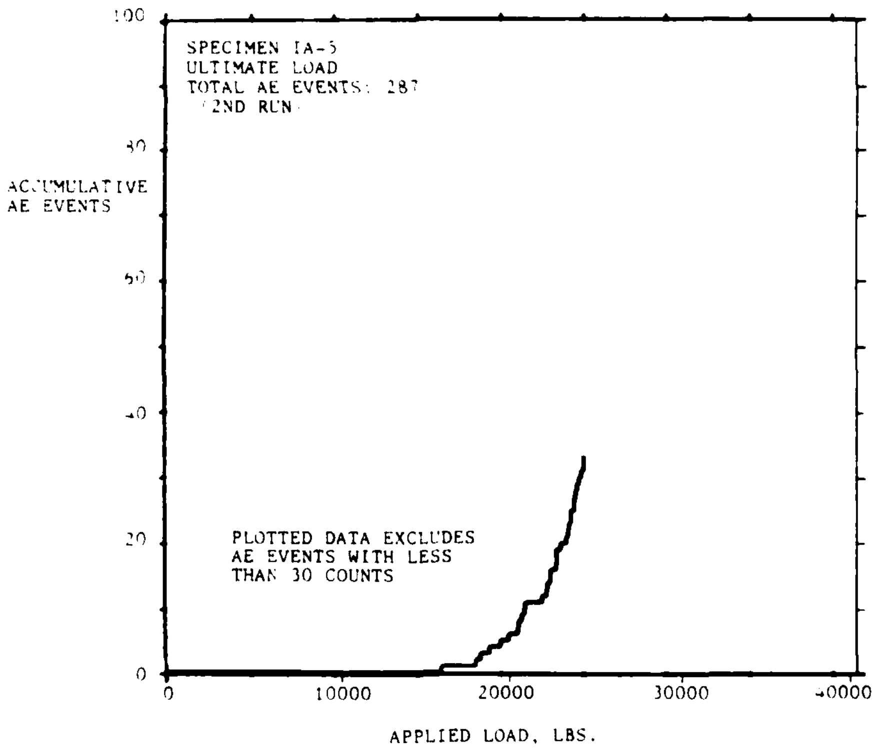


Figure A-62. Plots of Accumulative AE Events vs Applied Load for Type I-A Ultimate Specimens.

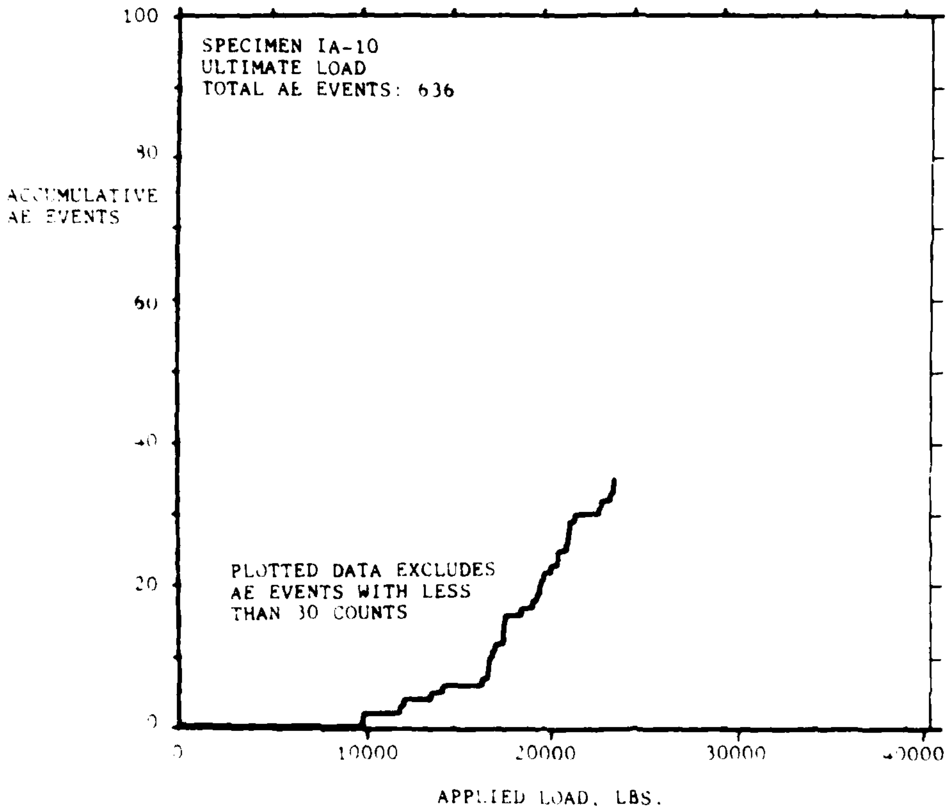


Figure A-63. Plots of Accumulative AE Events vs Applied Loads for Type I-A Ultimate Specimens.

APPENDIX B

DETAIL DAMAGE INFORMATION FOR TYPE I SPECIMENS

The detail information for the Type I specimens of Laminate B is presented in this appendix. It is presented in the order of increasing load levels. All specimens of the same load level are grouped together. Three figures are presented for each specimen. The first figure gives specimen type, laminate information, load conditions and expected number of fiber bundle fractures based on Acoustic Emission monitoring. The second figure consists of positive prints of enhanced x-ray radiographs made before and after loading. In addition, prints of a stereo x-ray pair are included for one specimen of each load level. The third figure consists of a lamina Damage Characterization Chart. This chart contains a pictorial sketch for each lamina with fiber orientations indicated on one side or edge of each sketch. The damage observed on each lamina is recorded on the appropriate sketch in a manner to indicate size and location relative to the open hole.

PRECEDING PAGE BLANK-NOT FILMED

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - B($\pm 45^{\circ}$, $\mp 45^{\circ}$, $\pm 45^{\circ}$, 0_6°)s

LOAD LEVEL - A

POUNDS LOAD - 14,500 PERCENT OF ULTIMATE - 41

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE B-1. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-8.

BEFORE LOADING AFTER LOADING

FIGURE B-2. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-8.

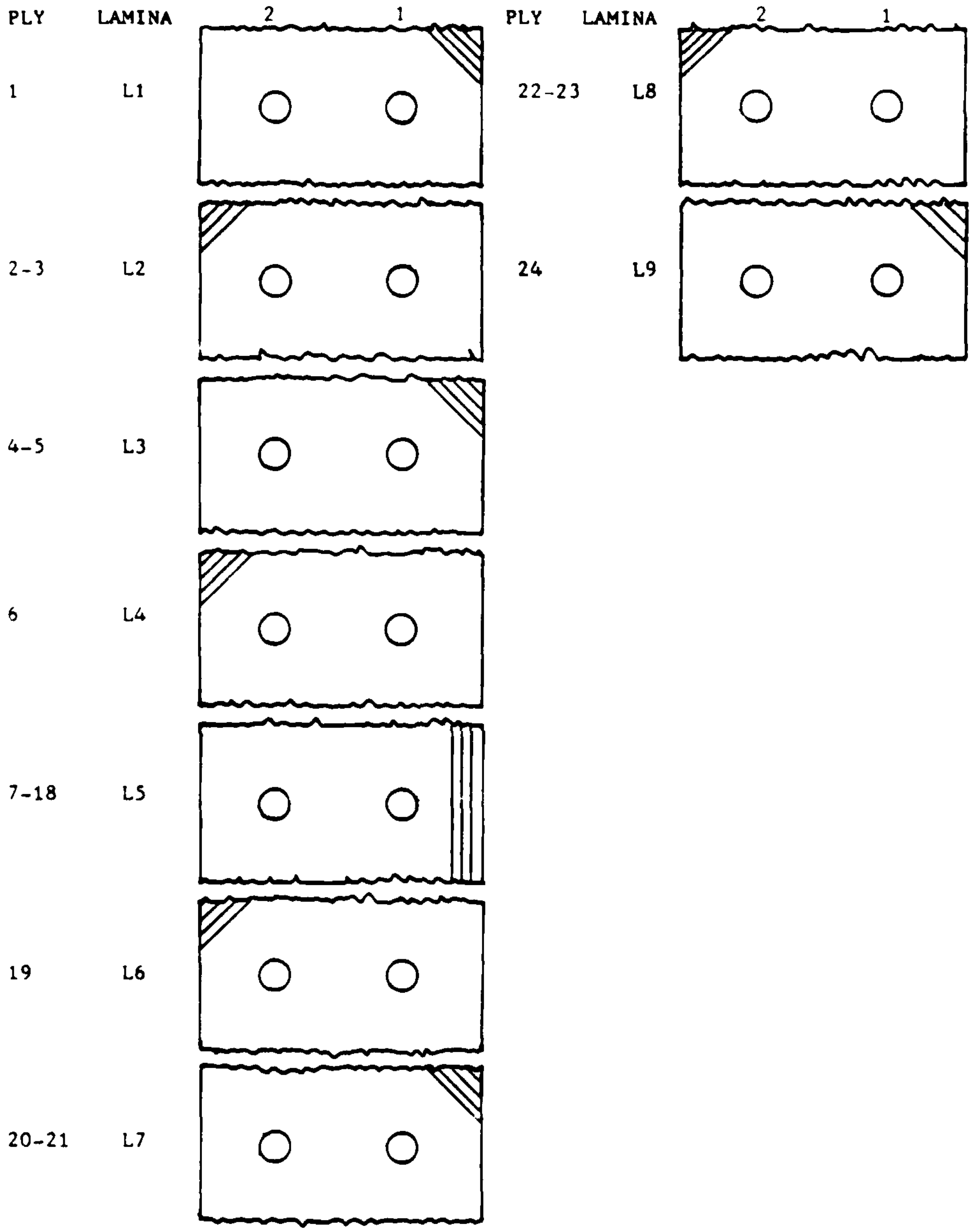


Figure B-3. Lamina Damage Characterization Chart for Specimen I-B- 8 Load Level A

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - B($\pm 45^\circ$, $\mp 45^\circ$, $\pm 45^\circ$, 0_6°)s

LOAD LEVEL - A

POUNDS LOAD - 14,500 PERCENT OF ULTIMATE - 41

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE B-4. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-16.

BEFORE LOADING

AFTER LOADING

FIGURE B-5. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-16.

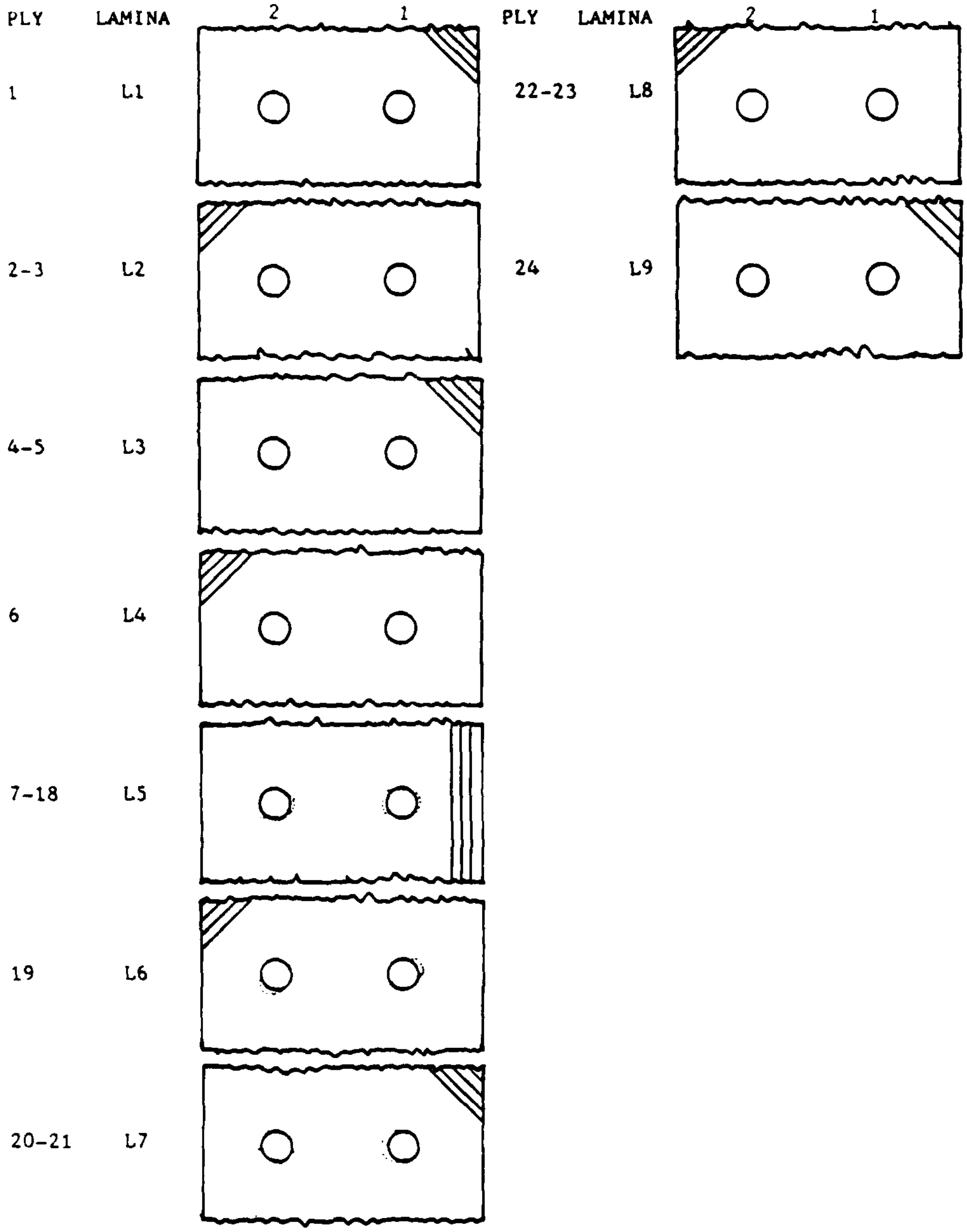


Figure B-6. Lamina Damage Characterization Chart for Specimen I-B- 16 Load Level A

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - B($\pm 45^{o}$, $\mp 45^{o}$, $\pm 45^{o}$, $0_6{}^{o}$)s

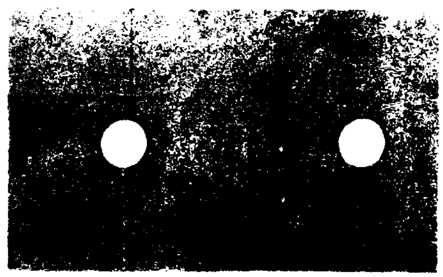
LOAD LEVEL - A

POUNDS LOAD - 14,500   PERCENT OF ULTIMATE - 41

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE B-7. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-26.

BEFORE LOADING



AFTER LOADING

FIGURE B-8. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-26.

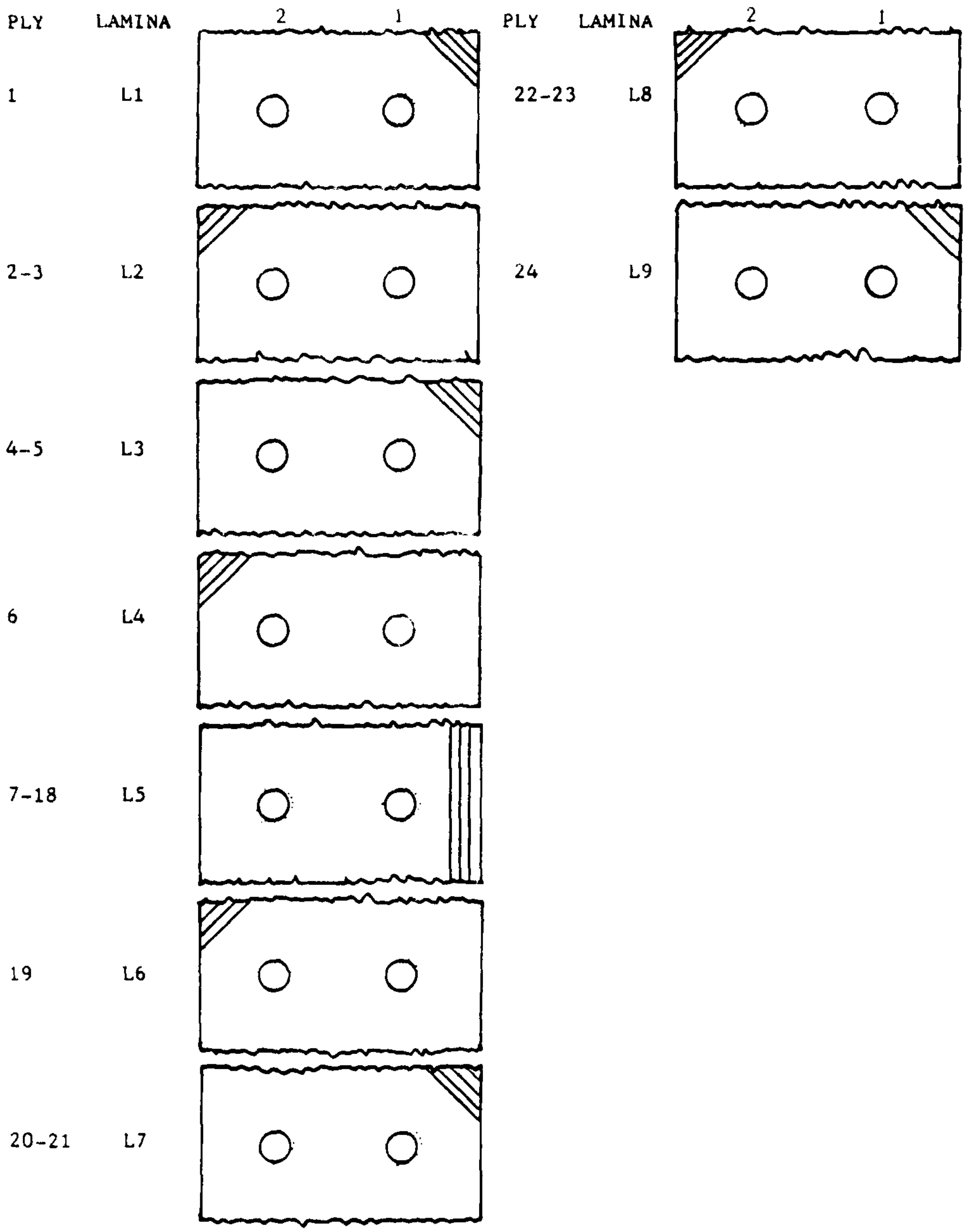


Figure B-9. Lamina Damage Characterization Chart for Specimen I-B-26 Load Level A

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - B($\pm45^\circ$, $\mp45^\circ$, $\pm45^\circ$, $0_6{}^\circ$)s

LOAD LEVEL - A

POUNDS LOAD - 14,500 PERCENT OF ULTIMATE - 41

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE B-10. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-1.

BEFORE LOADING

AFTER LOADING

FIGURE B-11. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-1.

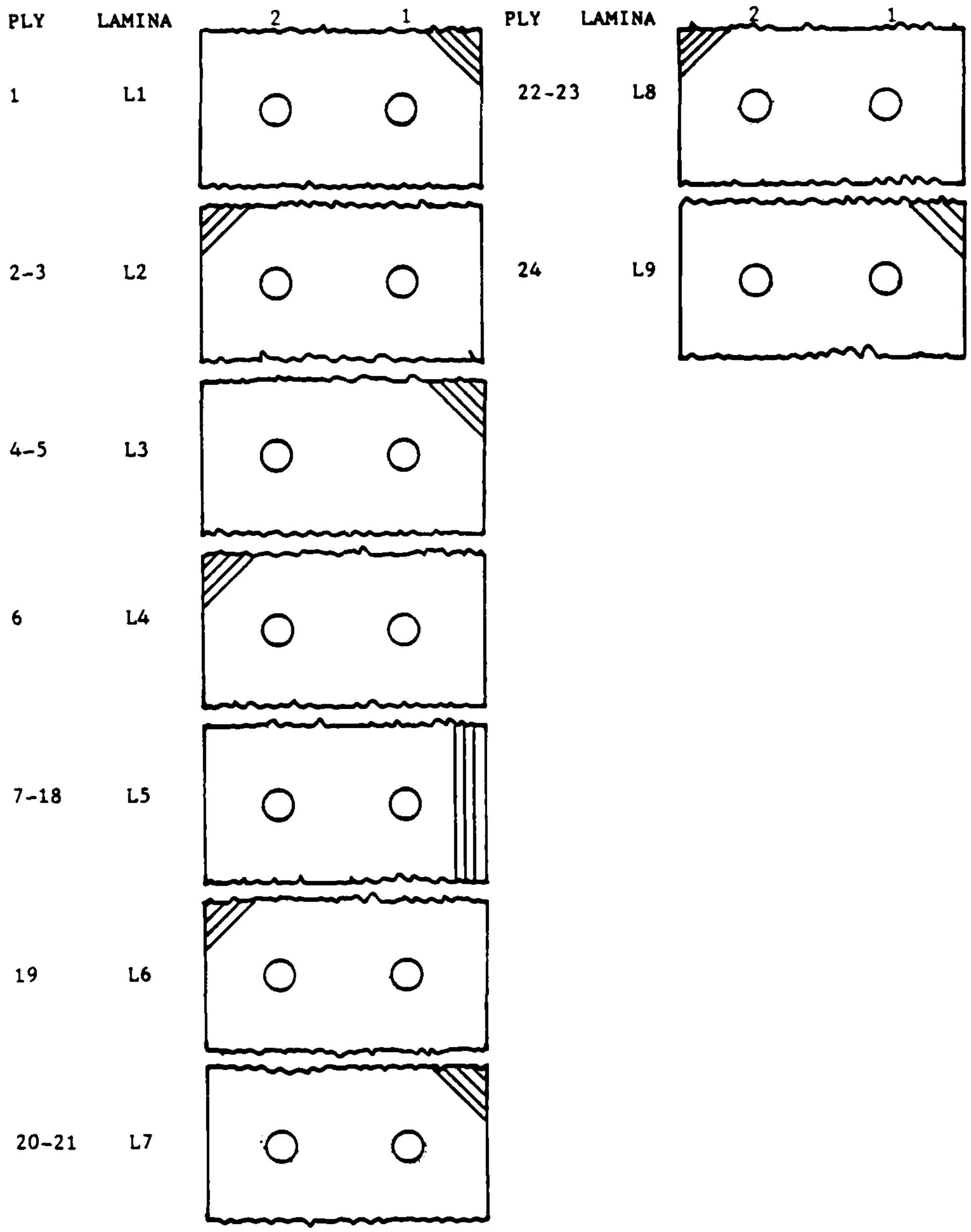


Figure B-12. Lamina Damage Characterization Chart for Specimen I-B-1 Load Level A

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - B($\pm 45^{\circ}$, $\mp 45^{\circ}$, $\pm 45^{\circ}$, $0_6{}^{\circ}$)s

LOAD LEVEL - A

POUNDS LOAD - 14,500 PERCENT OF ULTIMATE - 41

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES
BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE B-13. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-21.

BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE B-14. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-21.

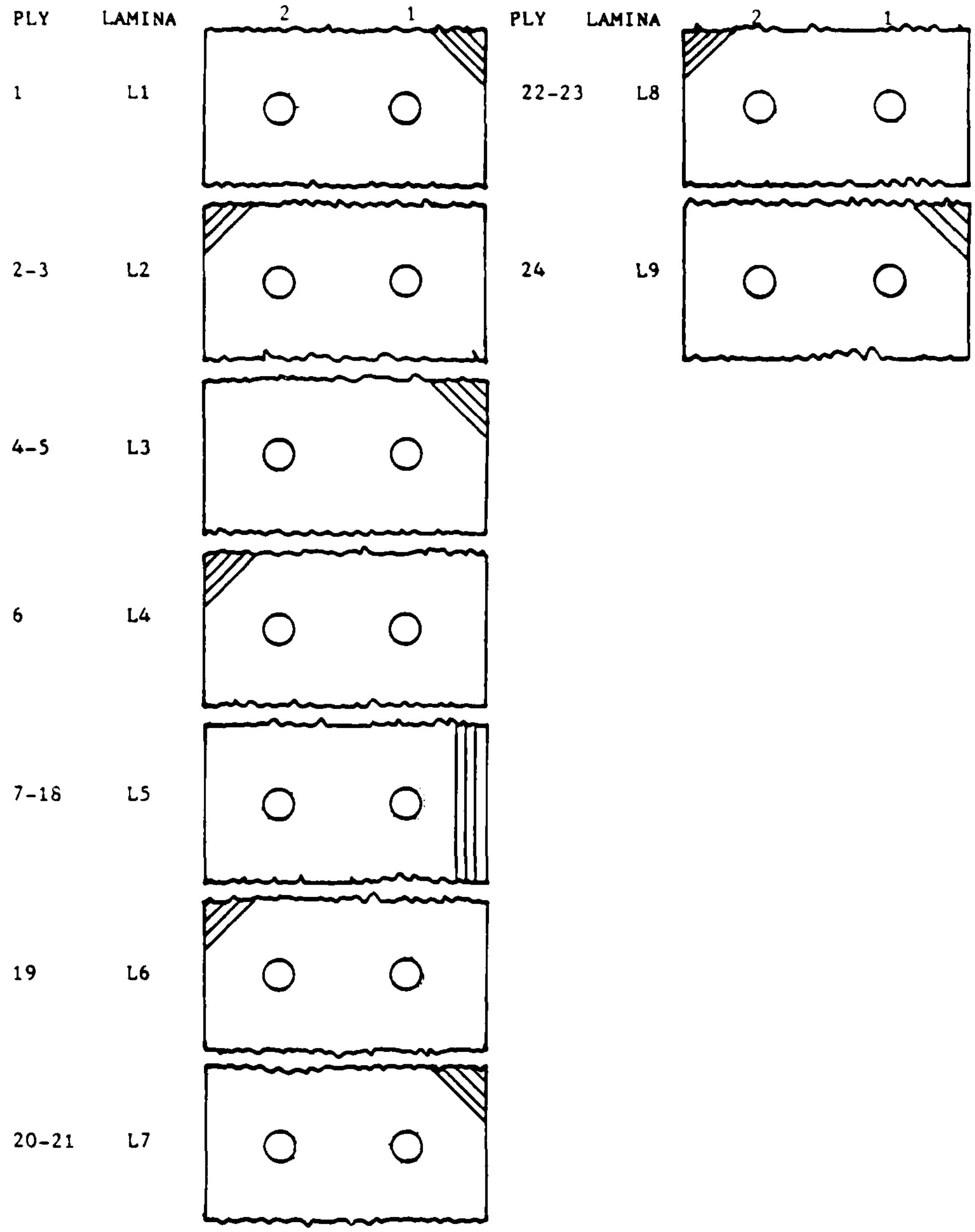


Figure B-15. Lamina Damage Characterization Chart for Specimen I-B-21 Load Level A

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - $B(\pm45^{\circ}, \mp45^{\circ}, \pm45^{\circ}, 0_6{}^{\circ})s$

LOAD LEVEL - C

POUNDS LOAD - 19,757   PERCENT OF ULTIMATE - 56

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE B-16. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-9.

BEFORE LOADING   AFTER LOADING

FIGURE B-17. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-9.

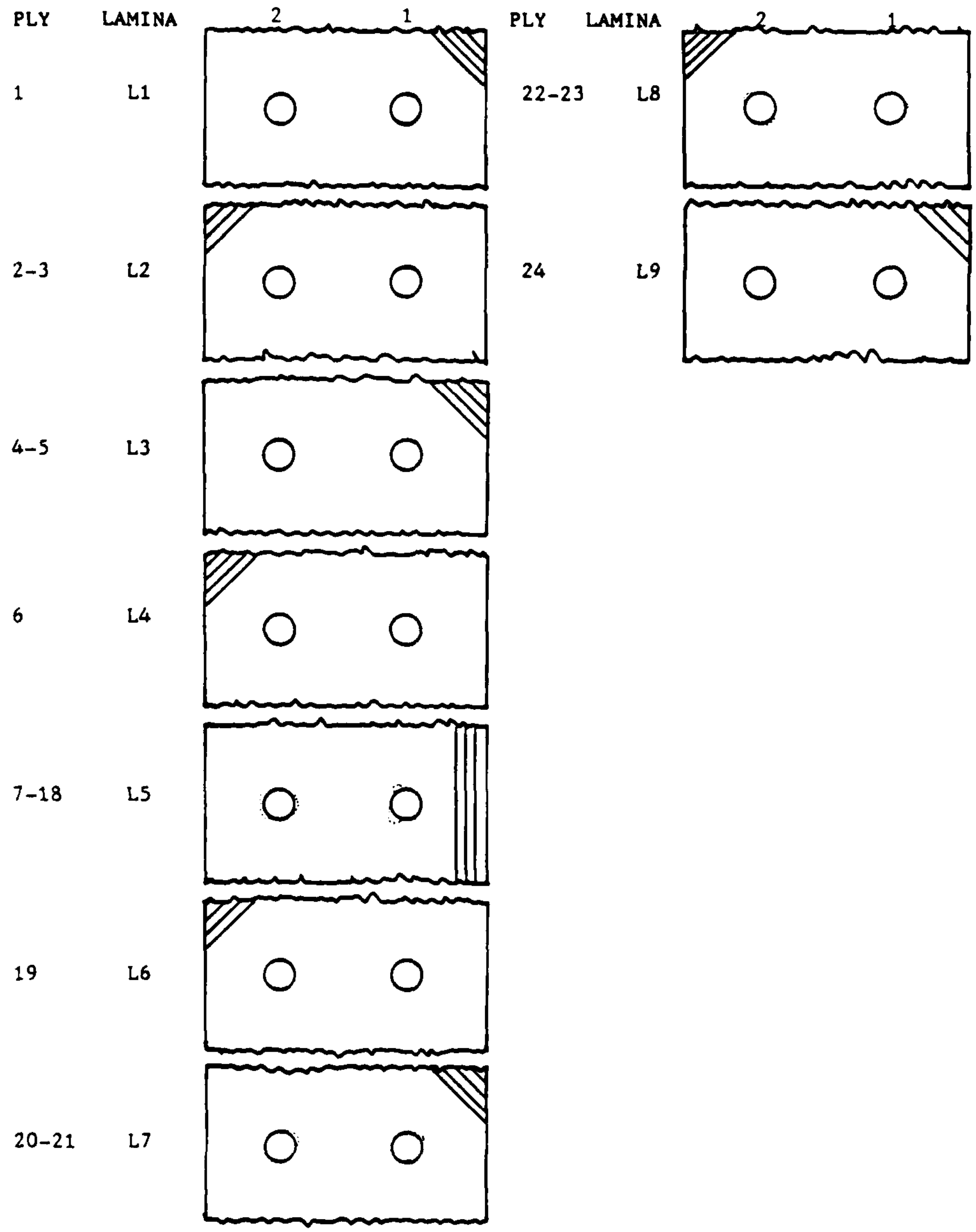


Figure B-18. Lamina Damage Characterization Chart for Specimen I-B-9 Load Level C

SPECIMEN TYPE - I(OPEN HOLE)

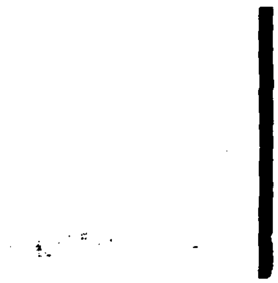
LAMINATE - B($\pm45^\circ$, $\mp45^\circ$, $\pm45^\circ$, $0_6{}^\circ$)s

LOAD LEVEL - C

POUNDS LOAD - 19,757   PERCENT OF ULTIMATE - 56

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE B-19. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-3.



BEFORE LOADING

AFTER LOADING

FIGURE B-20. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-3.

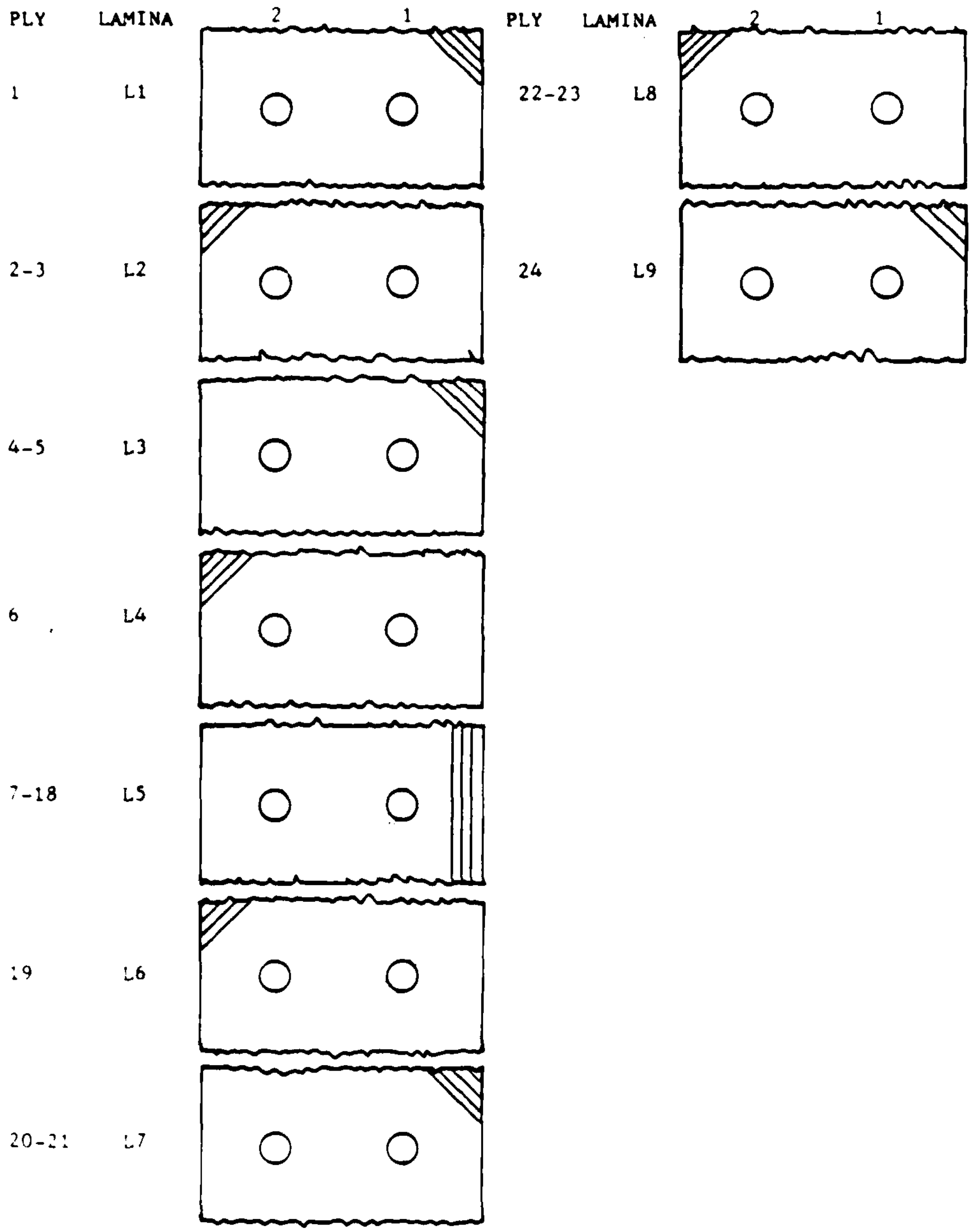


Figure B 21. Lamina Damage Characterization Chart for Specimen I-B-3 Load Level

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - B($\pm 45^{\circ}$, $\mp 45^{\circ}$, $\pm 45^{\circ}$, $0_6{}^{\circ}$)s

LOAD LEVEL - C

POUNDS LOAD - 19,757   PERCENT OF ULTIMATE - 56

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE B-22. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-11.

BEFORE LOADING   AFTER LOADING

FIGURE B-23. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-11.

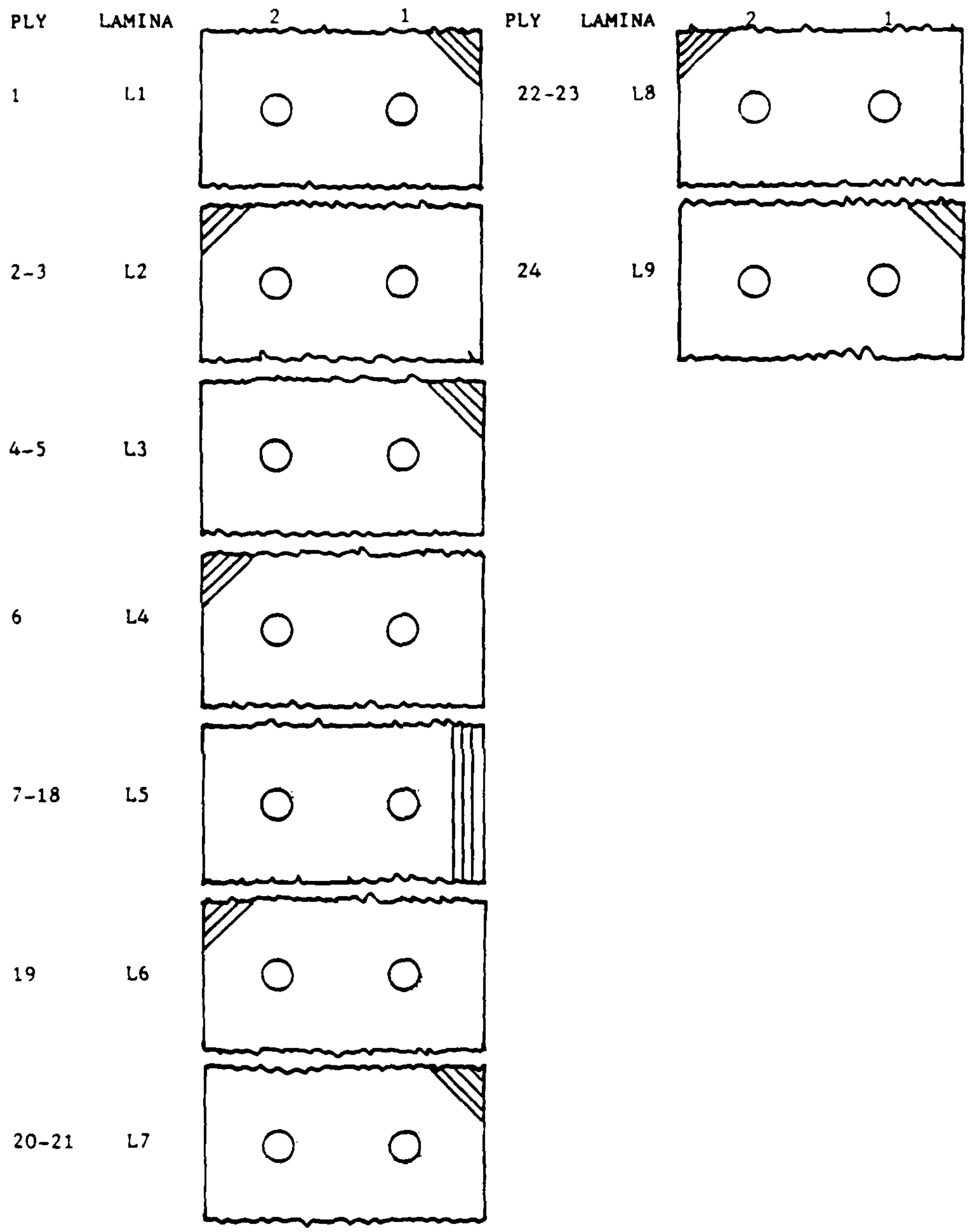


Figure B-24. Lamina Damage Characterization Chart for Specimen I-B-11 Load Level C

SPECIMEN TYPE - I(OPEN HOLE)

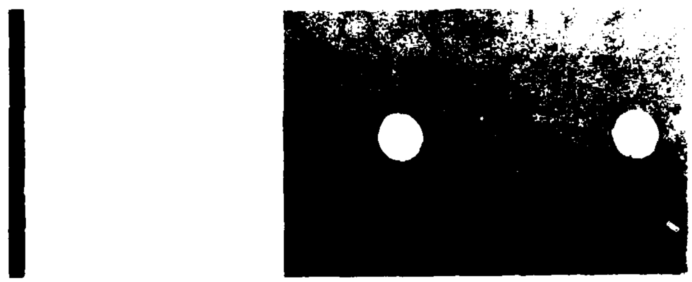
LAMINATE - B($\pm45^{o}$, $\mp45^{o}$, $\pm45^{o}$, 0_{6}^{o})s

LOAD LEVEL - C

POUNDS LOAD - 19,757 PERCENT OF ULTIMATE - 56

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE B-25. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-22.



BEFORE LOADING

AFTER LOADING

FIGURE B-26. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-22.

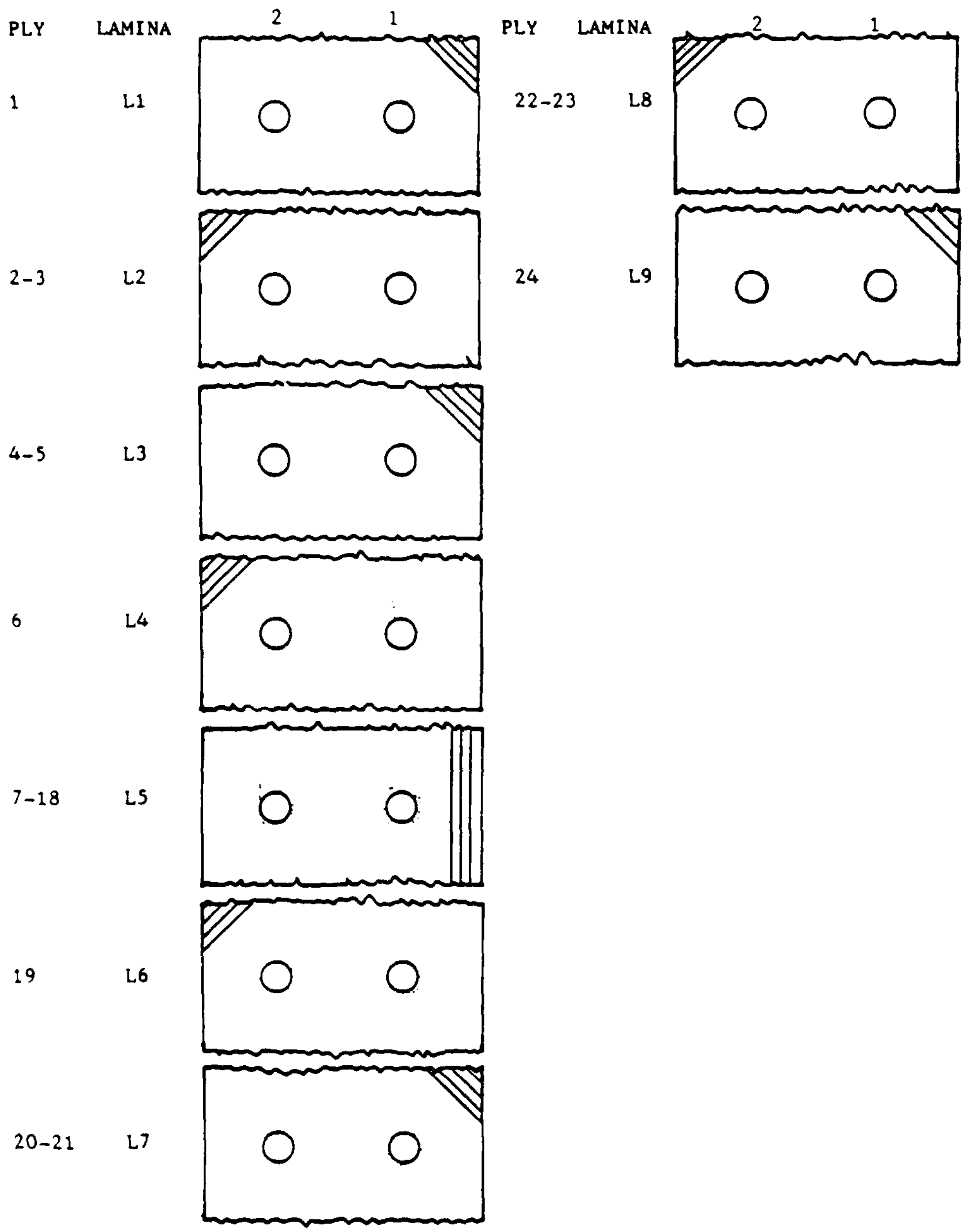


Figure B-27. Lamina Damage Characterization Chart for Specimen I-B-22 Load Level C

SPECIMEN TYPE - I(OPEN HOLE)

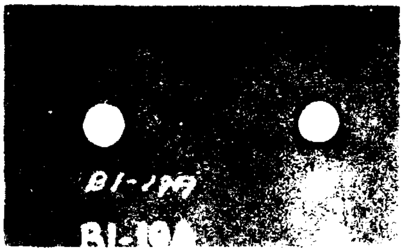
LAMINATE - $B(\pm45^{\circ}, \mp45^{\circ}, \pm45^{\circ}, 0_{6}^{\circ})s$

LOAD LEVEL - C

POUNDS LOAD - 19,757   PERCENT OF ULTIMATE - 56

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES
BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE B-28. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-19.



BEFORE LOADING   AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE B-29. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-19.

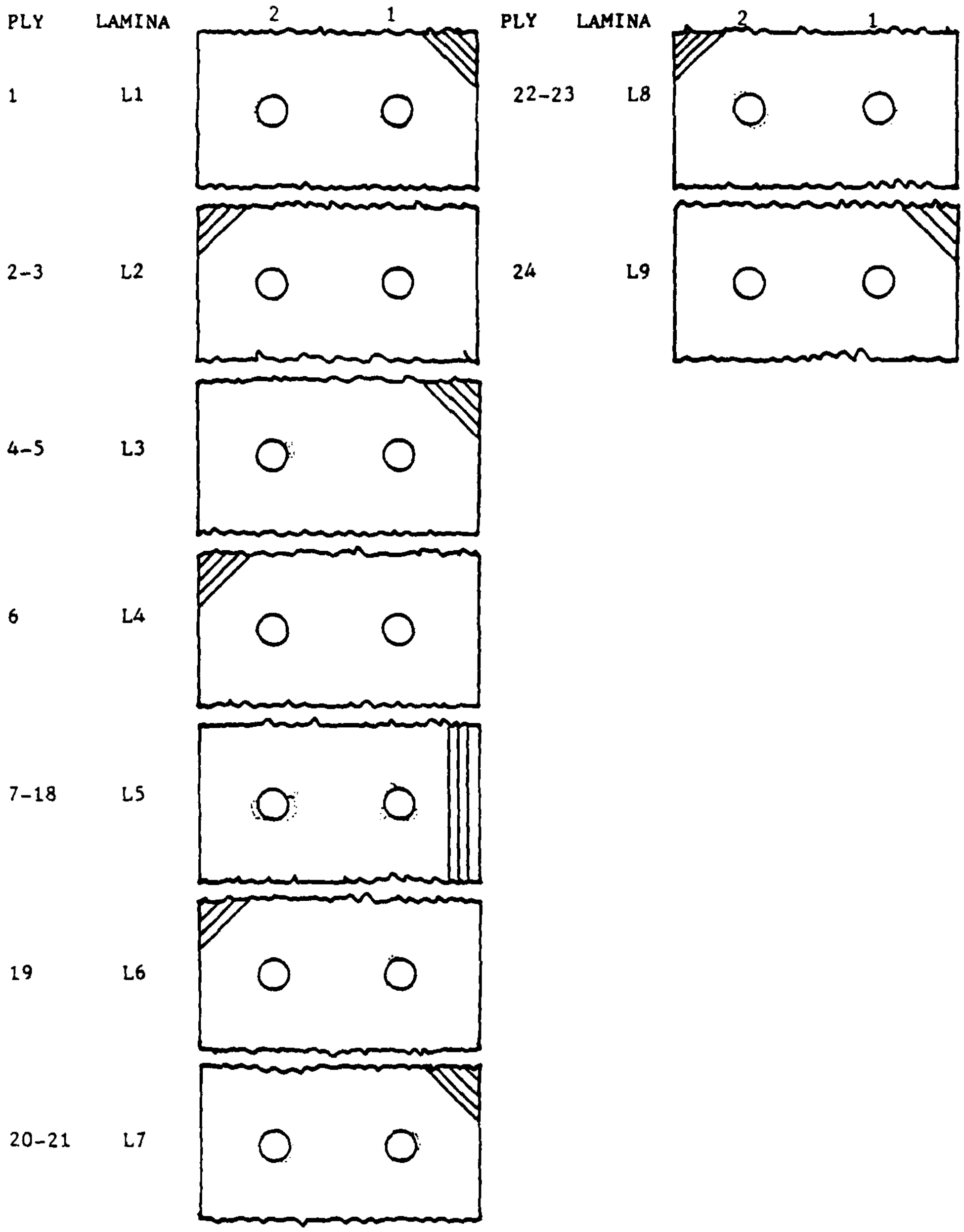


Figure B-30. Lamina Damage Characterization Chart for Specimen I-B-19 Load Level C

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - B($\pm 45^{\circ}$, $\mp 45^{\circ}$, $\pm 45^{\circ}$, 0_6°)s

LOAD LEVEL - D

POUNDS LOAD - 24,000 PERCENT OF ULTIMATE - 65

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 3

FIGURE B-31. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-4.

BEFORE LOADING AFTER LOADING

FIGURE B-32. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-4.

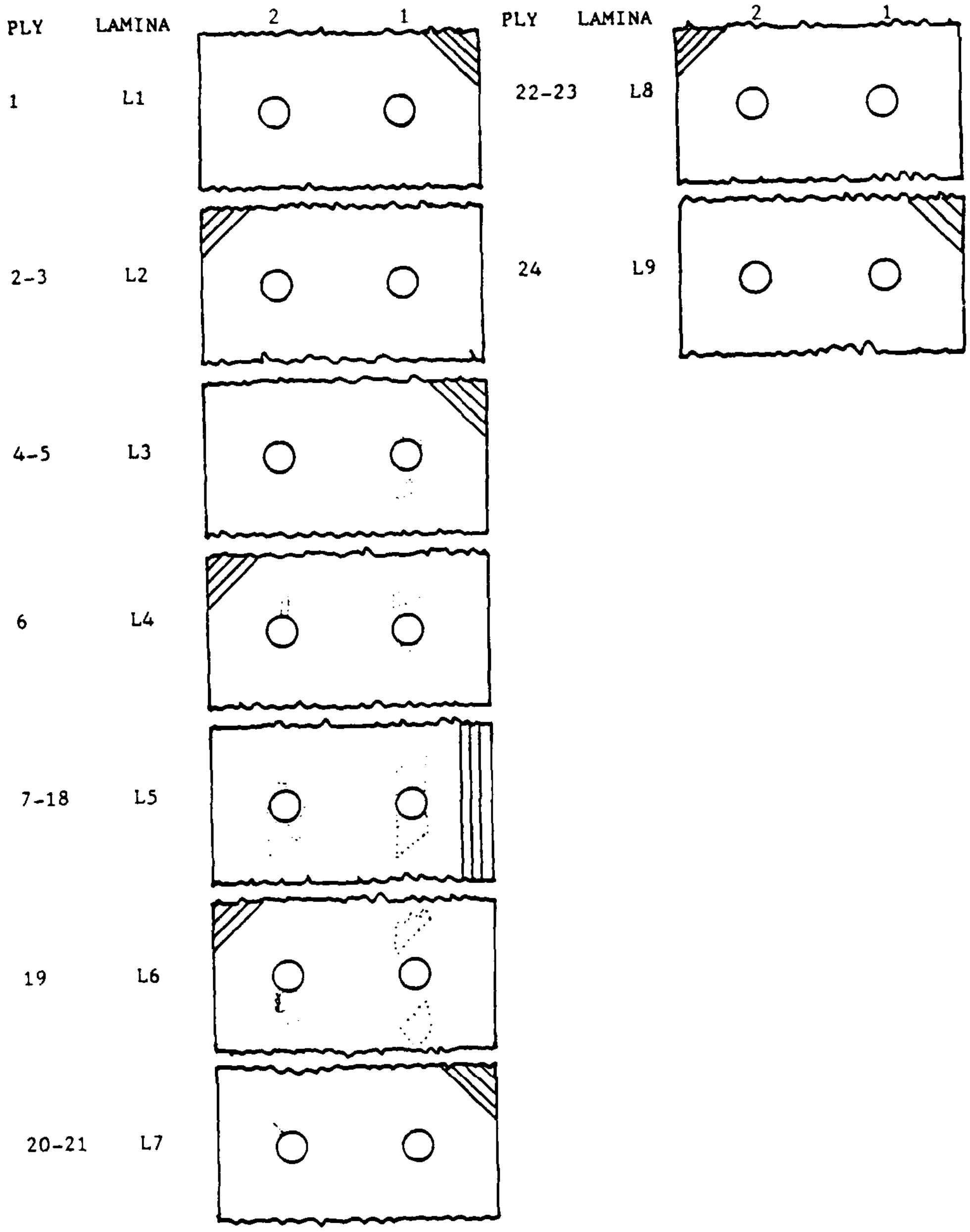


Figure B-33. Lamina Damage Characterization Chart for Specimen I-B- 4 Load Level D

SPECIMEN TYPE - I(OPEN HOLE)

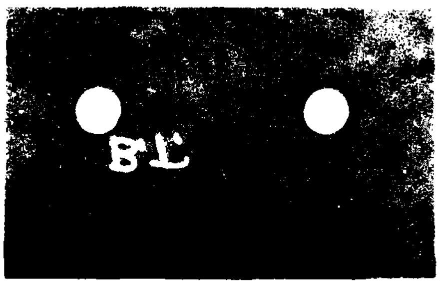
LAMINATE - B($\pm45^{\circ}$, $\mp45^{\circ}$, $\pm45^{\circ}$, 0_6°)s

LOAD LEVEL - D

POUNDS LOAD - 24,000   PERCENT OF ULTIMATE - 65

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 2

FIGURE B-34. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-2.



BEFORE LOADING

AFTER LOADING

FIGURE B-35. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-2.

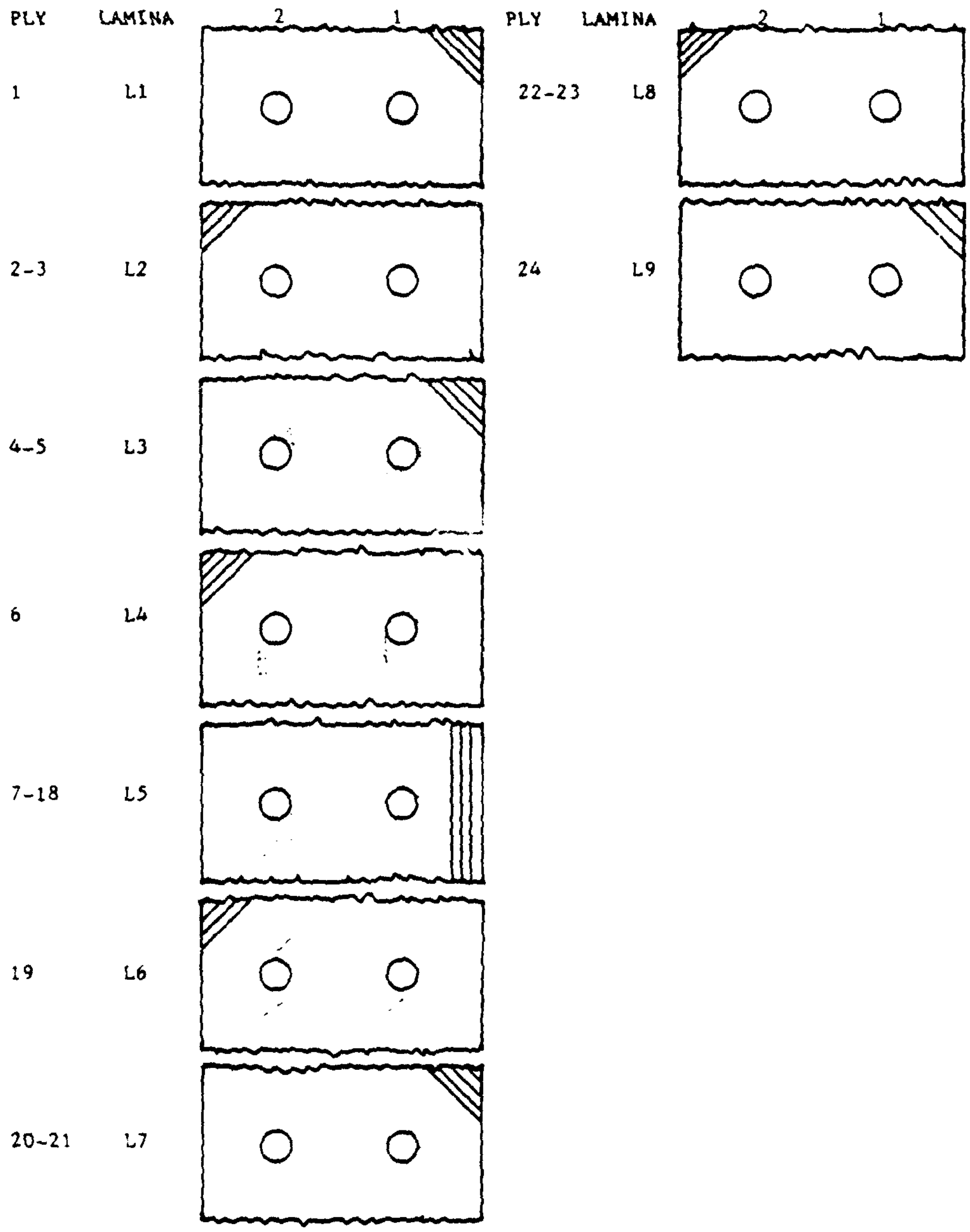


Figure B-36. Lamina Damage Characterization Chart for Specimen I-B-2 Load Level D

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - B($\pm 45^{\circ}$, $\mp 45^{\circ}$, $\pm 45^{\circ}$, $0_6{}^{\circ}$)s

LOAD LEVEL - D

POUNDS LOAD - 24,000 PERCENT OF ULTIMATE - 65

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 2

FIGURE B-37. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-20.

BEFORE LOADING AFTER LOADING

FIGURE B-38. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-20.

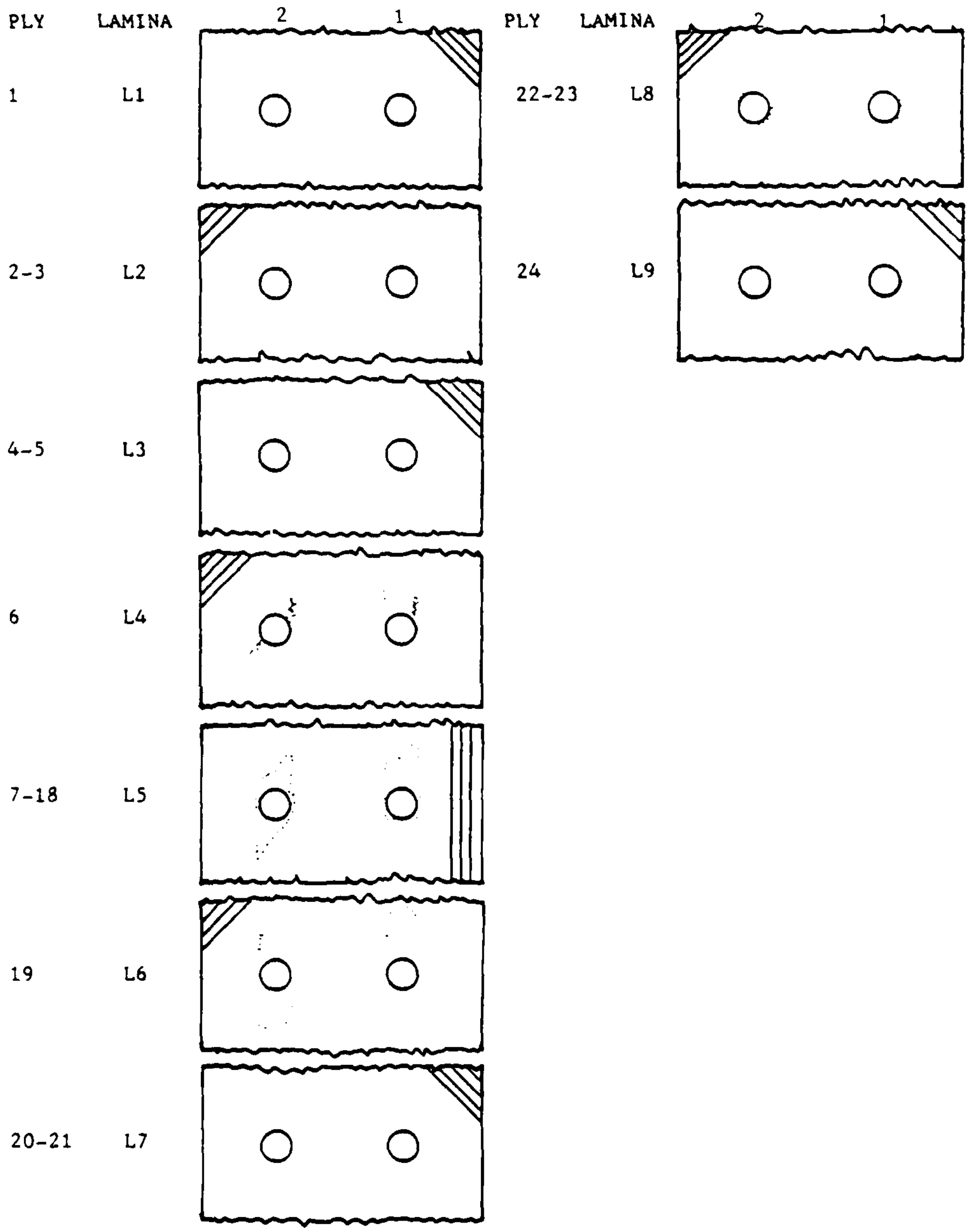


Figure B-39. Lamina Damage Characterization Chart for Specimen I-B- 20 Load Level D

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - B($\pm 45^{\circ}$, $\mp 45^{\circ}$, $\pm 45^{\circ}$, 0_6°)s

LOAD LEVEL - D

POUNDS LOAD - 24,000   PERCENT OF ULTIMATE - 65

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE B-40. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-17.

BEFORE LOADING   AFTER LOADING

FIGURE B-41. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-17.

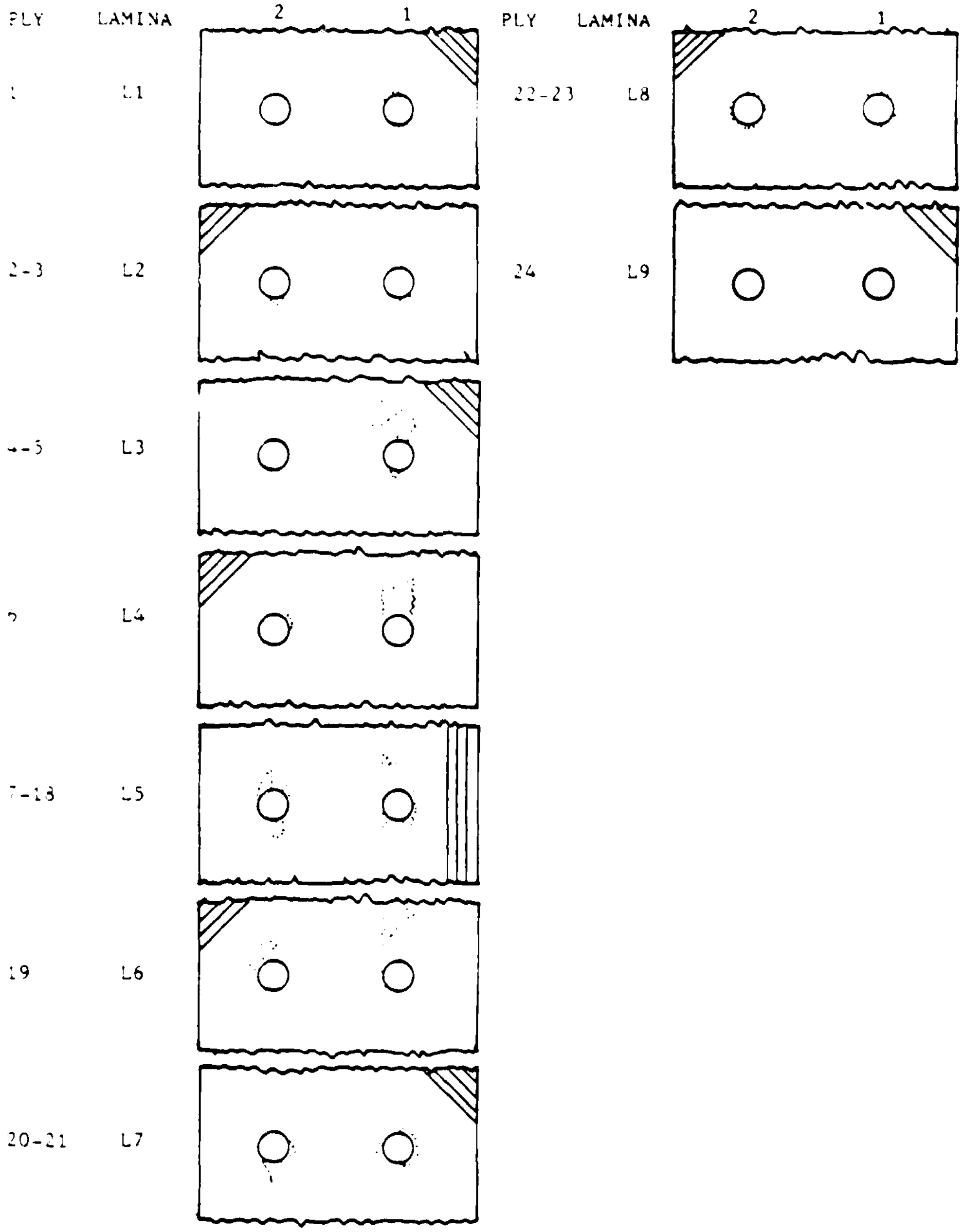


Figure B-42. Lamina Damage Characterization Chart for Specimen I-B-17 Load Level D

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - B($\pm 45^{o}$, $\mp 45^{o}$, $\pm 45^{o}$, $0_6{}^{o}$)s

LOAD LEVEL - D

POUNDS LOAD - 24,000   PERCENT OF ULTIMATE - 65

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES
BASED ON ACOUSTIC EMISSION MONITORING - 1

FIGURE B-43. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-7.

BEFORE LOADING   AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE B-44. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-7.

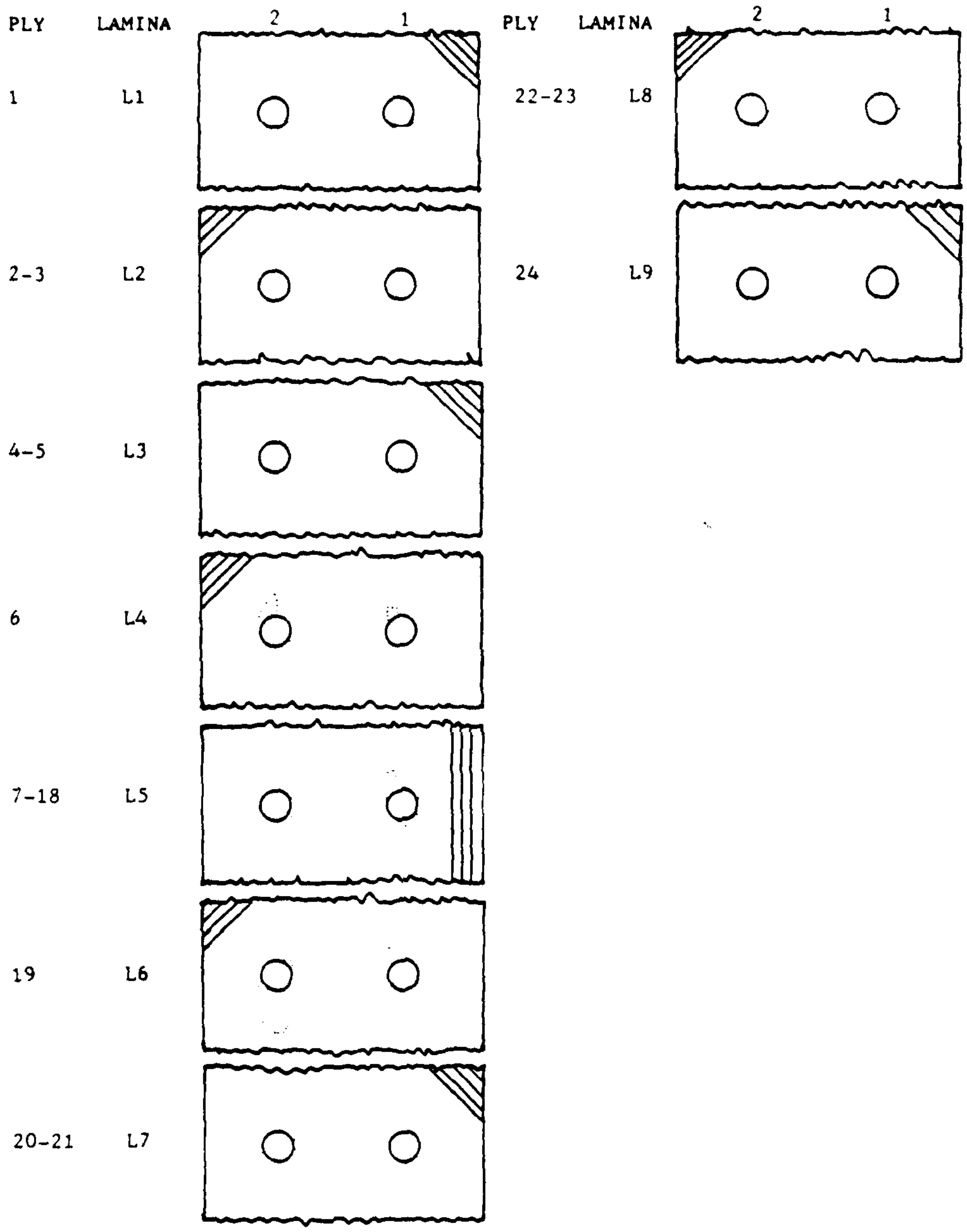


Figure B-45. Lamina Damage Characterization Chart for Specimen I-B-7 Load Level D

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - B($\pm 45^{\circ}$, $\mp 45^{\circ}$, $\pm 45^{\circ}$, $0_6{}^{\circ}$)s

LOAD LEVEL - B

POUNDS LOAD - 30,270   PERCENT OF ULTIMATE - 86

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 8

FIGURE B-46. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-27.

BEFORE LOADING   AFTER LOADING

FIGURE B-47. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-27.

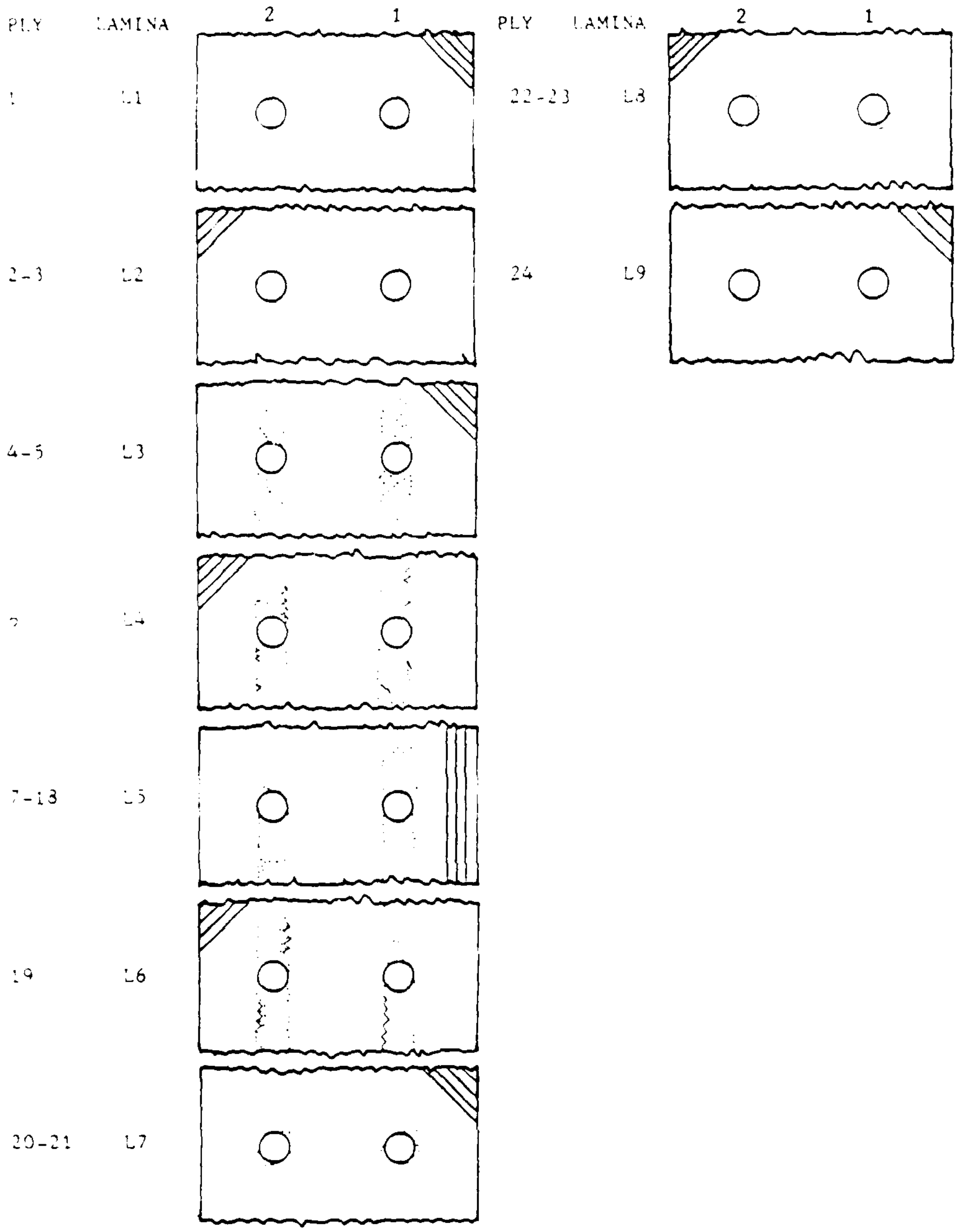


Figure B-48. Lamina Damage Characterization Chart for Specimen I-B-27 Load Level B

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - B($\pm 45^{\circ}$, $\mp 45^{\circ}$, $\pm 45^{\circ}$, 0_6°)s

LOAD LEVEL - B

POUNDS LOAD - 30,270 PERCENT OF ULTIMATE - 86

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 12

FIGURE B-49. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-6.

BEFORE LOADING AFTER LOADING

FIGURE B-50. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-6.

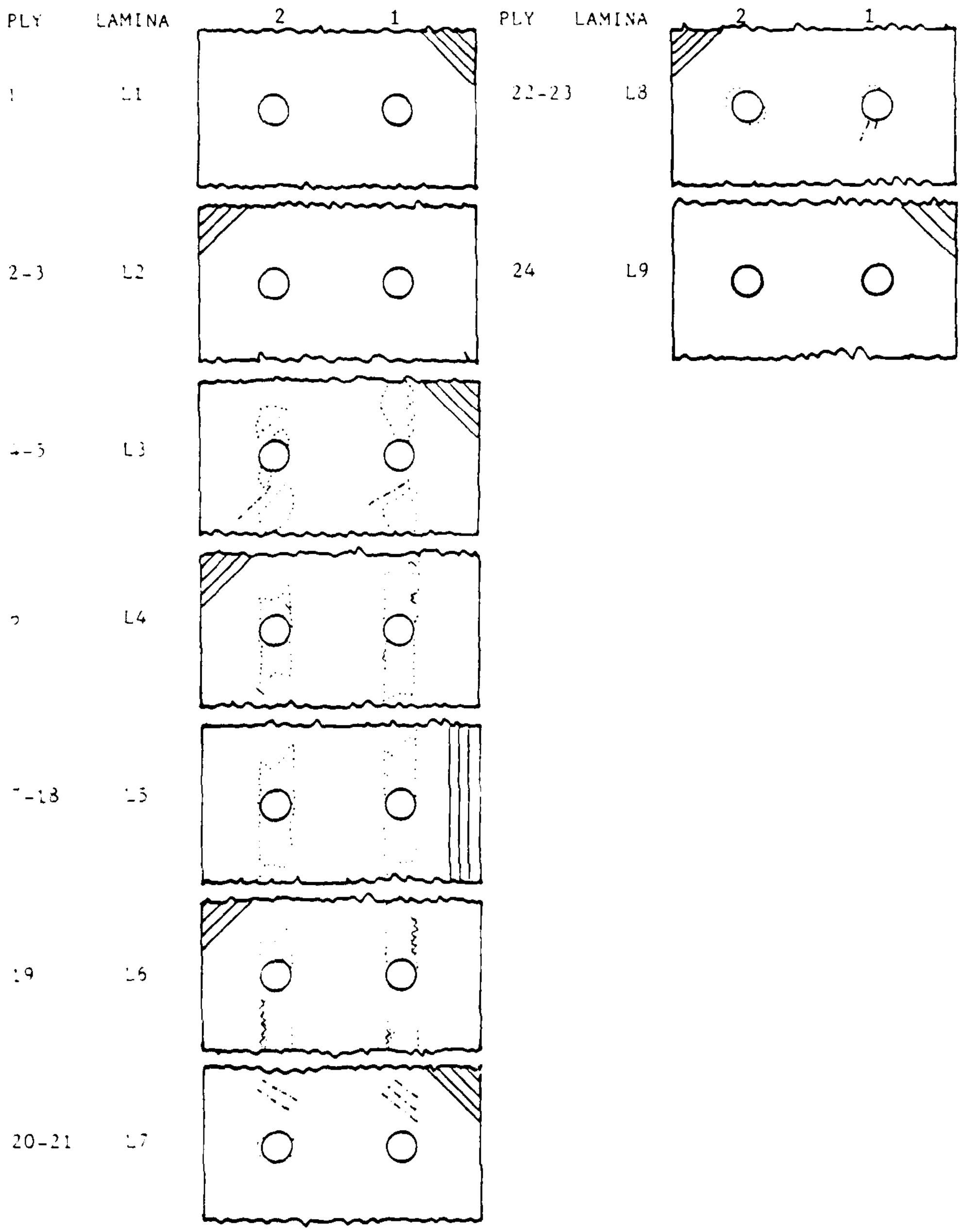


Figure B-51. Lamina Damage Characterization Chart for Specimen I-B-6 Load Level B

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - B($\pm45^{\circ}$, $\mp45^{\circ}$, $\pm45^{\circ}$, $0_6{}^{\circ}$)s

LOAD LEVEL - B

POUNDS LOAD - 30,270   PERCENT OF ULTIMATE - 86

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 27

FIGURE B-52. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-14.

BEFORE LOADING   AFTER LOADING

FIGURE B-53. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-14.

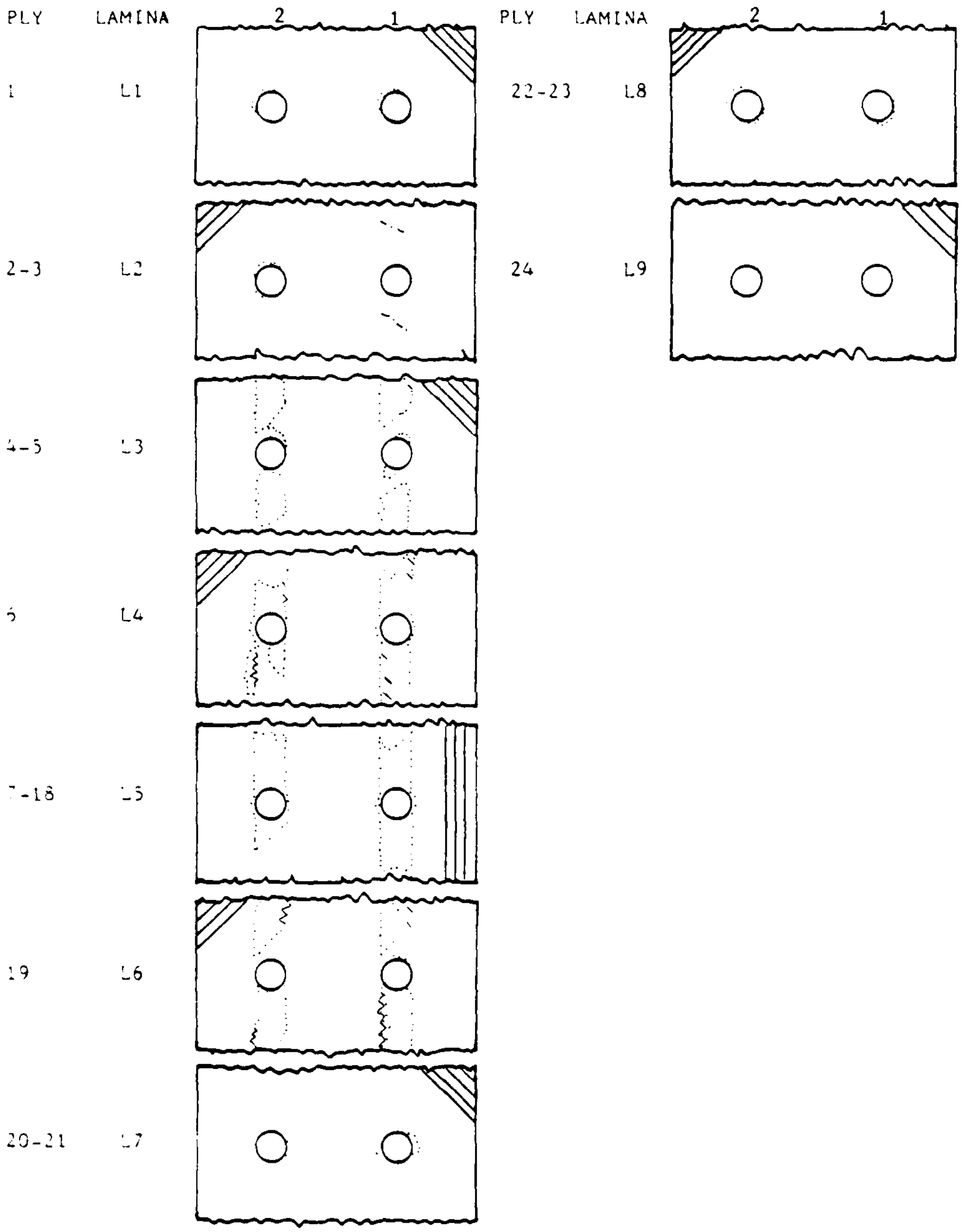


Figure B-54. Lamina Damage Characterization Chart for Specimen [illegible]-B-14 Load Level B

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - B($\pm45^{\circ}$, $\mp45^{\circ}$, $\pm45^{\circ}$, 0_6°)s

LOAD LEVEL - B

POUNDS LOAD - 30,270   PERCENT OF ULTIMATE - 86

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 8

FIGURE B-55. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-24.

BEFORE LOADING   AFTER LOADING

FIGURE B-56. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-24.

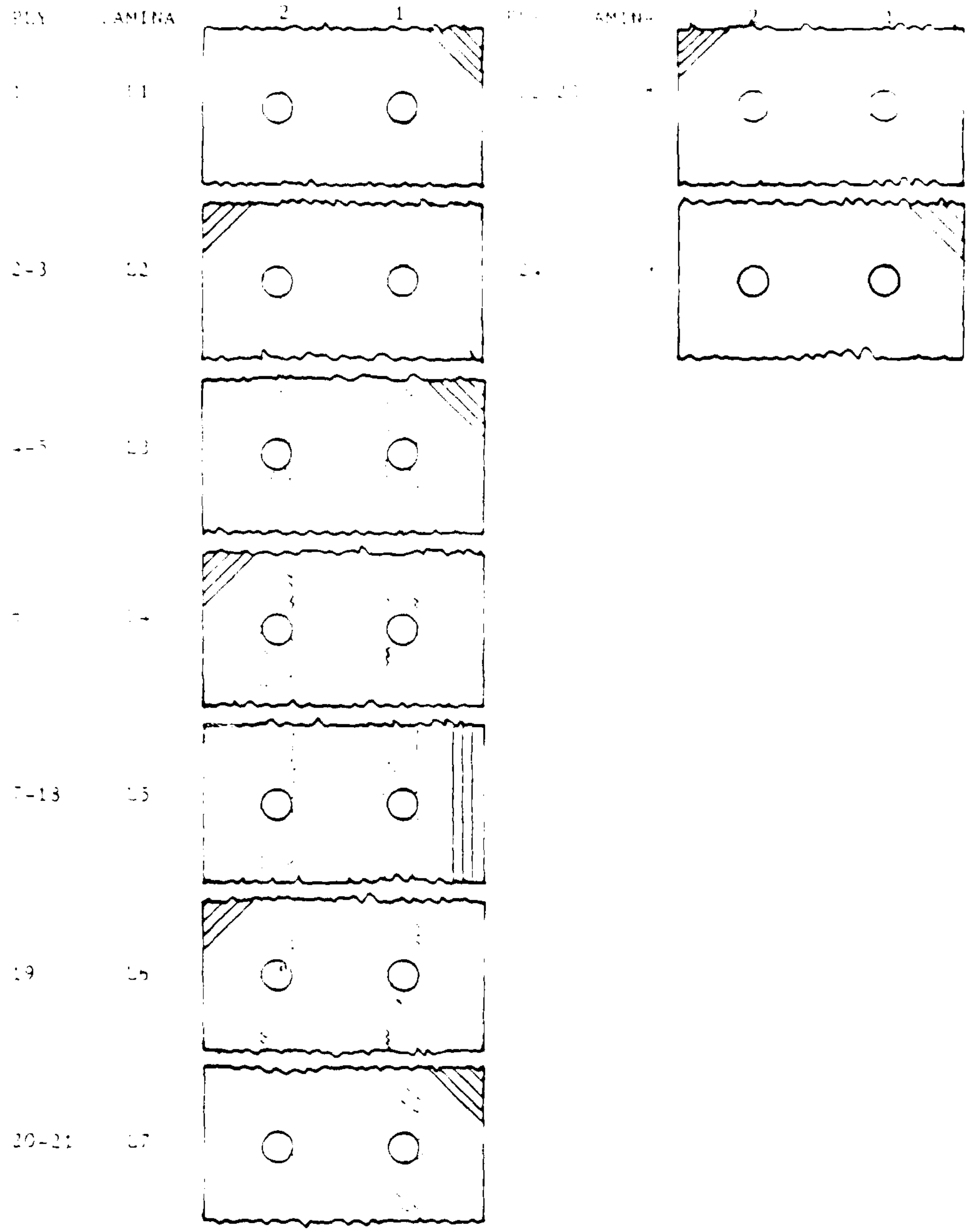


Figure B-57. Lamina Damage Characterization Chart for Specimen [illegible]-3-24 Load Level B

SPECIMEN TYPE - I(OPEN HOLE)

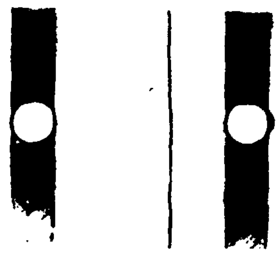
LAMINATE - B($\pm 45^{\circ}$, $\mp 45^{\circ}$, $\pm 45^{\circ}$, $0_6{}^{\circ}$)s

LOAD LEVEL - B

POUNDS LOAD - 30,270 PERCENT OF ULTIMATE - 86

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES
BASED ON ACOUSTIC EMISSION MONITORING - 13

FIGURE B-58. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-B-18.



BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE B-59. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-B-18.

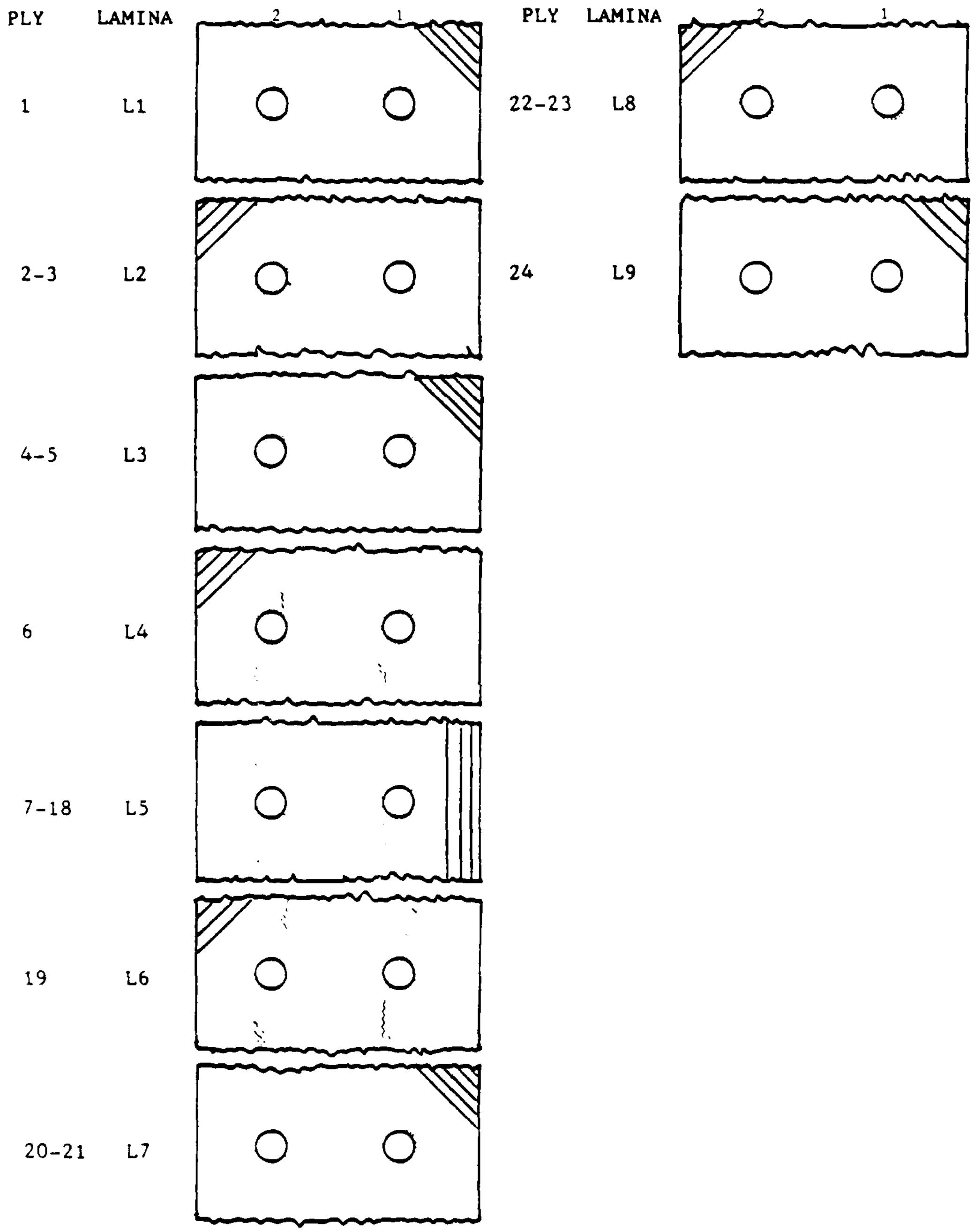


Figure B-60 Lamina Damage Characterization Chart for Specimen I-B-18 Load Level B

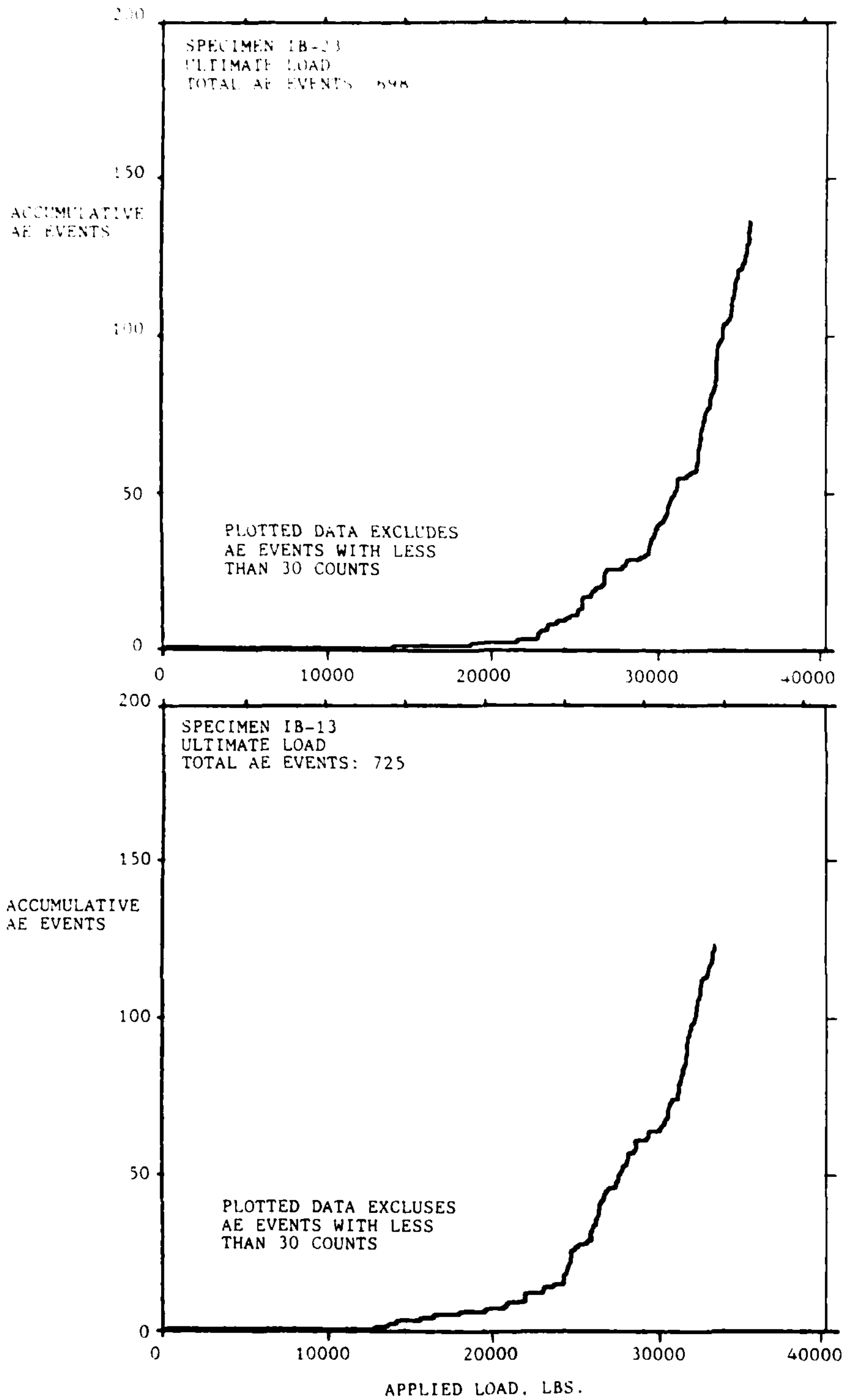


Figure B-61. Plots of Accumulative AE Events vs Applied Loads for Type I-B Ultimate Specimens.

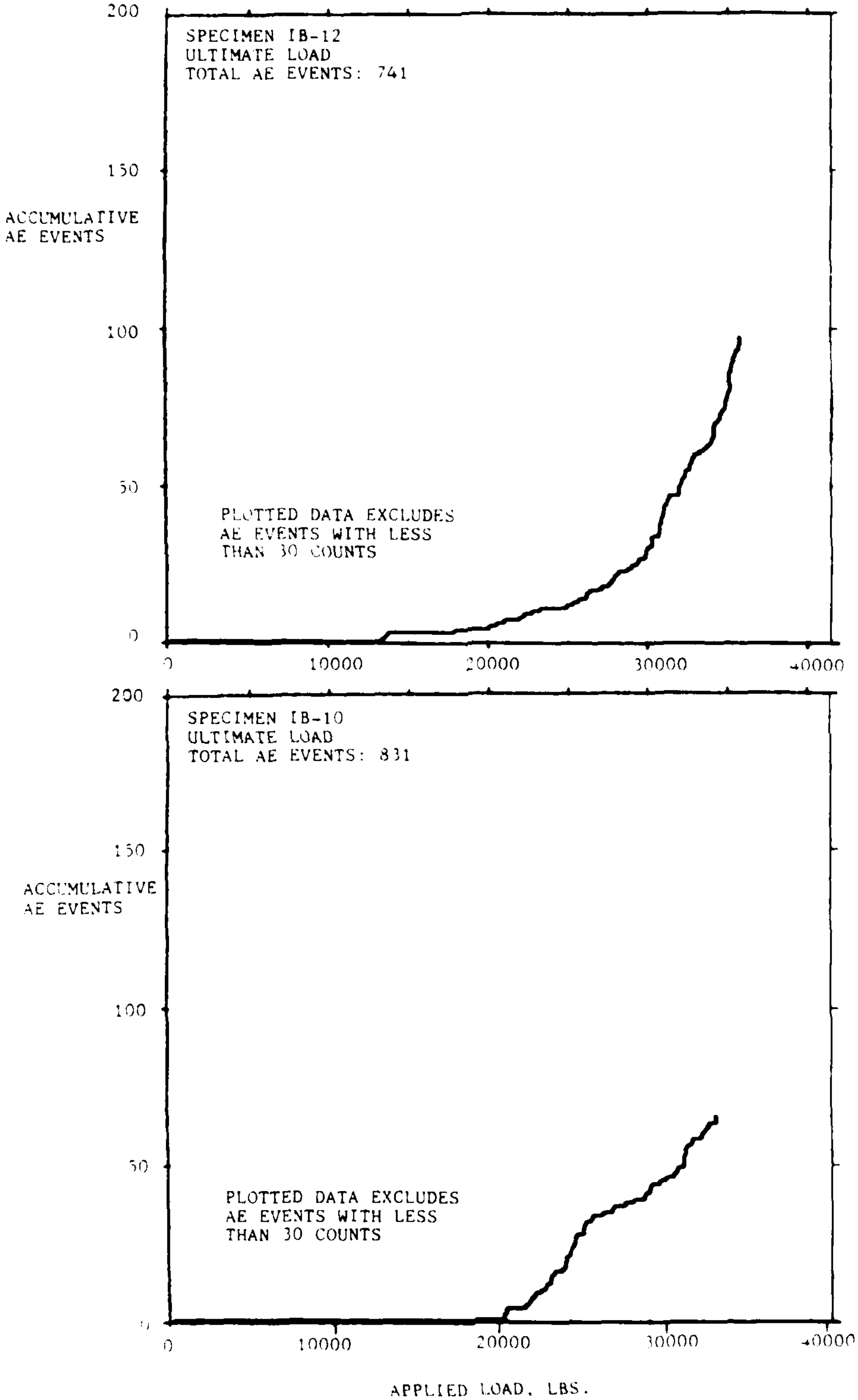


Figure B-62. Plots of Accumulative AE Events vs Applied Loads for Type I-B Ultimate Specimens.

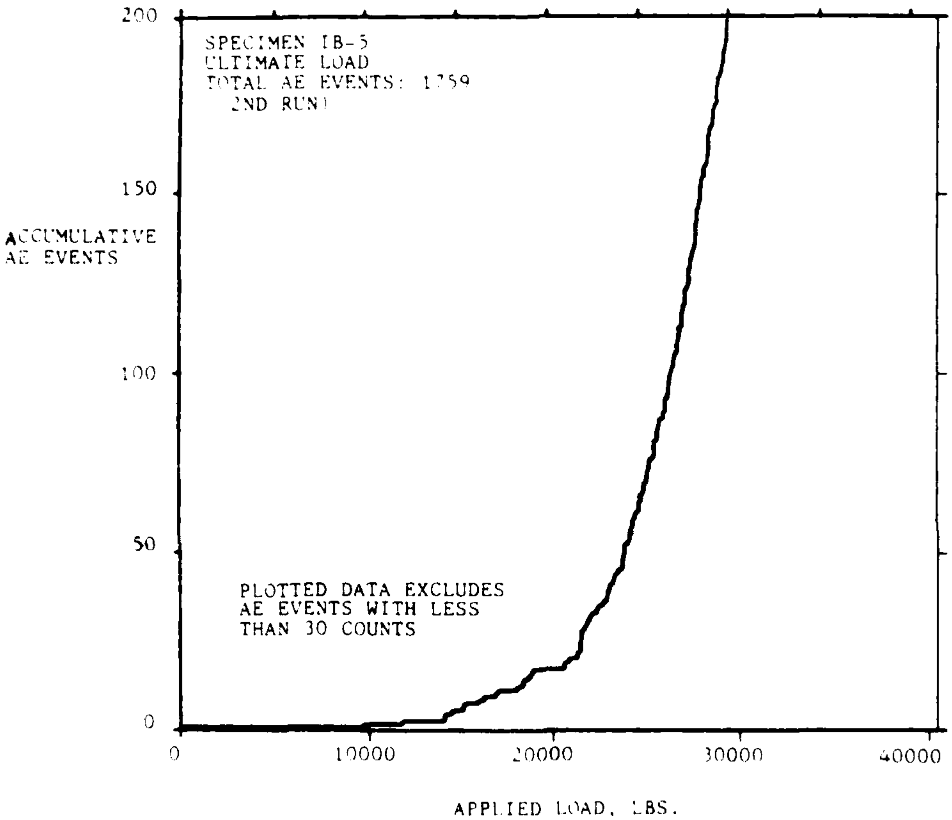


Figure B-63. Plots of Accumulative AE Events vs Applied Loads for Type I-B Ultimate Specimens.

APPENDIX C

DETAIL DAMAGE INFORMATION FOR TYPE I SPECIMENS

The detail information for the Type I specimens of Laminate C is presented in this appendix. It is presented in the order of increasing load levels. All specimens of the same load level are grouped together. Three figures are presented for each specimen. The first figure gives specimen type, laminate information, load conditions and expected number of fiber bundle fractures based on Acoustic Emission monitoring. The second figure consists of positive prints of enhanced x-ray radiographs made before and after loading. In addition, prints of a stereo x-ray pair are included for one specimen of each load level. The third figure consists of a Lamina Damage Characterization Chart. This chart contains a pictorial sketch for each lamina with fiber orientations indicated on one side or edge of each sketch. The damage observed on each lamina is recorded on the appropriate sketch in a manner to indicate size and location relative to the open hole.

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - C($\pm 45^\circ$, 0°, 90°, $\mp 45^\circ$, 0°, 90°, $\pm 45^\circ$, 0°, 90°)s

LOAD LEVEL - A

POUNDS LOAD - 9538 PERCENT OF ULTIMATE - 60

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-1. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-26.

BEFORE LOADING AFTER LOADING

FIGURE C-2. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-26.

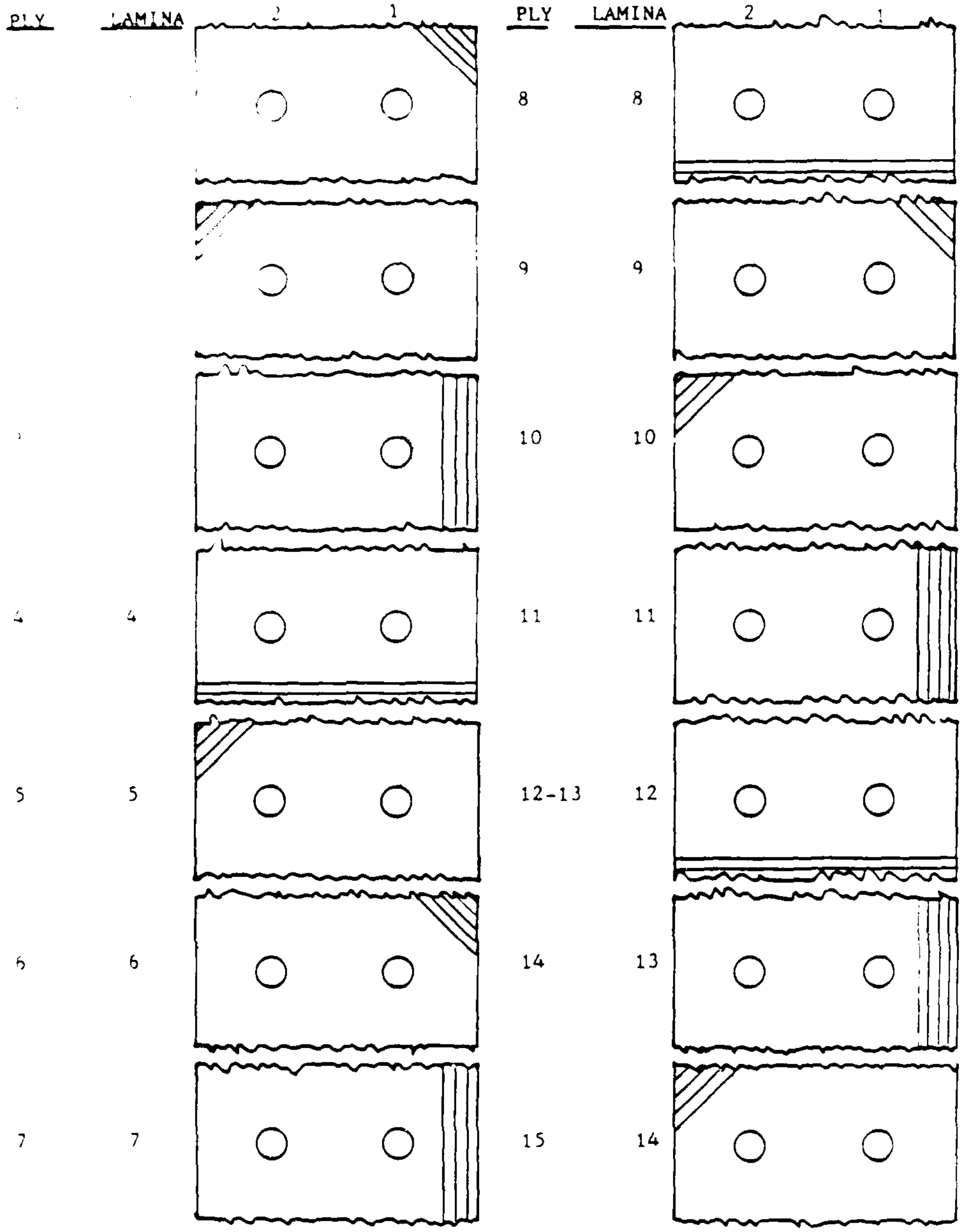


Figure C-3. Lamina Damage Characterization Chart for Specimen I-C 26 Load Level A (Continued)

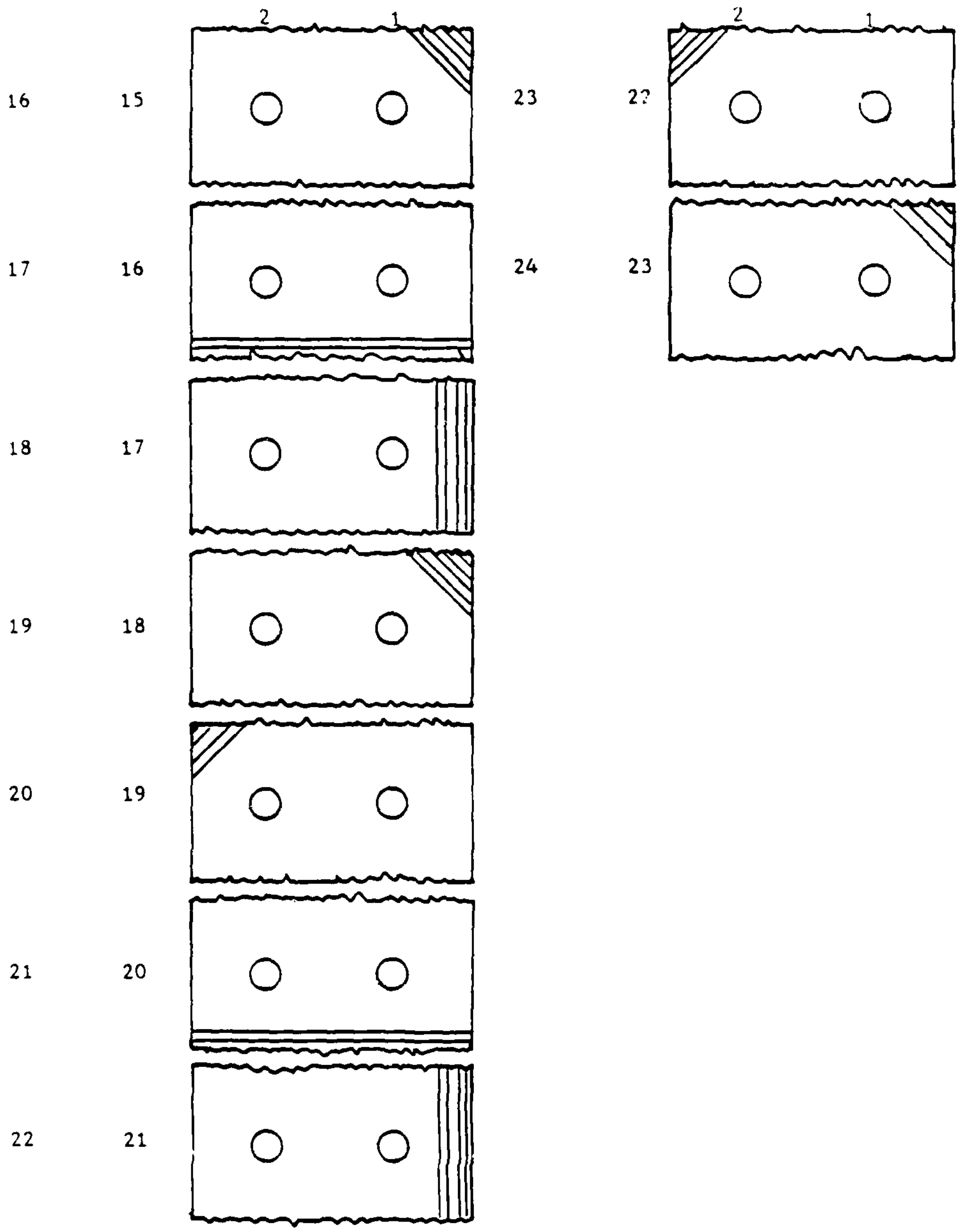


Figure C-3. Lamina Damage Characterization Chart for Specimen I-C-26 Load Level A

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - $C(\pm 45^\circ, 0^\circ, 90^\circ, \mp 45^\circ, 0^\circ, 90^\circ, \pm 45^\circ, 0^\circ, 90^\circ)_s$

LOAD LEVEL - A

POUNDS LOAD - 9538 PERCENT OF ULTIMATE - 60

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-4. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-8.

BEFORE LOADING

AFTER LOADING

FIGURE C-5. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-8.

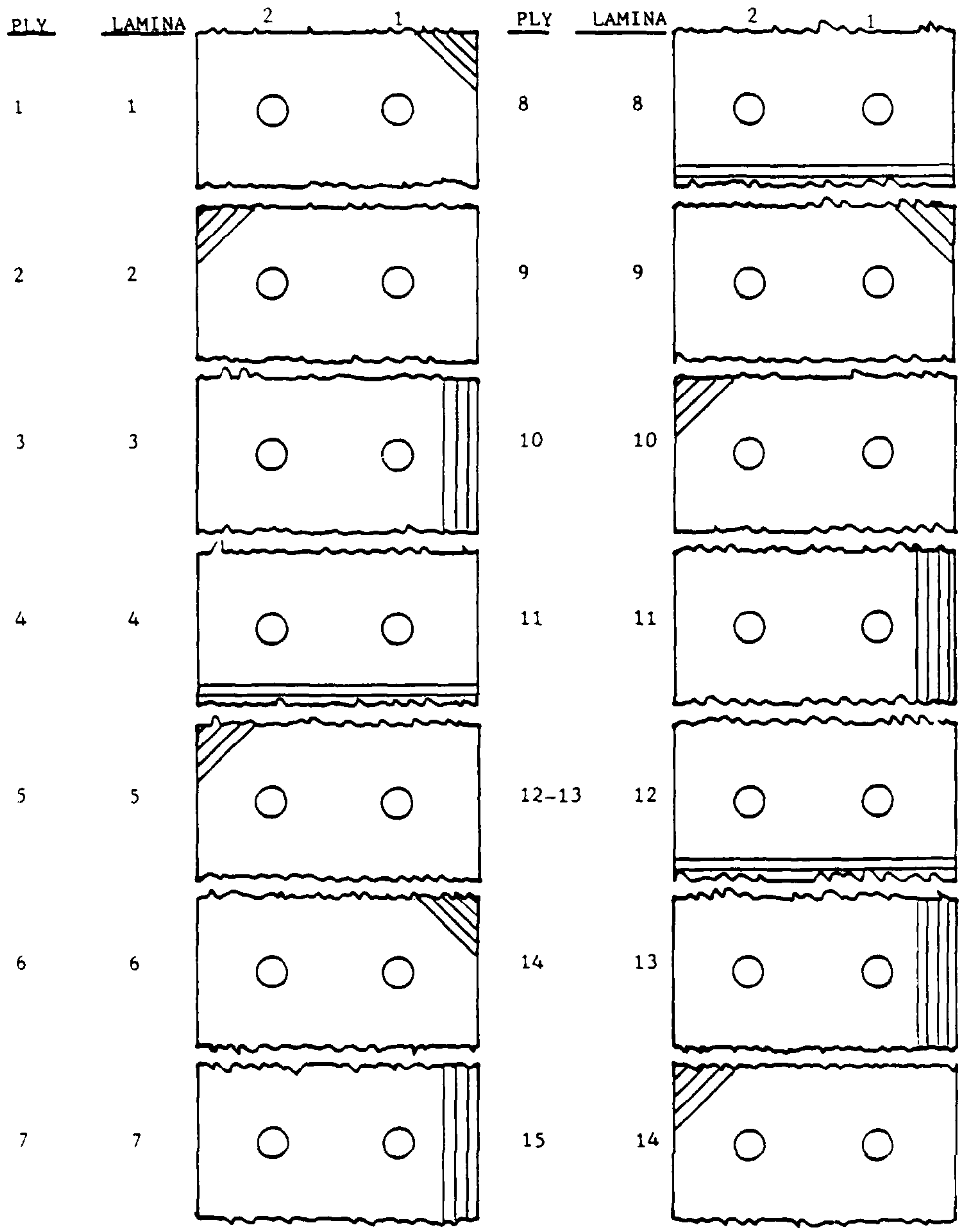


Figure C-6. Lamina Damage Characterization Chart for Specimen I-C-8 Load Level A (Continued)

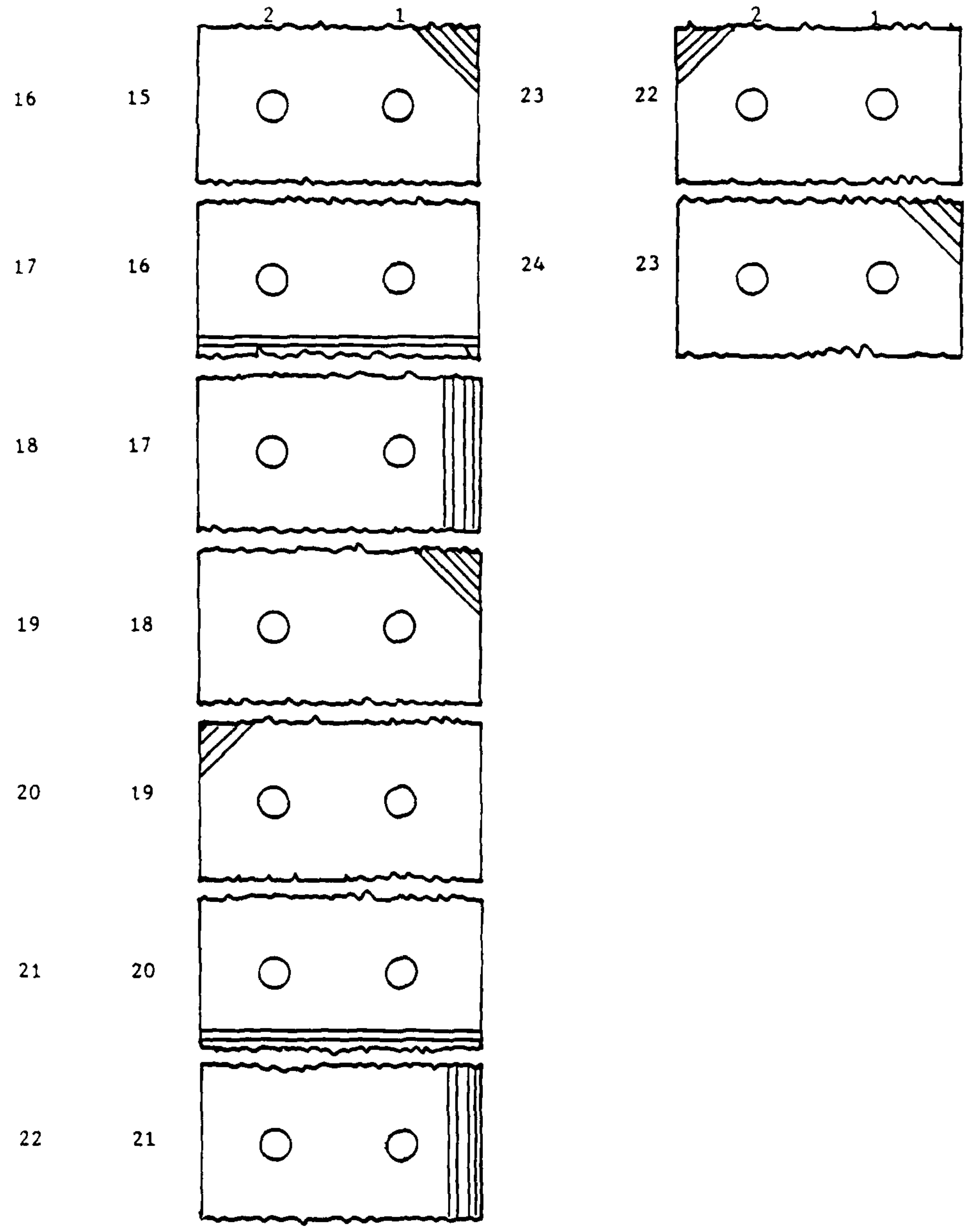


Figure C-6. Lamina Damage Characterization Chart for Specimen I-C- 8 Load Level A

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - $C(\pm45^\circ, 0^\circ, 90^\circ, \mp45^\circ, 0^\circ, 90^\circ, \pm45^\circ, 0^\circ, 90^\circ)_s$

LOAD LEVEL - A

POUNDS LOAD - 9538 PERCENT OF ULTIMATE - 60

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-7. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-16.

BEFORE LOADING

AFTER LOADING

FIGURE C-8. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-16.

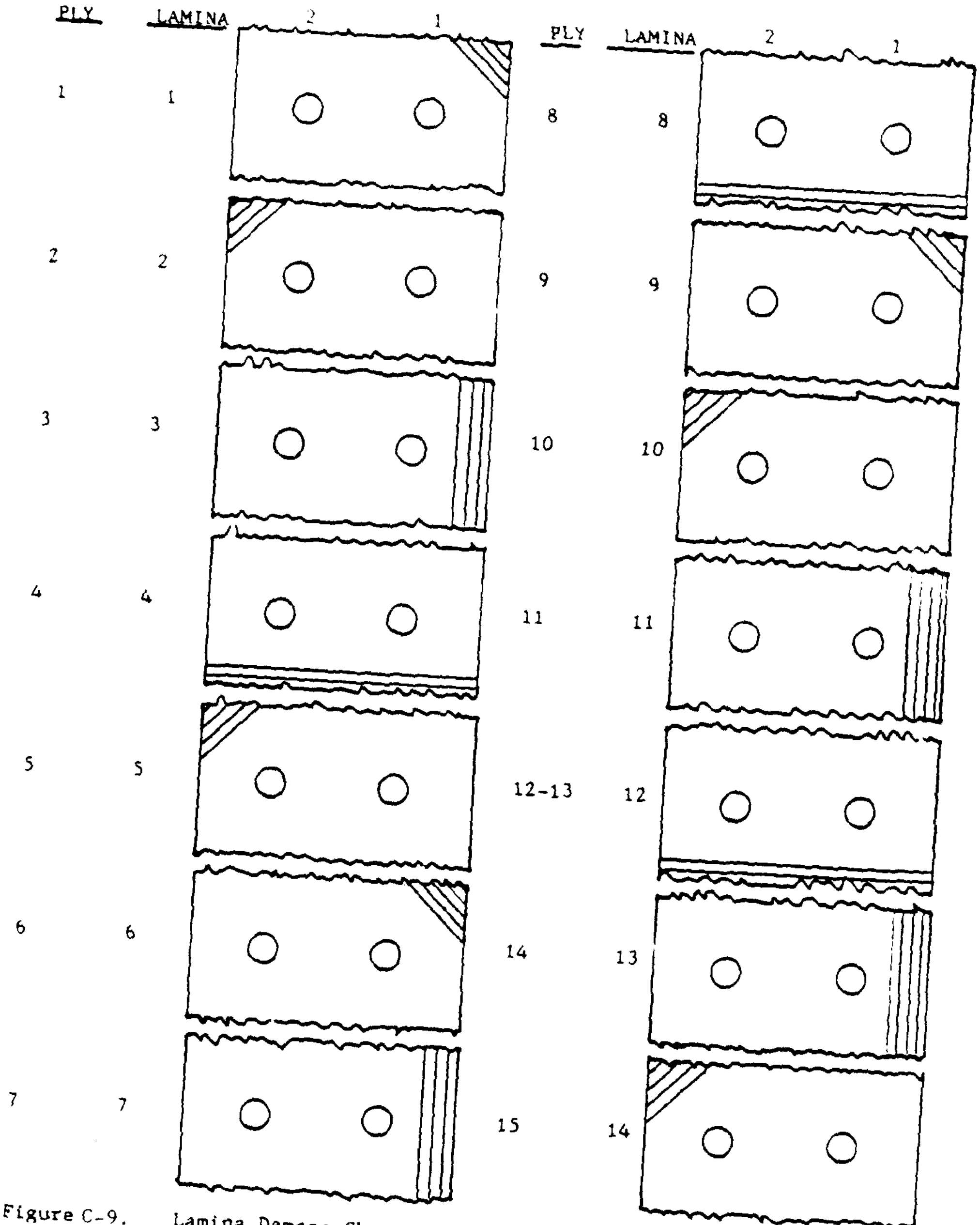


Figure C-9. Lamina Damage Characterization Chart for Specimen I-C-16 Load Level A (Continued)

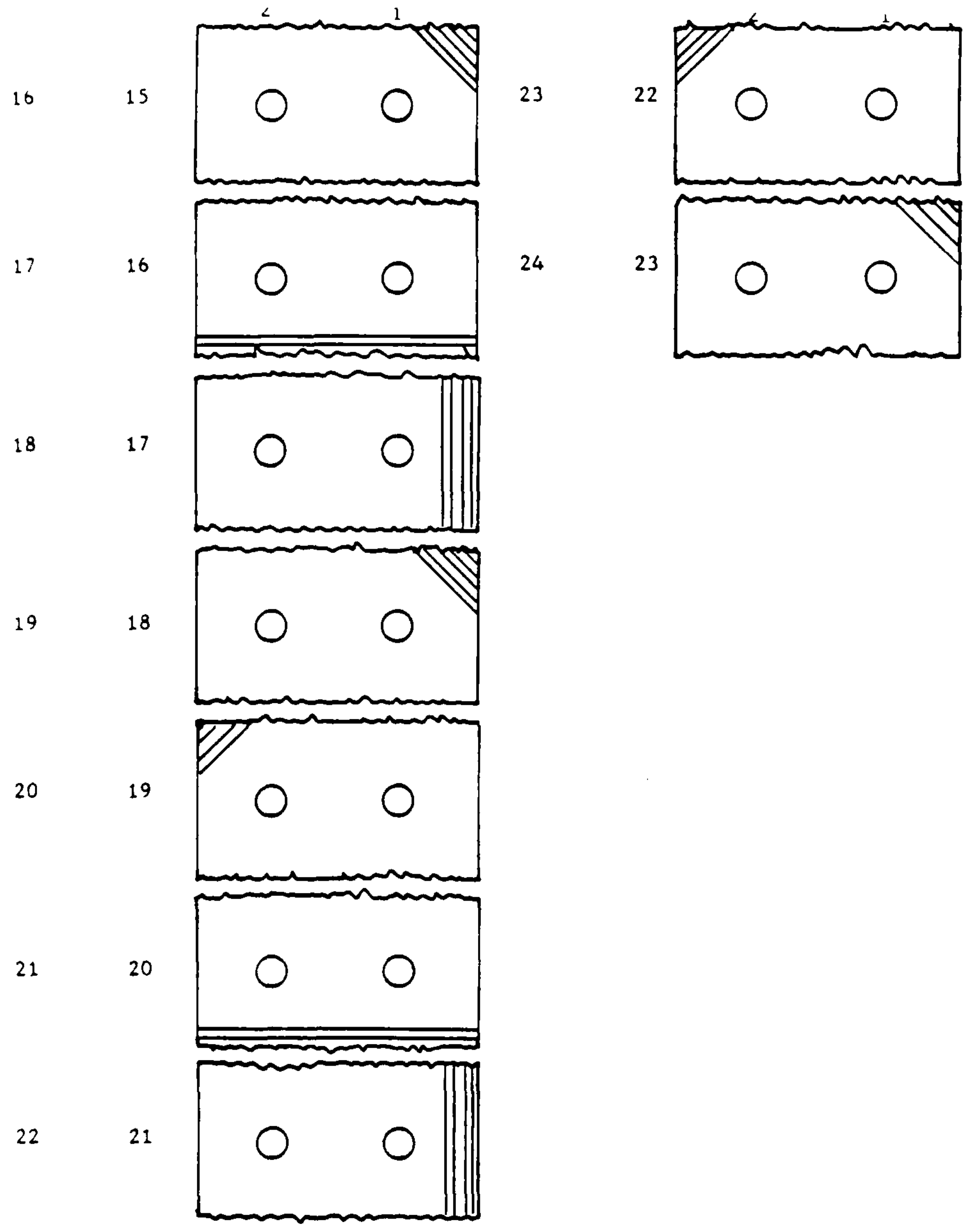


Figure C-9. Lamina Damage Characterization Chart for Specimen I-C- 16 Load Level A

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - C($\pm$45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)s

LOAD LEVEL - A

POUNDS LOAD - 9538 PERCENT OF ULTIMATE - 60

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-10. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-21.

BEFORE LOADING AFTER LOADING

FIGURE C-11. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-21.

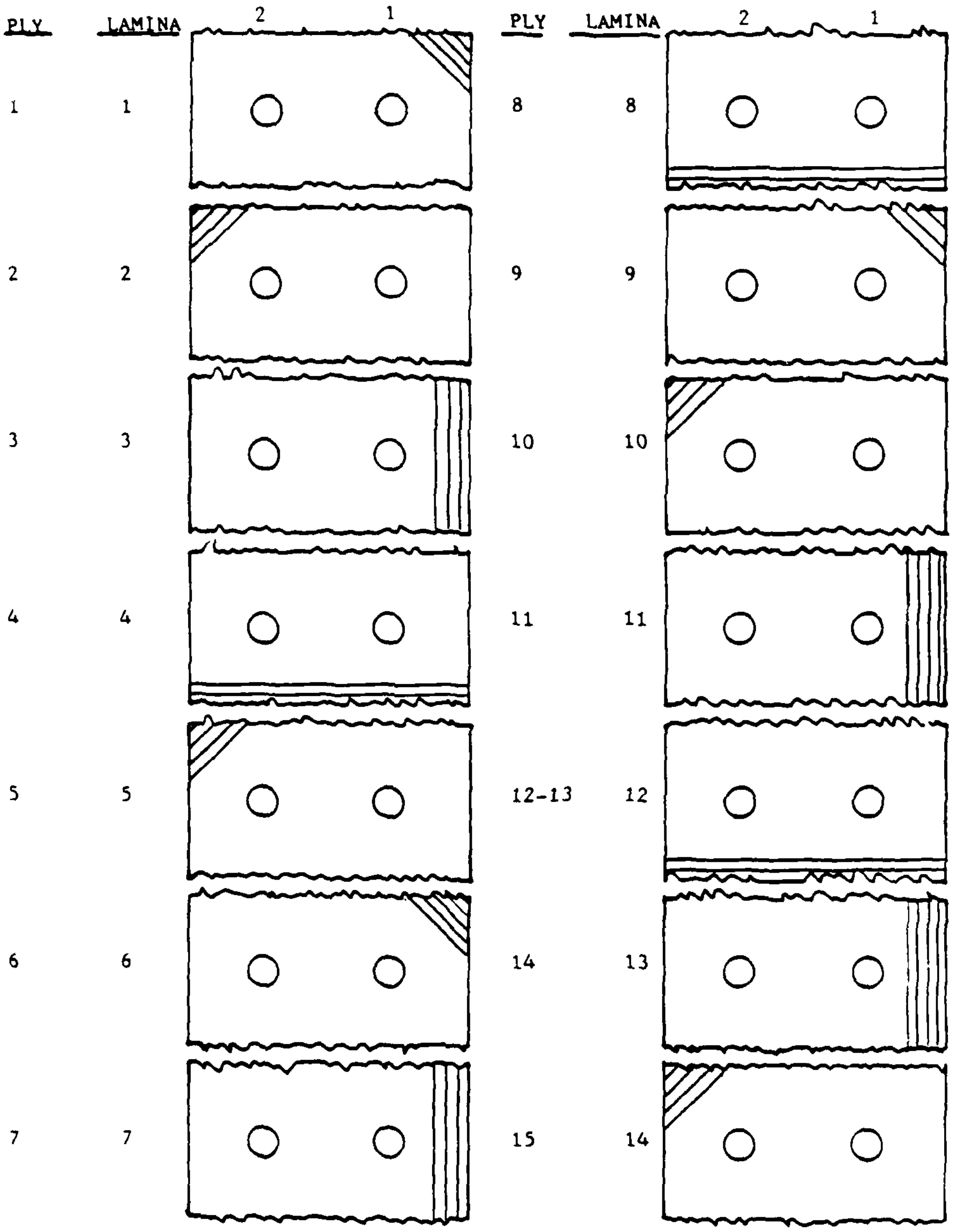


Figure C-12. Lamina Damage Characterization Chart for Specimen I-C-21 Load Level A (Continued)

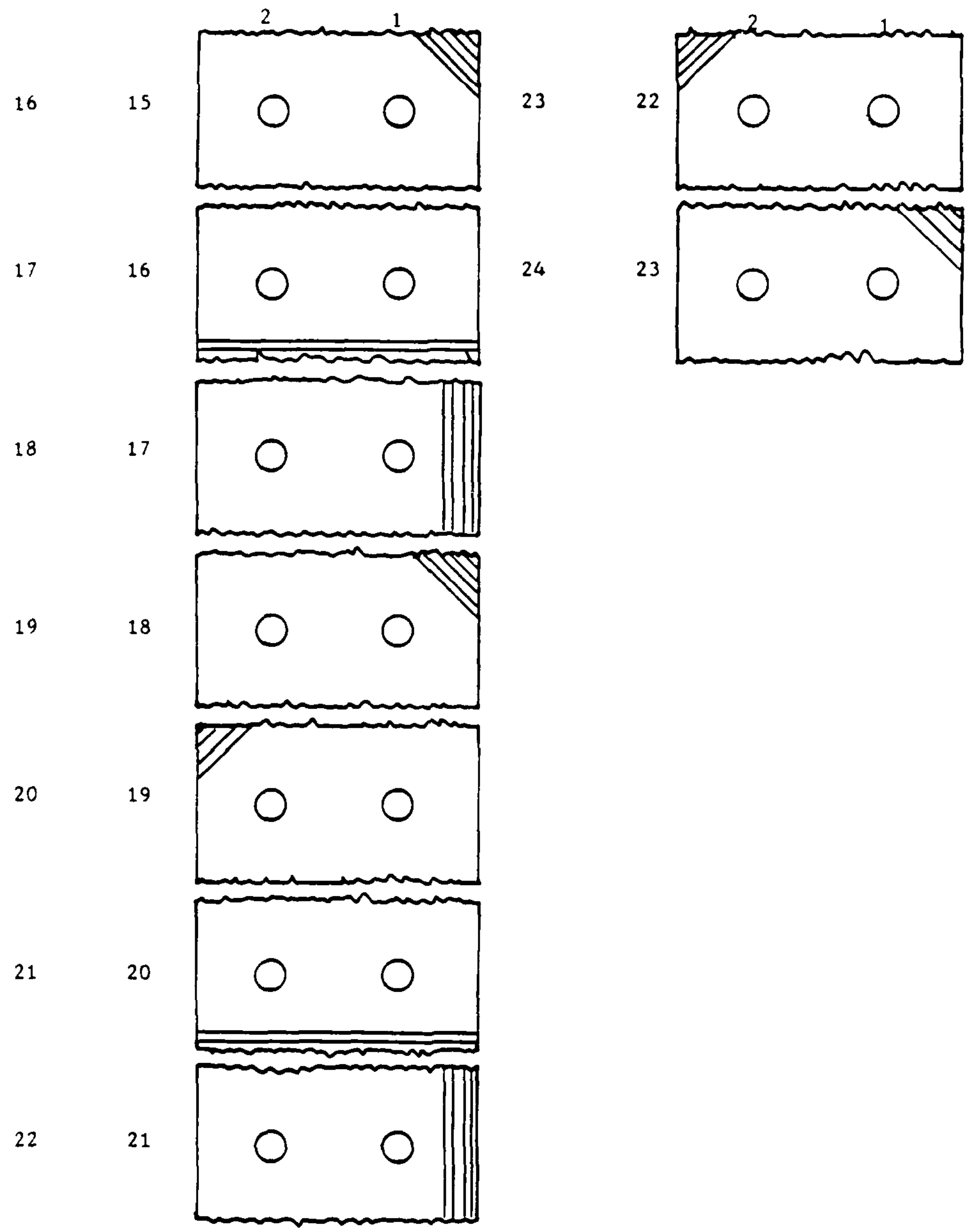


Figure C-12. Lamina Damage Characterization Chart for Specimen I-C-21 Load Level A

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - $C(\pm 45^{\circ}, 0^{\circ}, 90^{\circ}, \mp 45^{\circ}, 0^{\circ}, 90^{\circ}, \pm 45^{\circ}, 0^{\circ}, 90^{\circ})_s$

LOAD LEVEL - A

POUNDS LOAD - 9538   PERCENT OF ULTIMATE - 60

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES
BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-13. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-1.

BEFORE LOADING

AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE C-14. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-1.

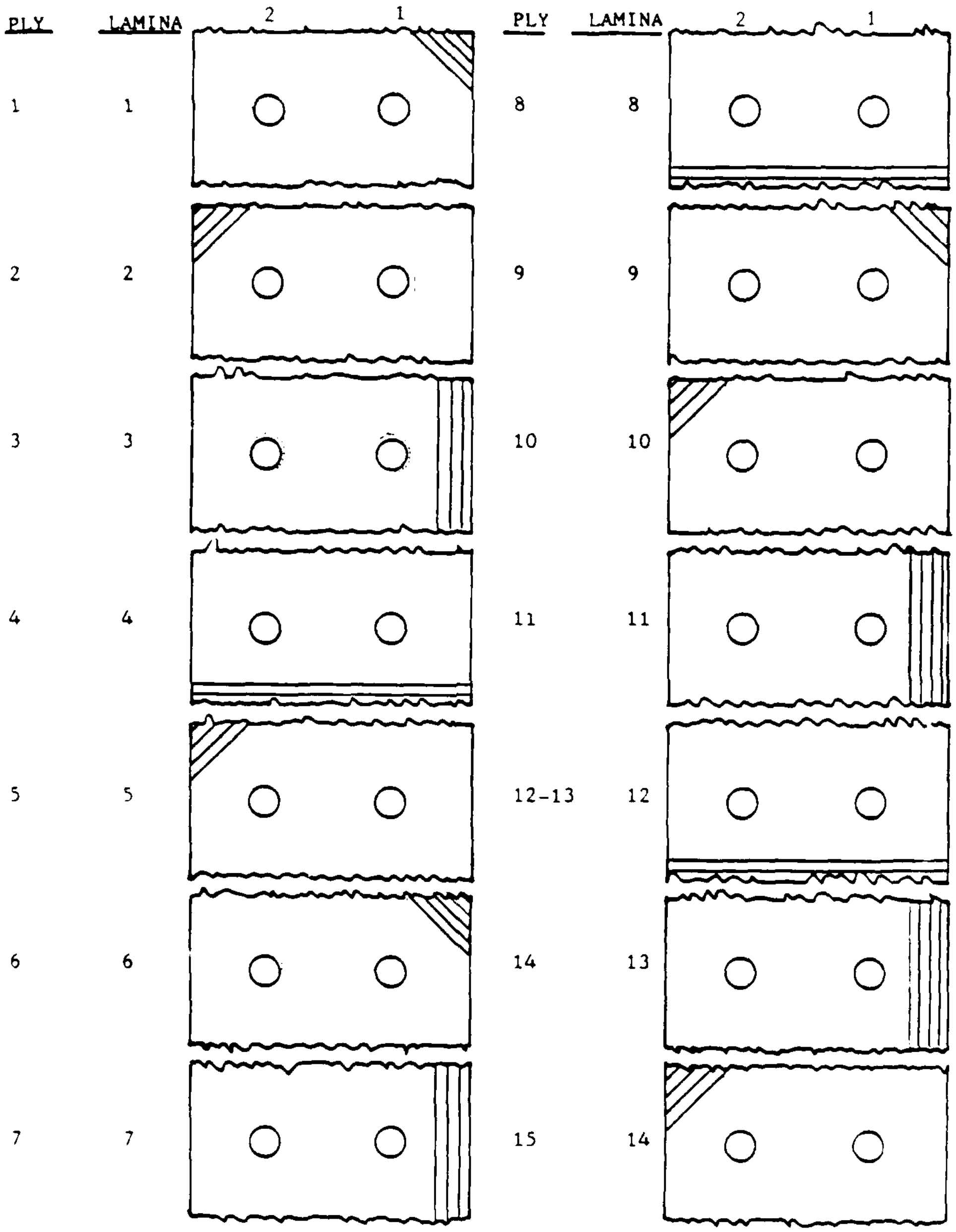


Figure C-15. Lamina Damage Characterization Chart for Specimen I-C-1 Load Level A (Continued)

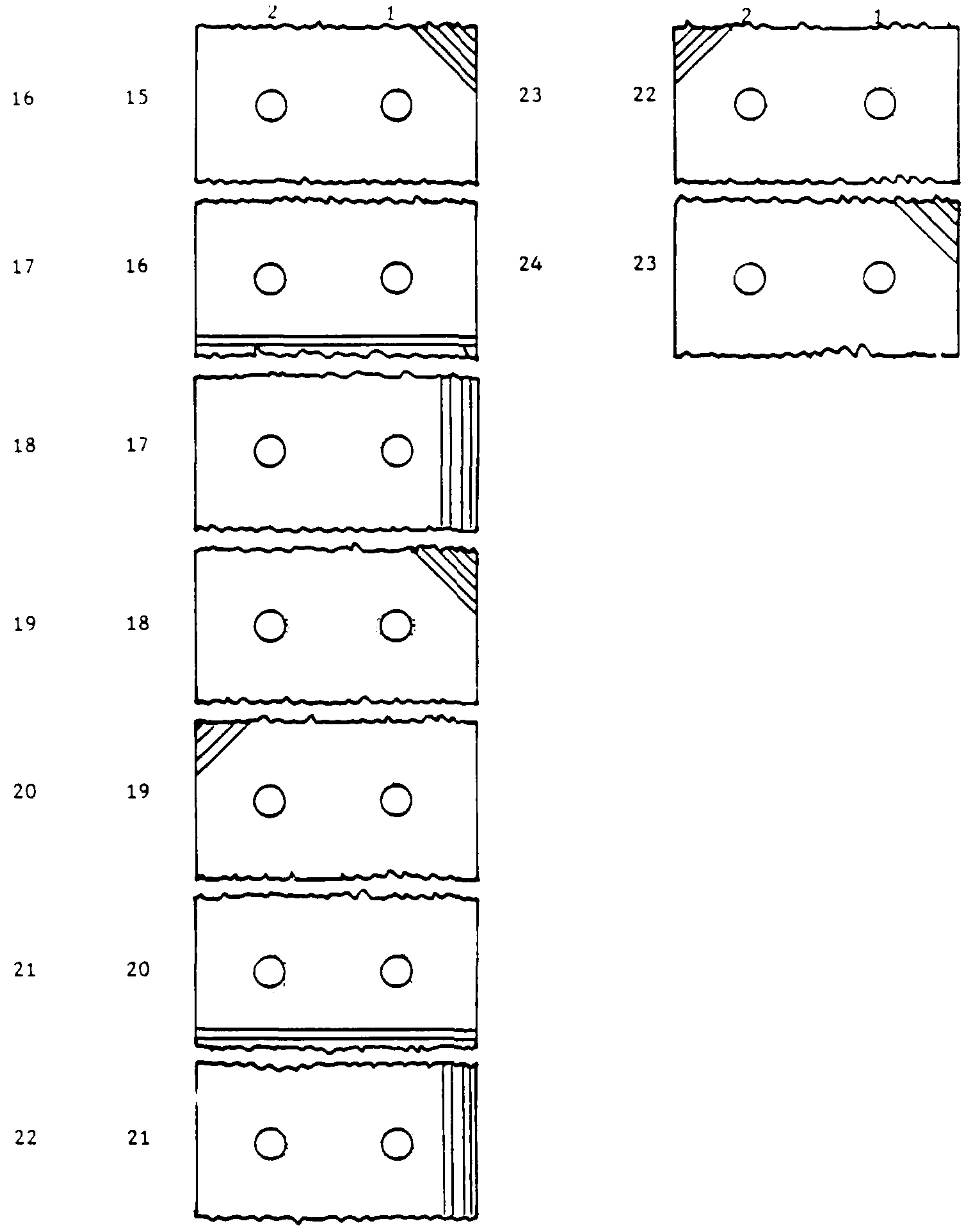


Figure C-15. Lamina Damage Characterization Chart for Specimen I-C-1 Load Level A

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - C($\pm45^\circ$, 0°, 90°, $\mp45^\circ$, 0°, 90°, $\pm45^\circ$, 0°, 90°)s

LOAD LEVEL - C

POUNDS LOAD - 11,640 PERCENT OF ULTIMATE - 73

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-16. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-3.

BEFORE LOADING

AFTER LOADING

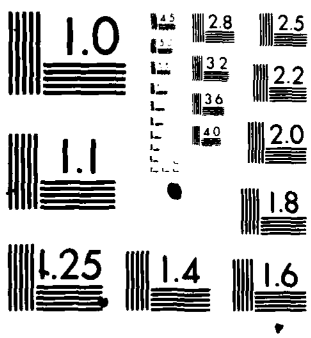
FIGURE C-17. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-3.

AD-A116 120 LOCKHEED-GEORGIA CO MARIETTA F/G 11/4
DAMAGE PROGRESSION IN GRAPHITE-EPOXY BY A DEPLYING TECHNIQUE.(U)
DEC 81 S M FREEMAN F33615-80-C-3224

UNCLASSIFIED LG-81ER0245 AFWAL-TR-81-3157 NL

3 of 6
AD A116120

116120



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

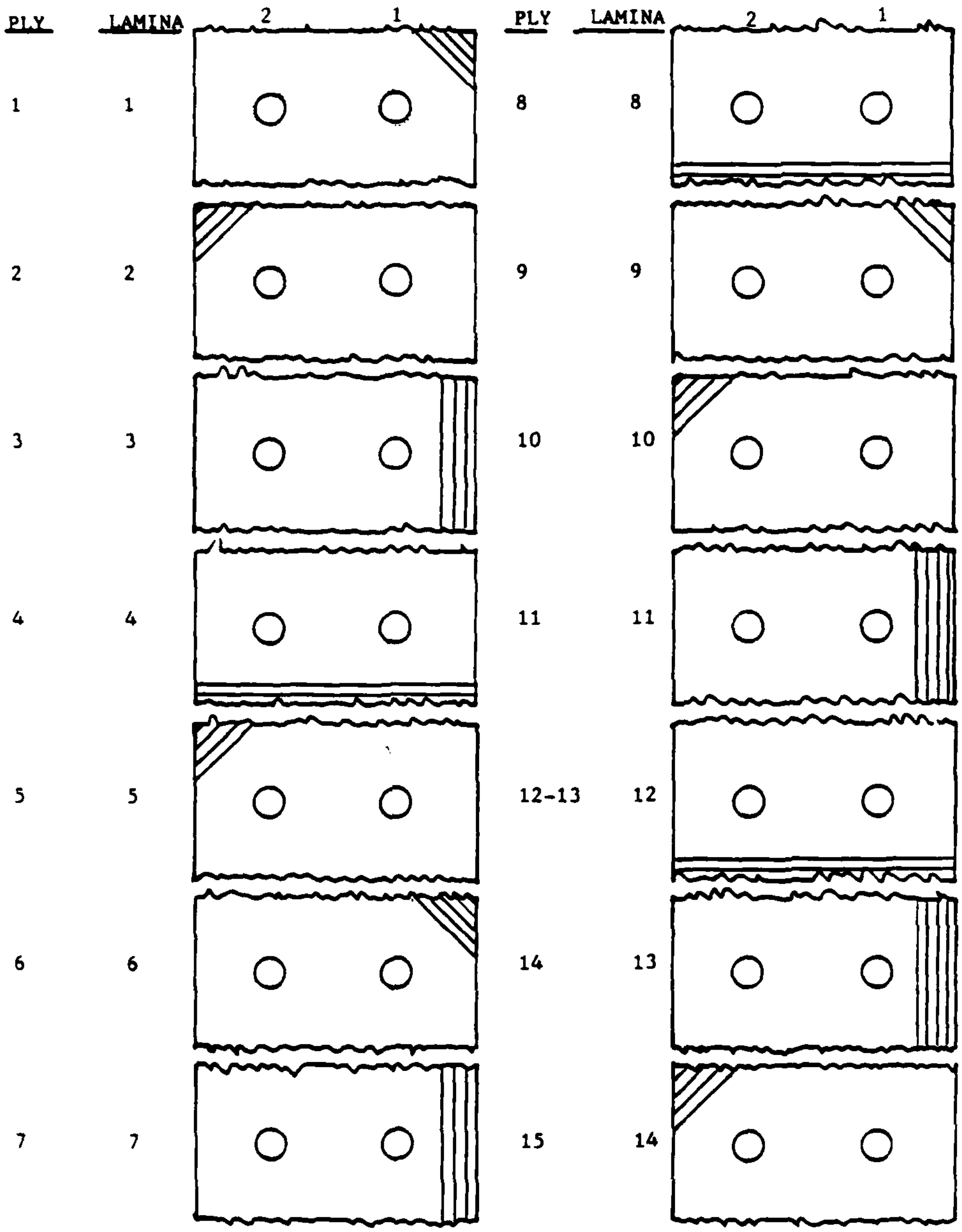


Figure C-18. Lamina Damage Characterization Chart for Specimen I-C-3 Load Level C (Continued)

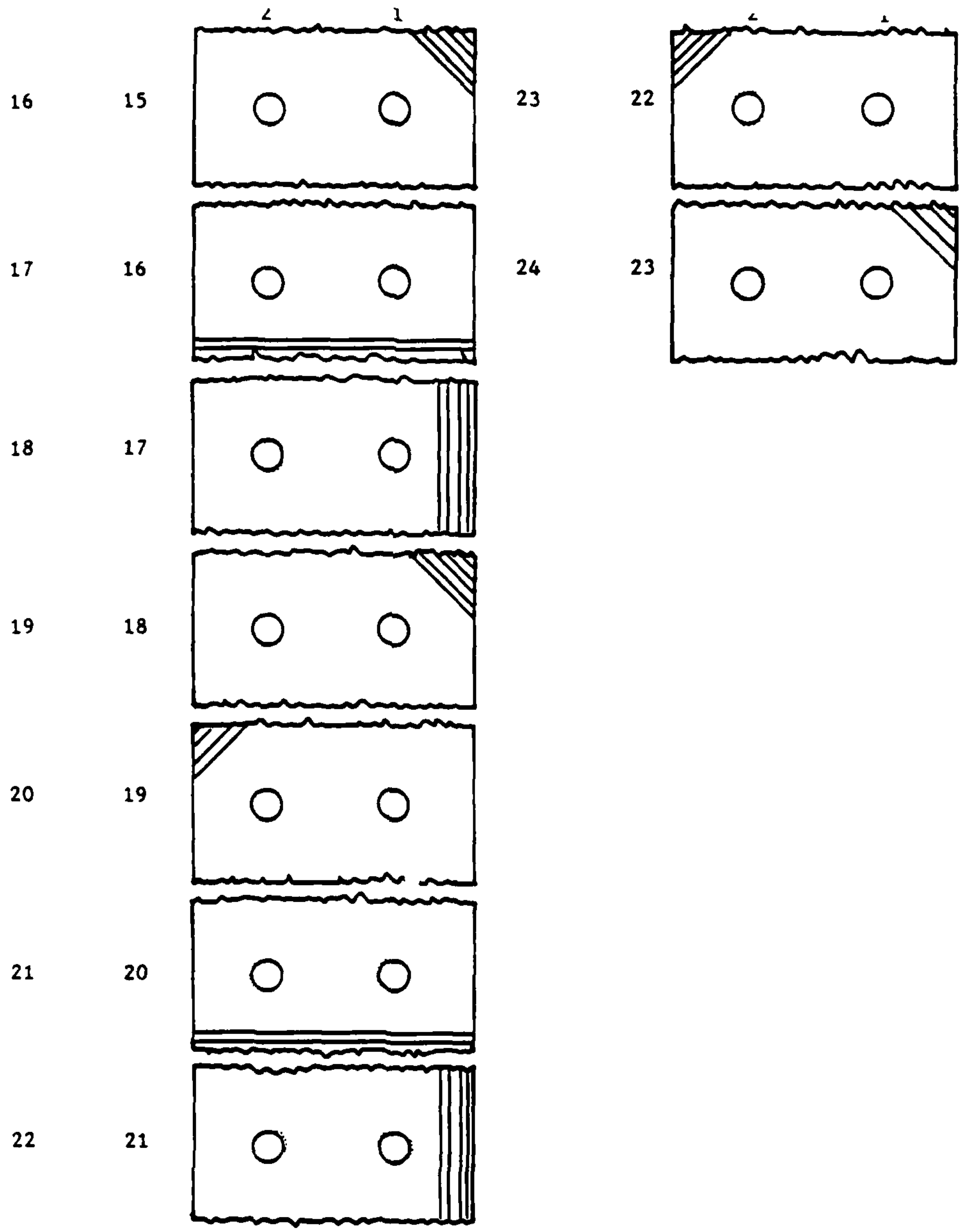


Figure C-18. Lamina Damage Characterization Chart for Specimen
I-C-3 Load Level C

SPECIMEN TYPE - I(OPEN HOLE)

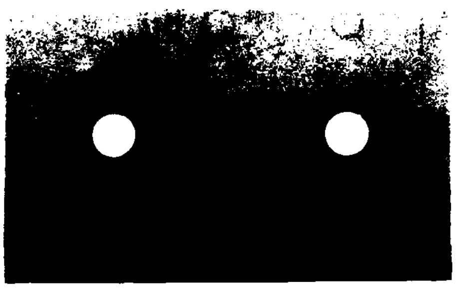
LAMINATE - C($\pm45^\circ$, 0°, 90°, $\mp45^\circ$, 0°, 90°, $\pm45^\circ$, 0°, 90°)s

LOAD LEVEL - C

POUNDS LOAD - 11,640 PERCENT OF ULTIMATE - 73

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-19. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-19.



BEFORE LOADING

AFTER LOADING

FIGURE C-20. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-19.

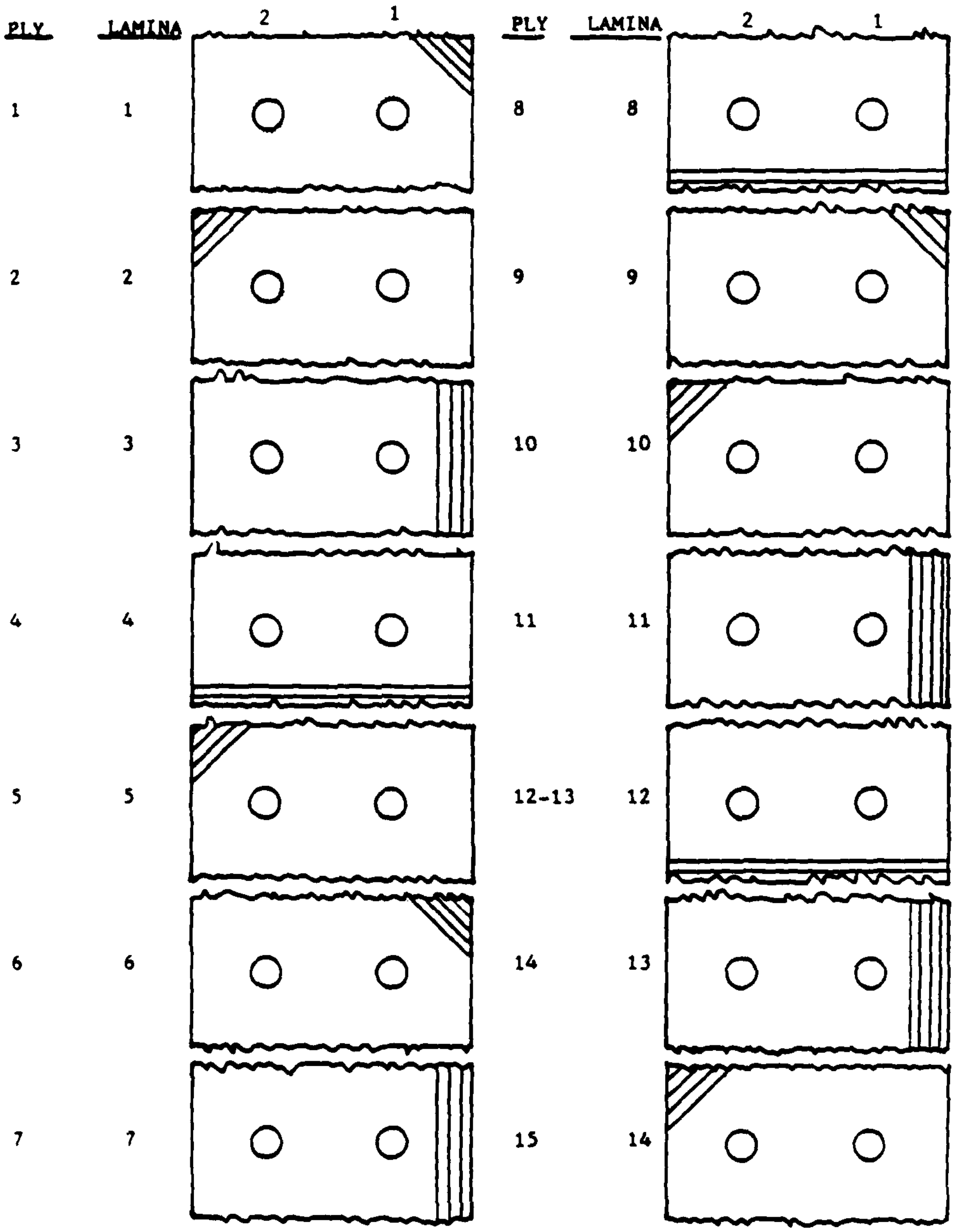


Figure C-21. Lamina Damage Characterization Chart for Specimen I-C-19 Load Level C (Continued)

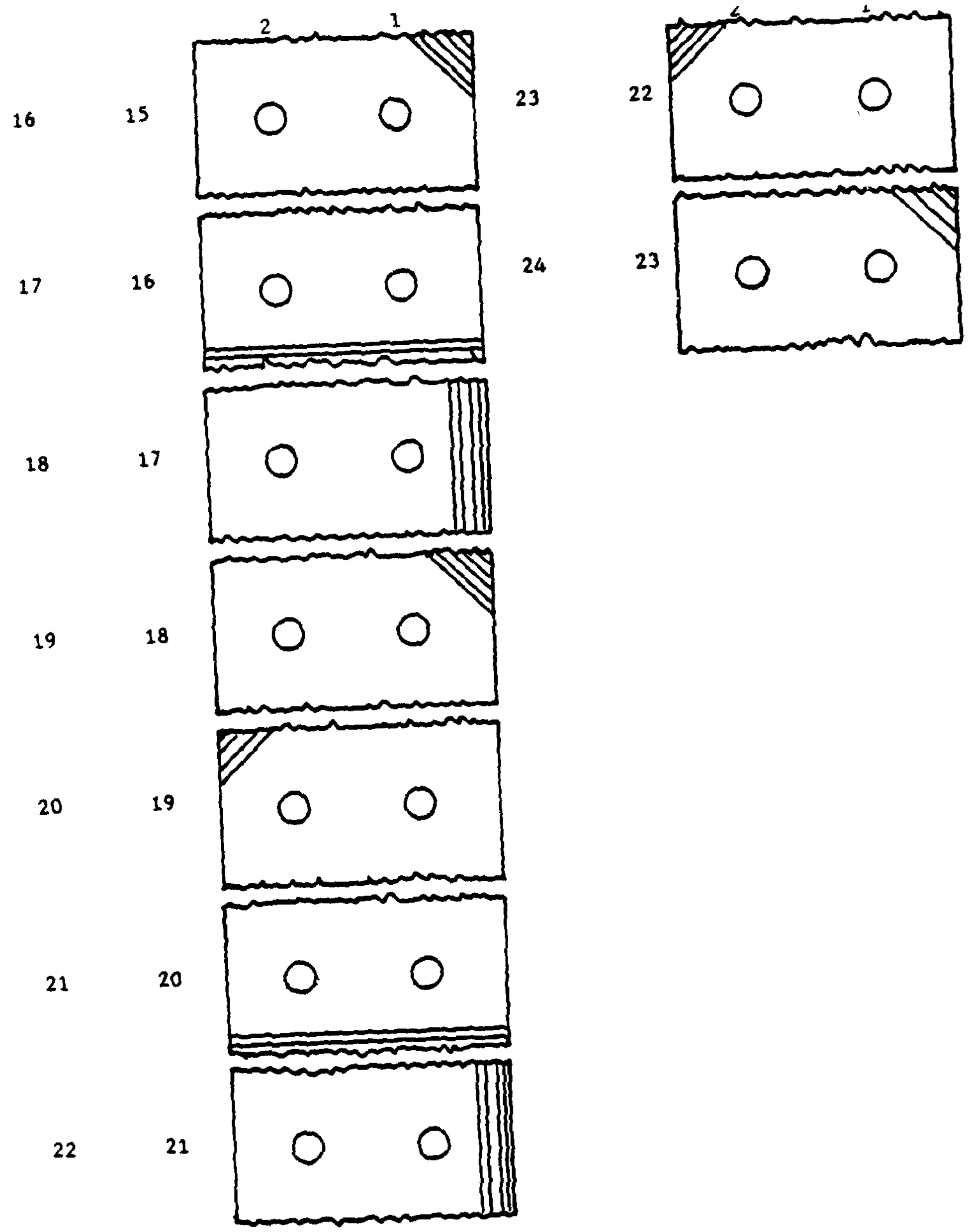


Figure C-21. Lamina Damage Characterization Chart for Specimen I-C- 19 Load Level C

SPECIMEN TYPE - I(OPEN HOLE)

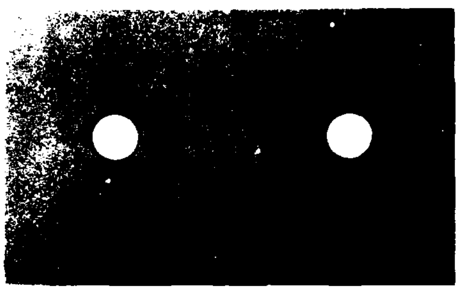
LAMINATE - C($\pm45^\circ$, 0°, 90°, $\mp45^\circ$, 0°, 90°, $\pm45^\circ$, 0°, 90°)s

LOAD LEVEL - C

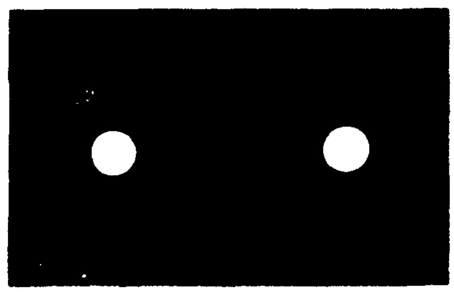
POUNDS LOAD - 11,640 PERCENT OF ULTIMATE - 73

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-22. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-22.



BEFORE LOADING



AFTER LOADING

FIGURE C-23. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-22.

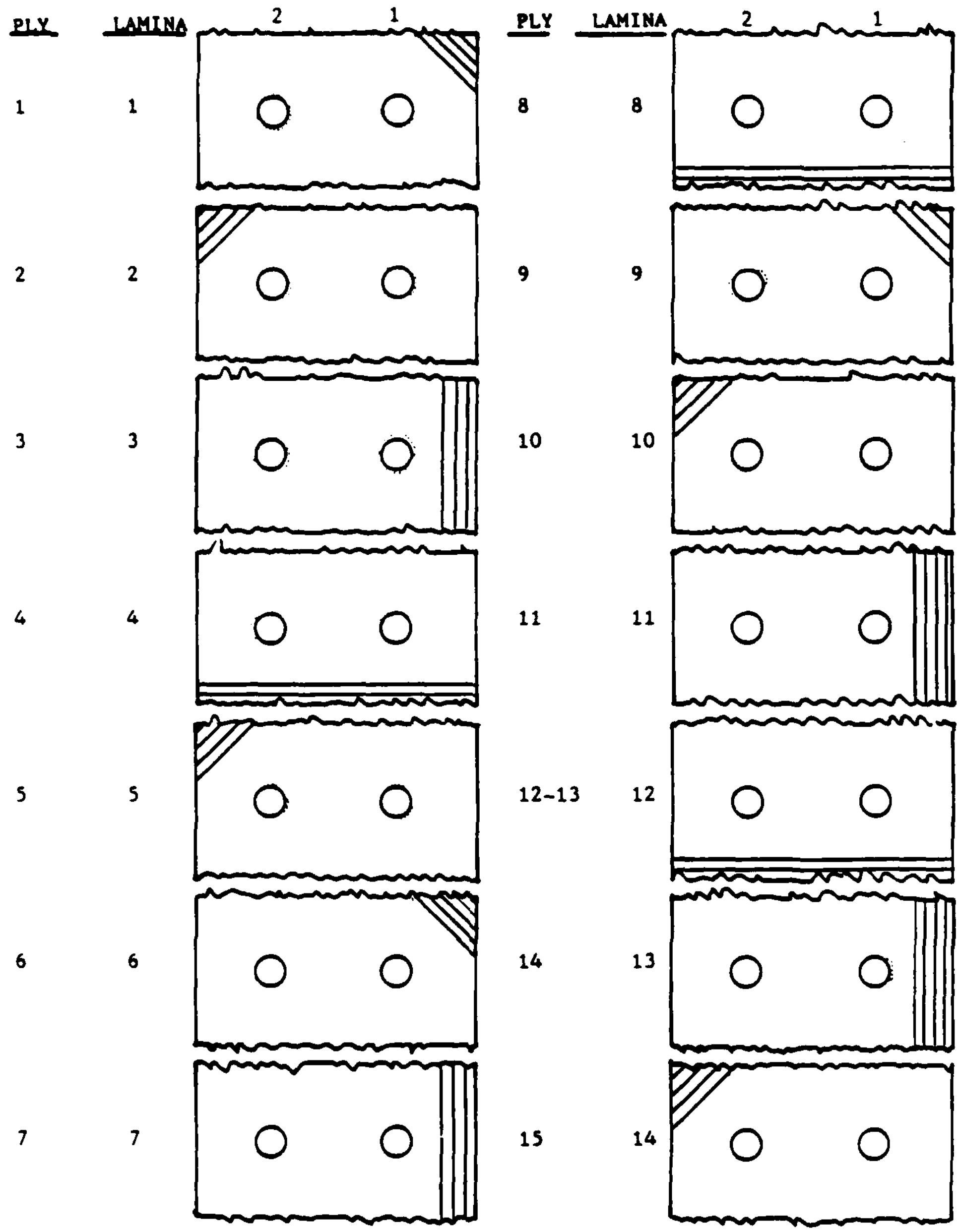


Figure C-24. Lamina Damage Characterization Chart for Specimen I-C-22 Load Level C (Continued)

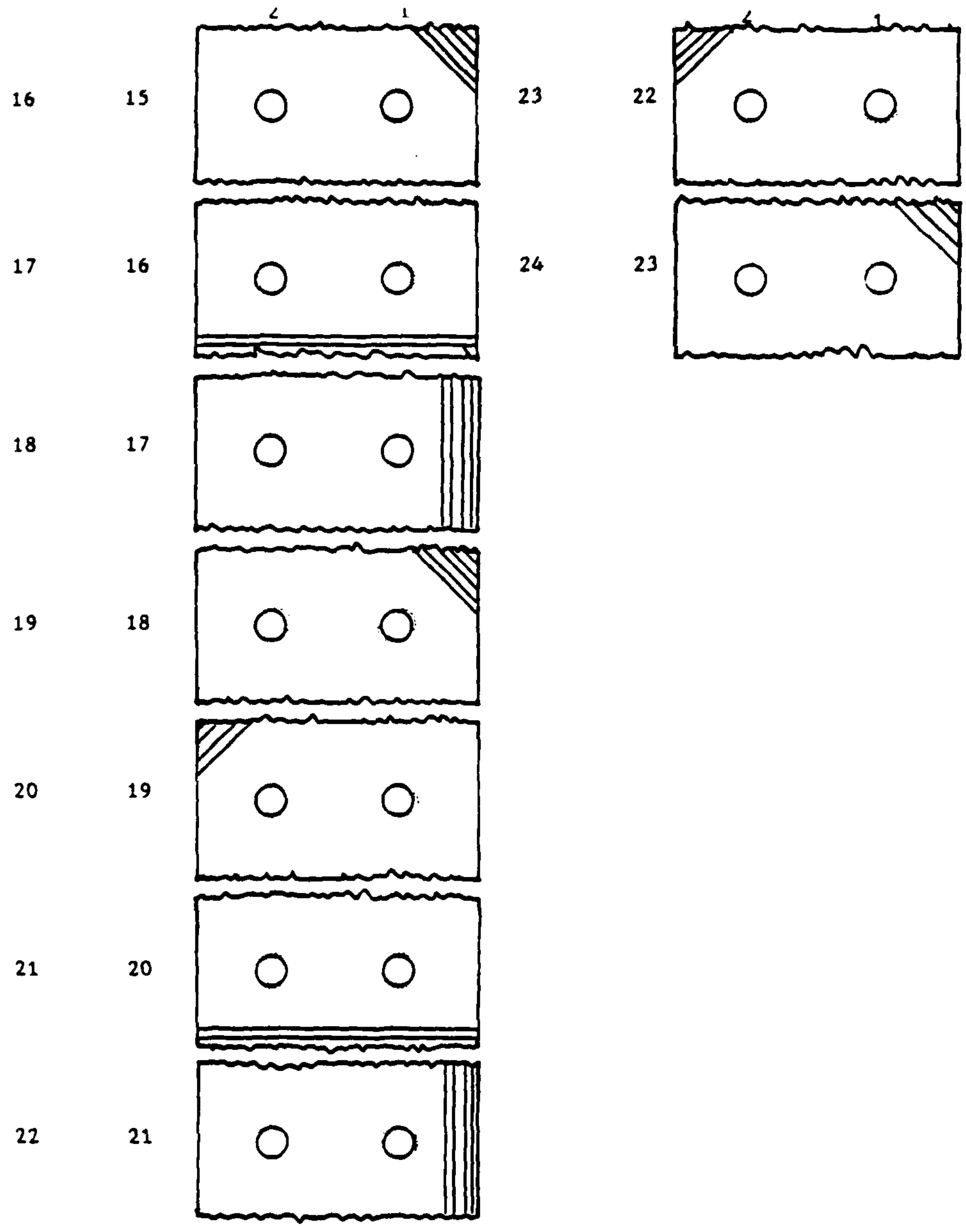


Figure C-24. Lamina Damage Characterization Chart for Specimen I-C- 22 Load Level C

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - C($\pm$45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)s

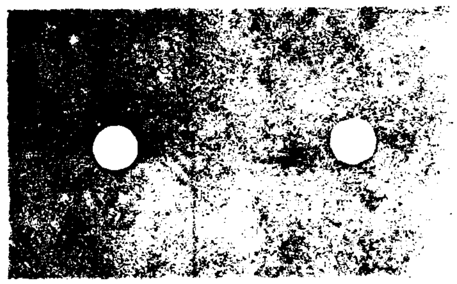
LOAD LEVEL - C

POUNDS LOAD - 11,640   PERCENT OF ULTIMATE - 73

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-25. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-9.

BEFORE LOADING



AFTER LOADING

FIGURE C-26. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-9.

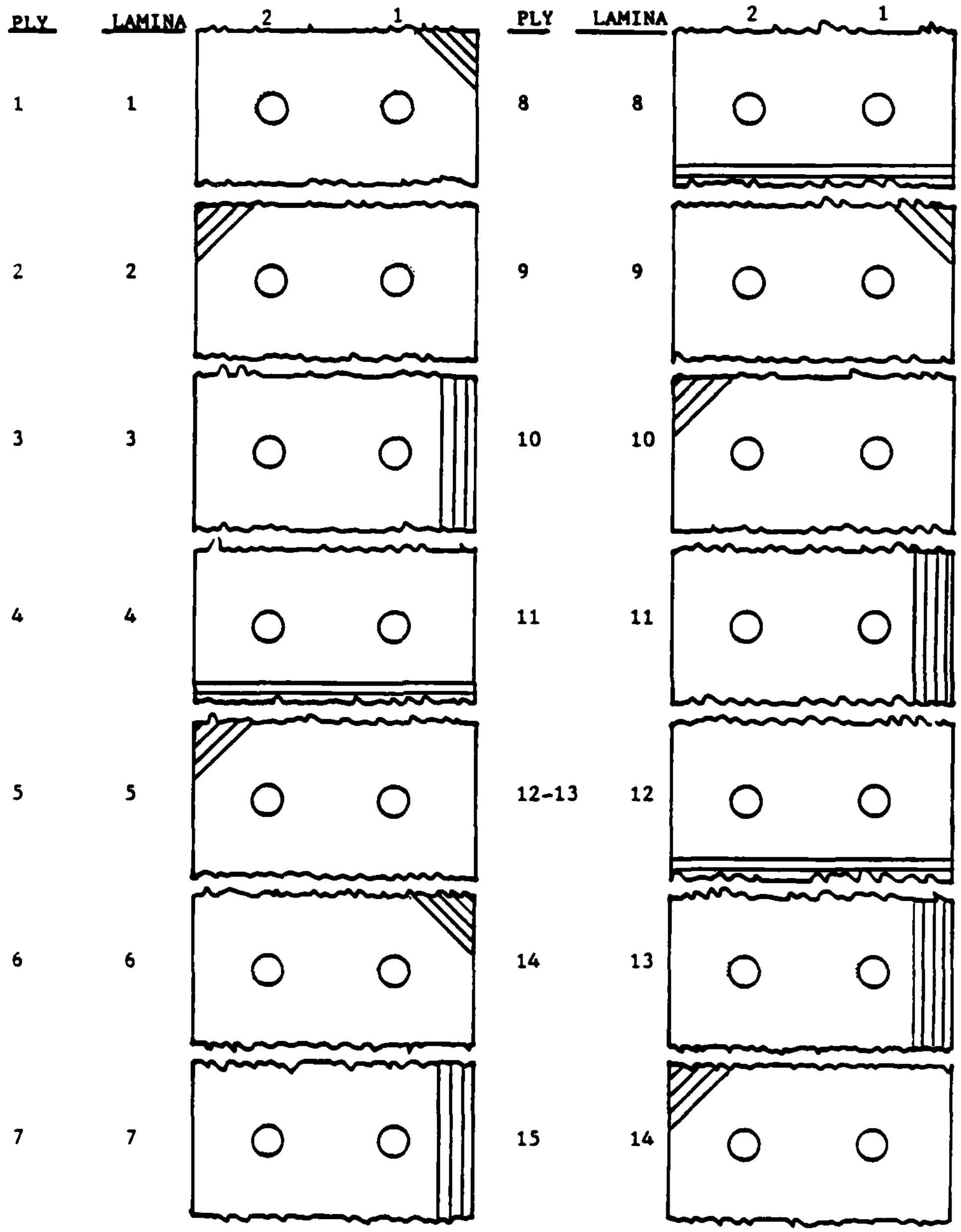


Figure C-27. Lamina Damage Characterization Chart for Specimen I-C-9 Load Level C (Continued)

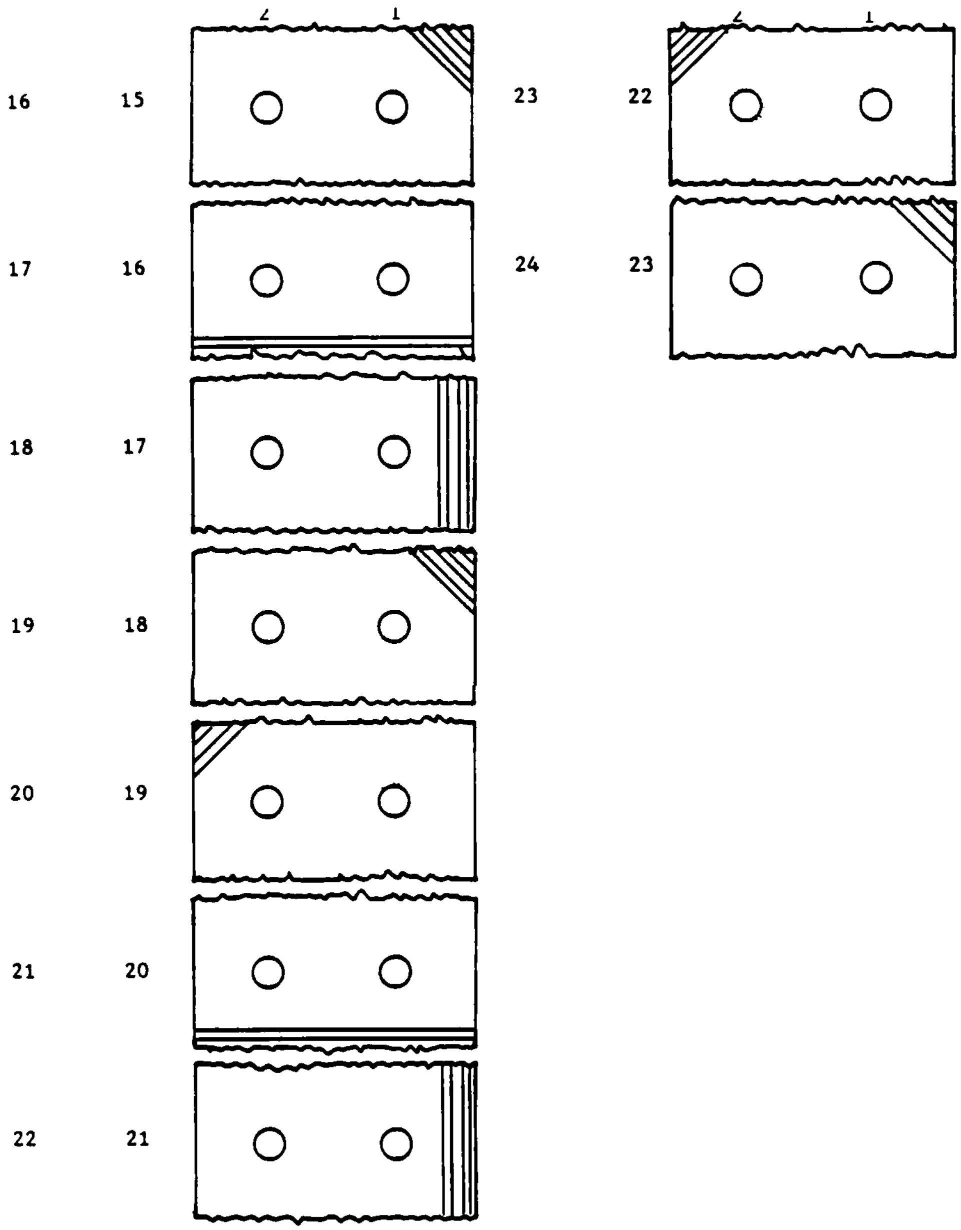


Figure C-27. Lamina Damage Characterization Chart for Specimen
I-C- 9 Load Level C

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - C($\pm45^{\circ}$, 0°, 90°, $\mp45^{\circ}$, 0°, 90°, $\pm45^{\circ}$, 0°, 90°)s

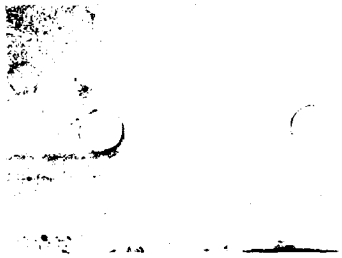
LOAD LEVEL - C

POUNDS LOAD - 11,640 PERCENT OF ULTIMATE - 73

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES
BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-28. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-11.

BEFORE LOADING



AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE C-29. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-11.

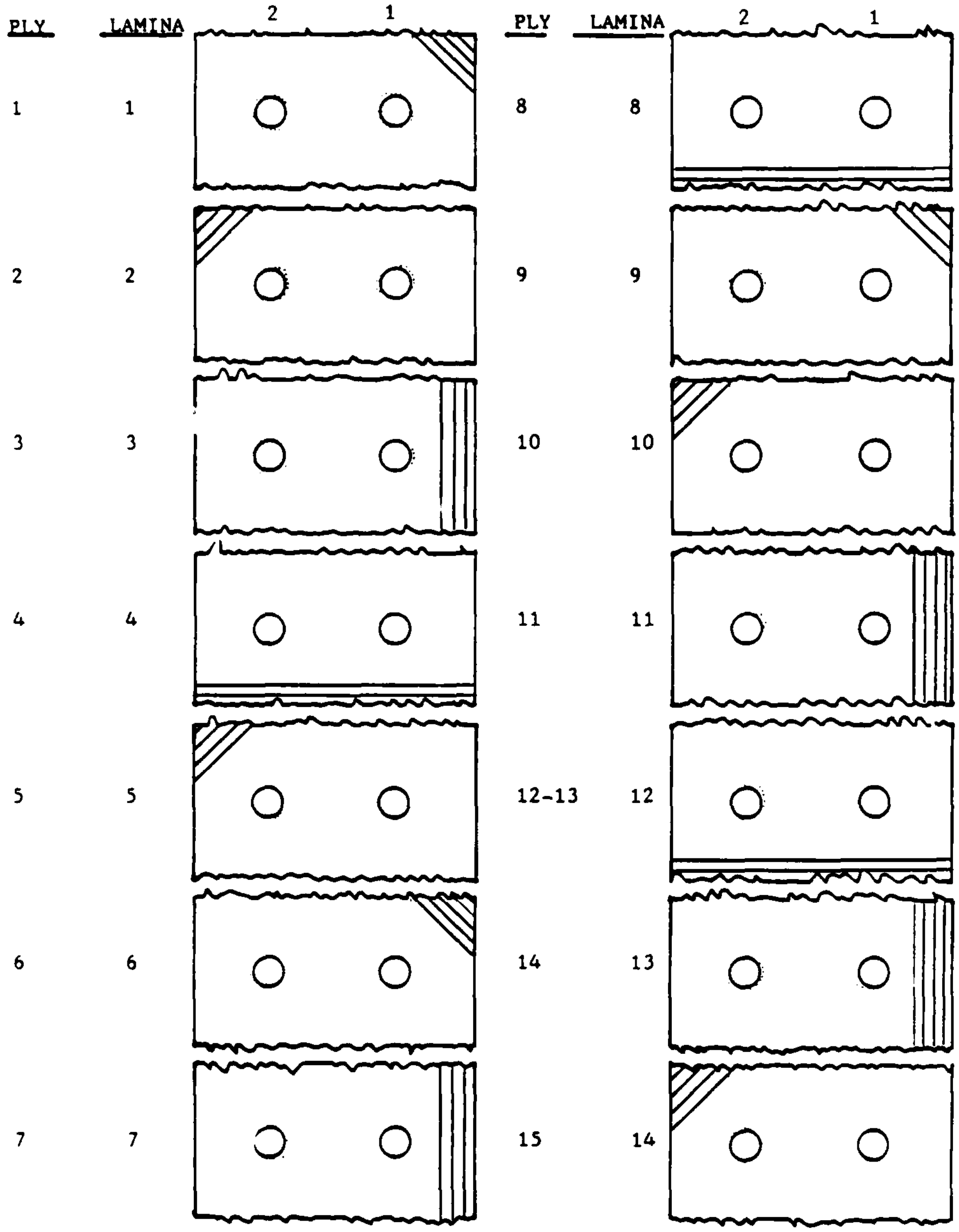


Figure C-30. Lamina Damage Characterization Chart for Specimen I-C-11 Load Level C (Continued)

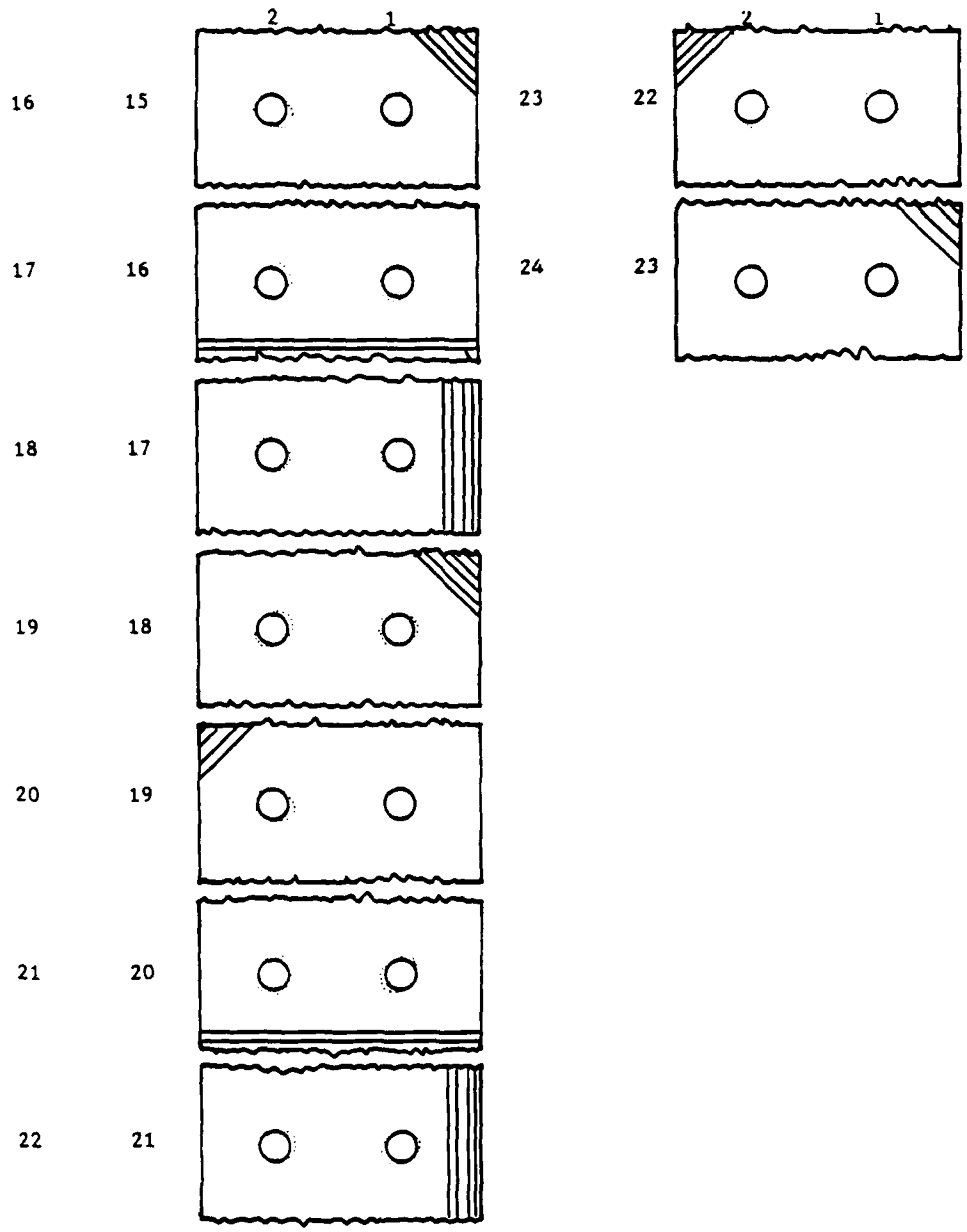


Figure C-30. Lamina Damage Characterization Chart for Specimen
I-C- 11 Load Level C

SPECIMEN TYPE - I(OPEN HOLE)

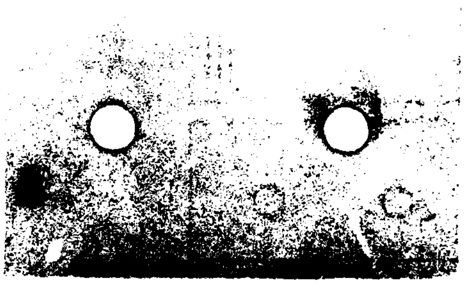
LAMINATE - $C(\pm45^{\circ}, 0^{\circ}, 90^{\circ}, \mp45^{\circ}, 0^{\circ}, 90^{\circ}, \pm45^{\circ}, 0^{\circ}, 90^{\circ})_s$

LOAD LEVEL - D

POUNDS LOAD - 13,742   PERCENT OF ULTIMATE - 87

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 2

FIGURE C-31. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-2.



BEFORE LOADING

AFTER LOADING

FIGURE C-32. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-2.

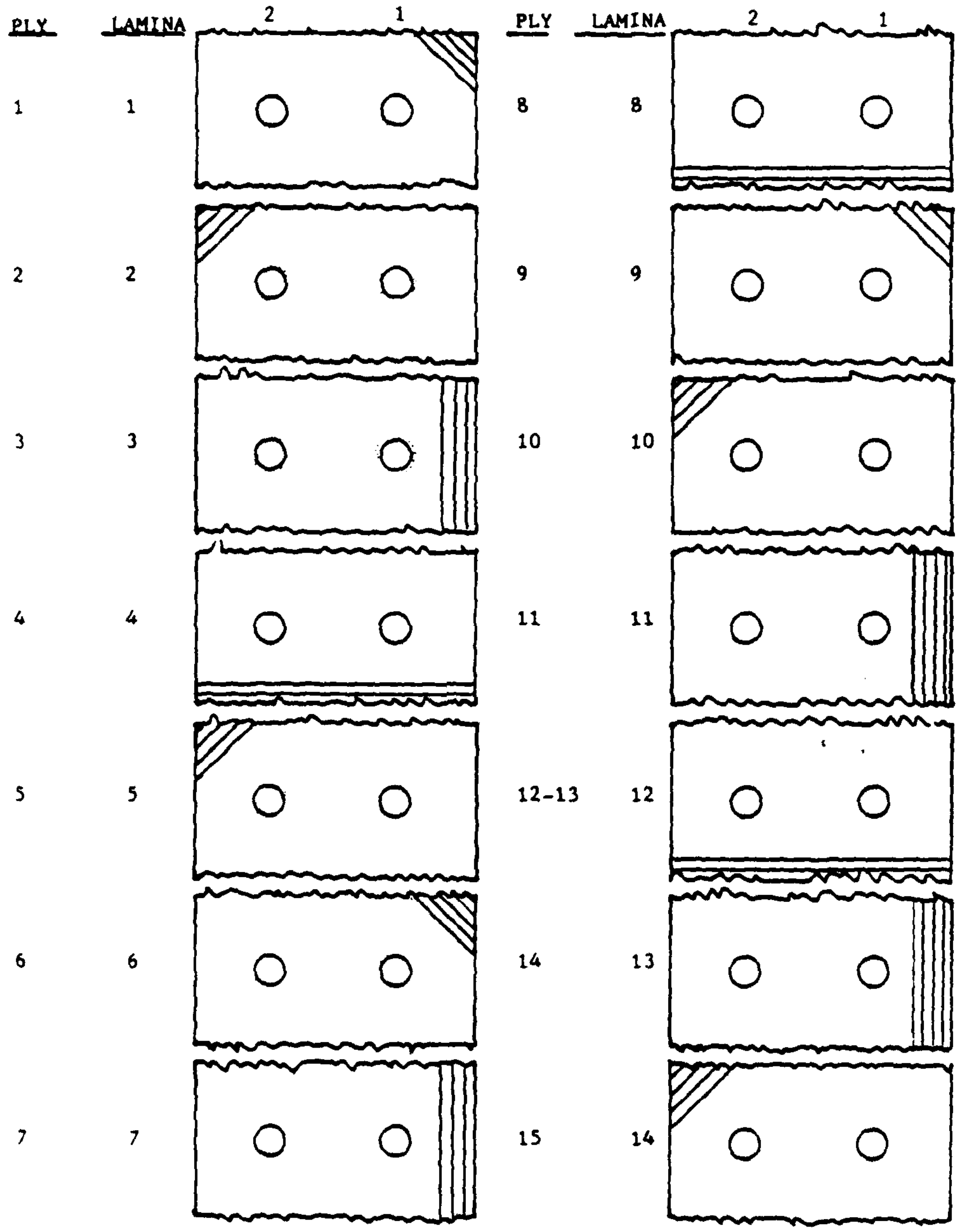


Figure C-33. Lamina Damage Characterization Chart for Specimen I-C-2 Load Level D (Continued)

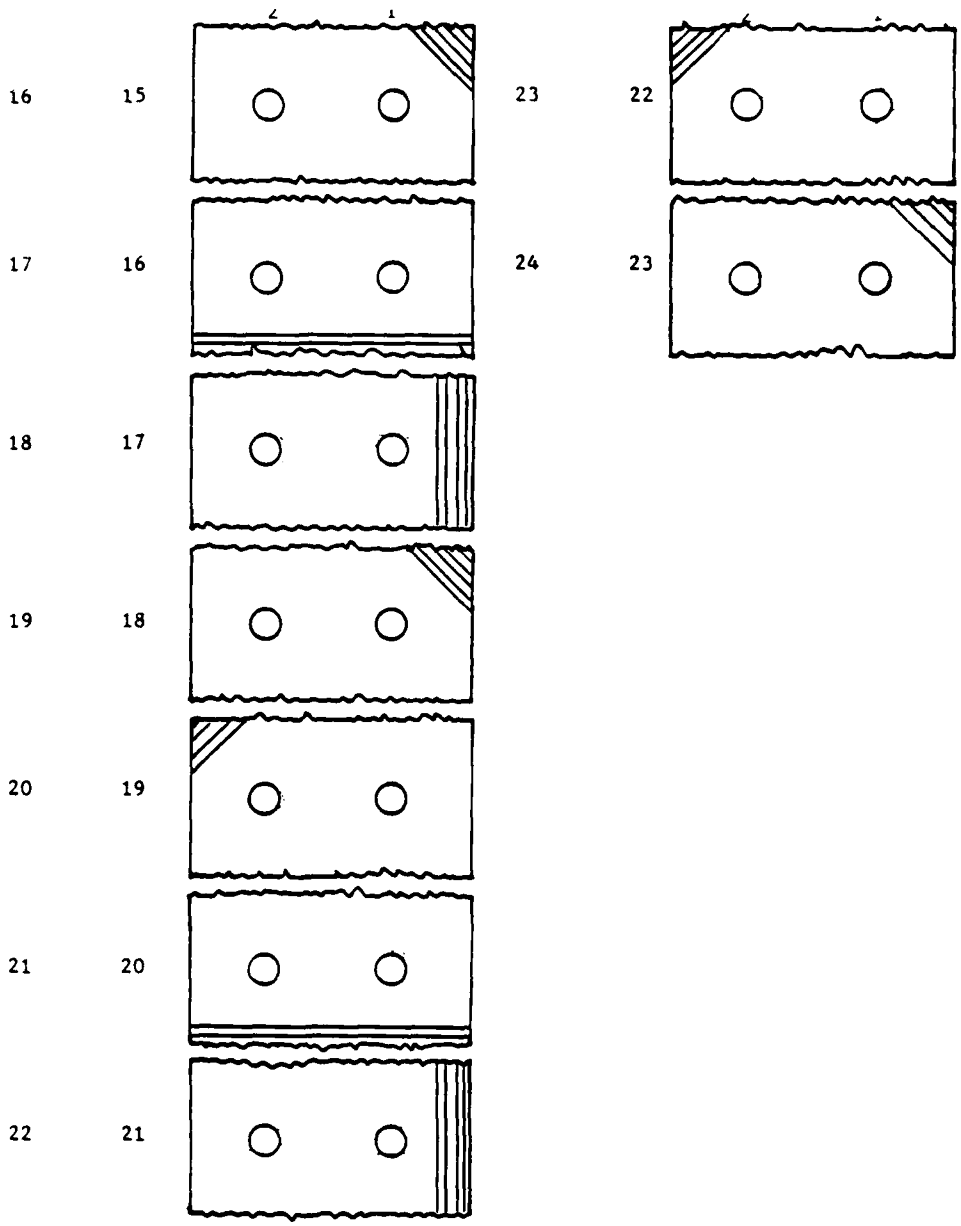


Figure C-31 Lamina Damage Characterization Chart for Specimen
I-C-2 Load Level D

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - C($\pm 45^{\circ}$, 0°, 90°, $\mp 45^{\circ}$, 0°, 90°, $\pm 45^{\circ}$, 0°, 90°)s

LOAD LEVEL - D

POUNDS LOAD - 13,742 PERCENT OF ULTIMATE - 87

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-34. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-4.

BEFORE LOADING

AFTER LOADING

FIGURE C-35. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-4.

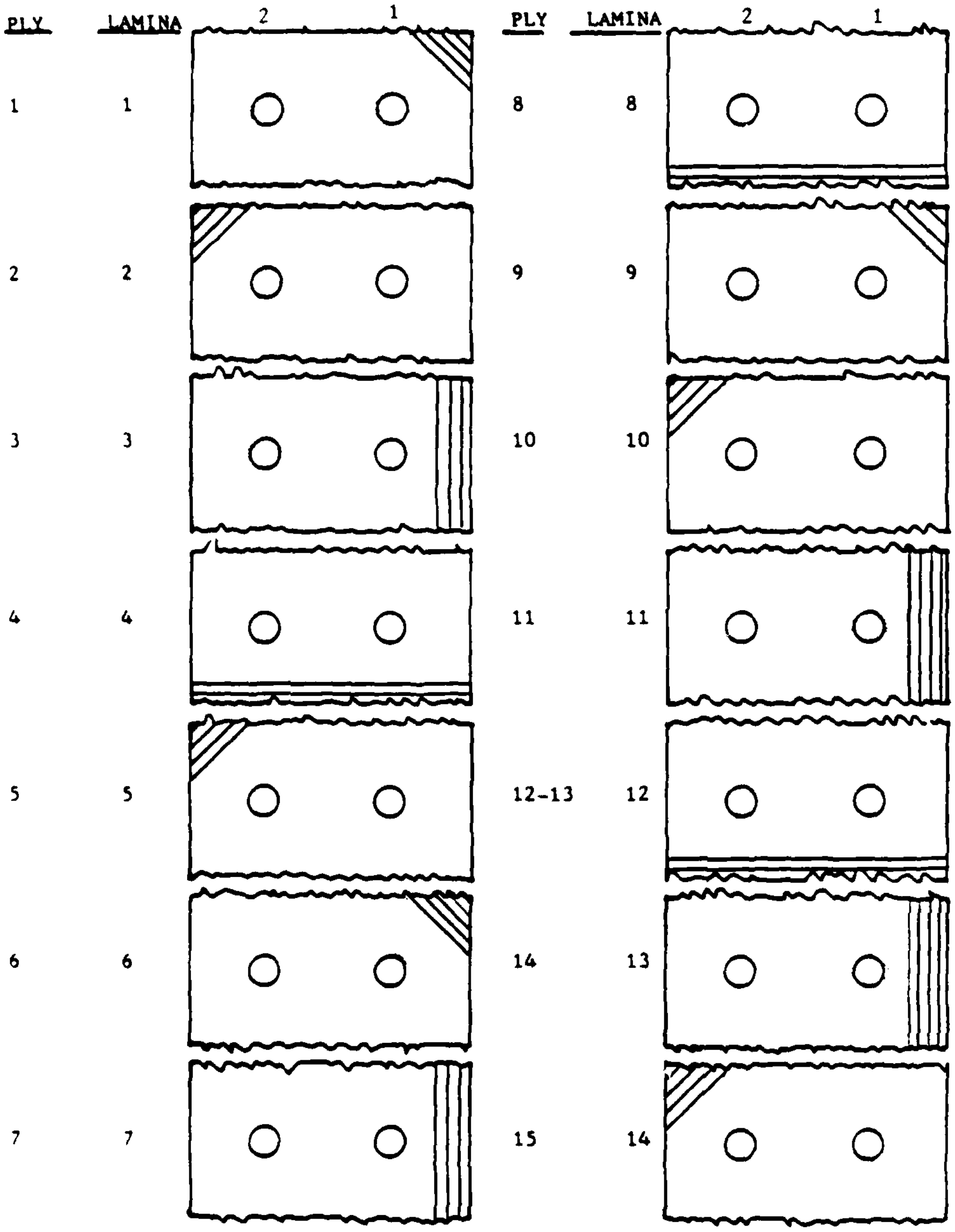


Figure C-36. Lamina Damage Characterization Chart for Specimen I-C-4 Load Level D (Continued)

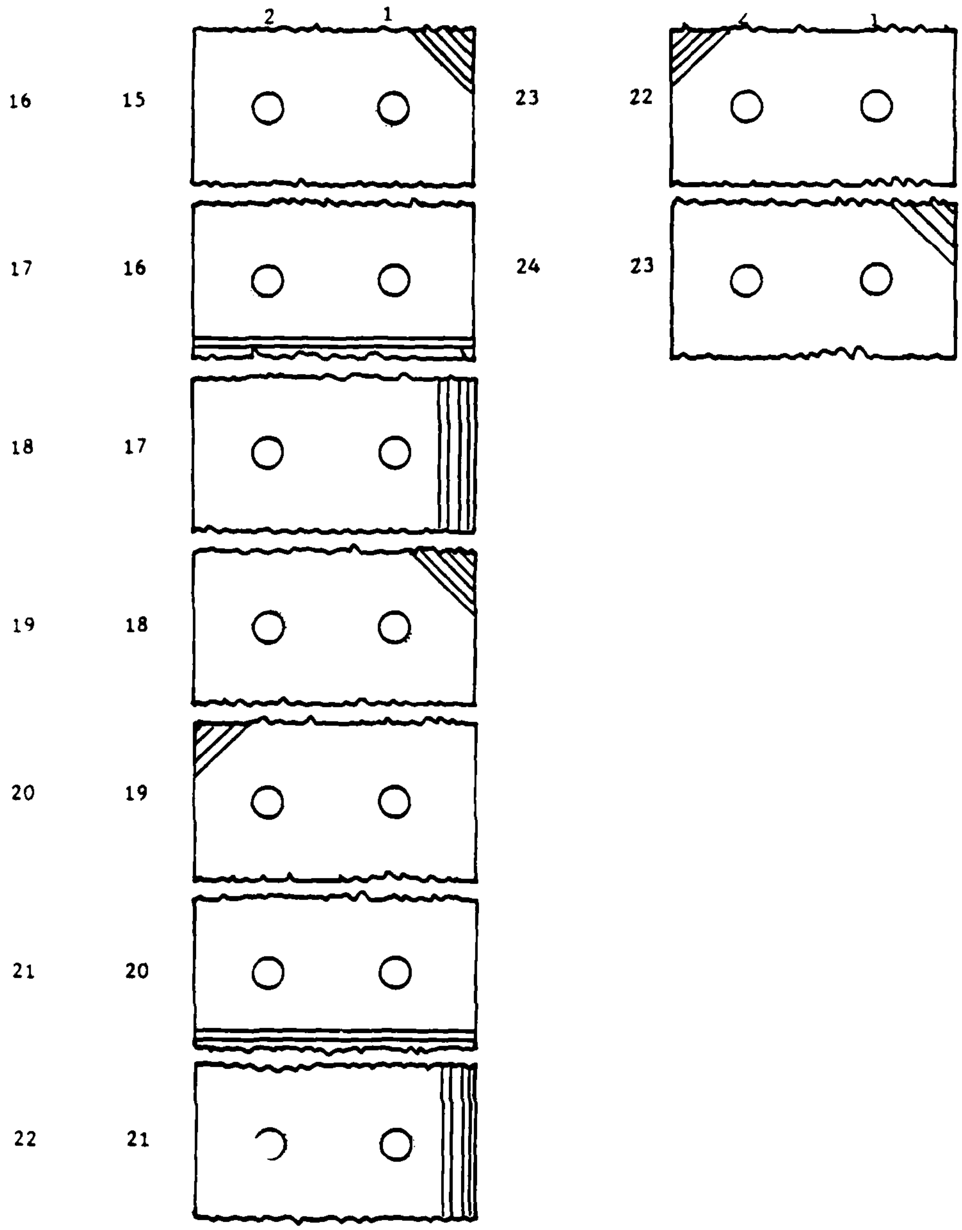


Figure C-36. Lamina Damage Characterization Chart for Specimen
I-C-4 Load Level D

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - $C(\pm 45^\circ, 0^\circ, 90^\circ, \mp 45^\circ, 0^\circ, 90^\circ, \pm 45^\circ, 0^\circ, 90^\circ)_s$

LOAD LEVEL - D

POUNDS LOAD - 13,742 PERCENT OF ULTIMATE - 87

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-37. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-20.

BEFORE LOADING AFTER LOADING

FIGURE C-38. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-20.

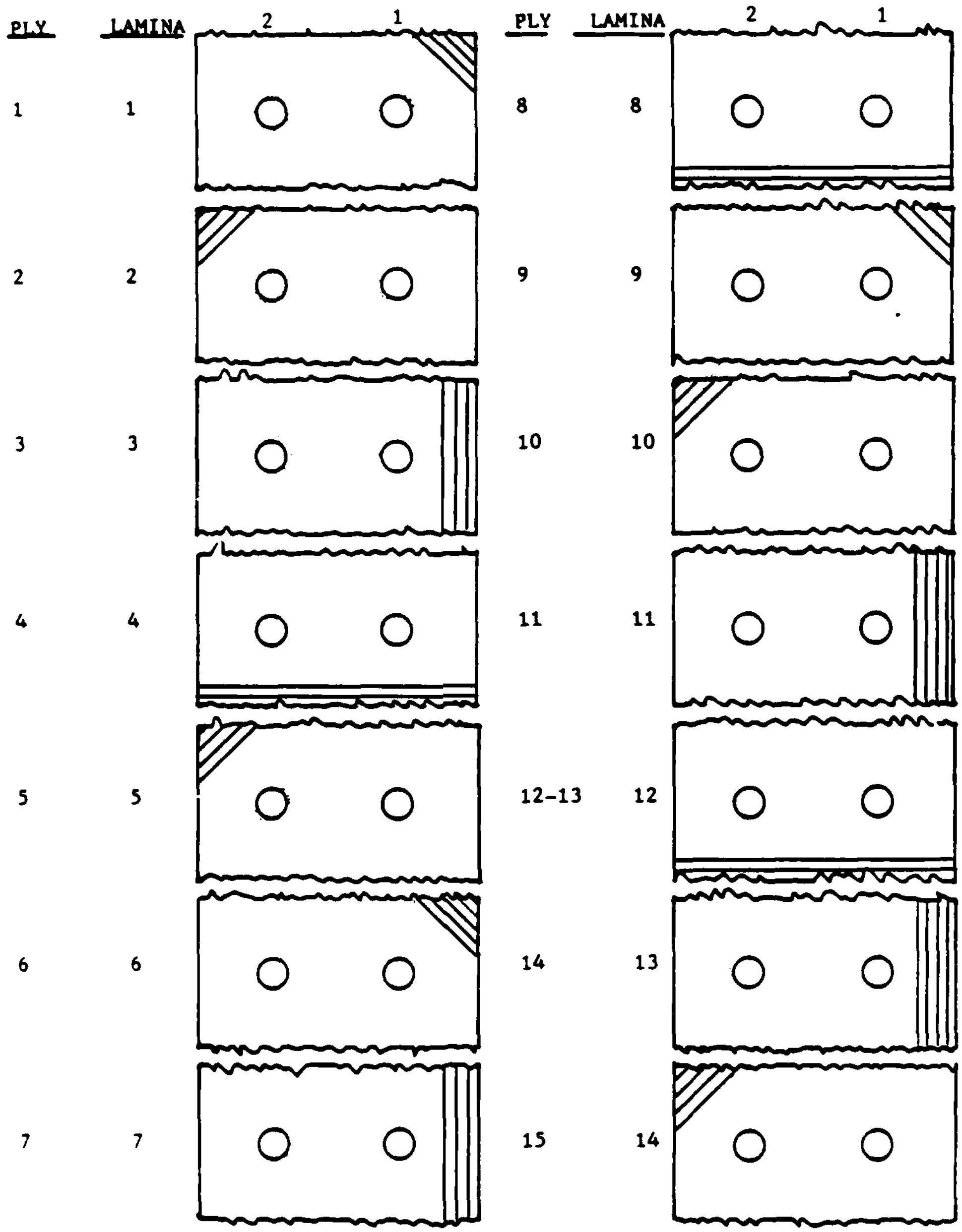


Figure C-39. Lamina Damage Characterization Chart for Specimen I-C-20 Load Level D (Continued)

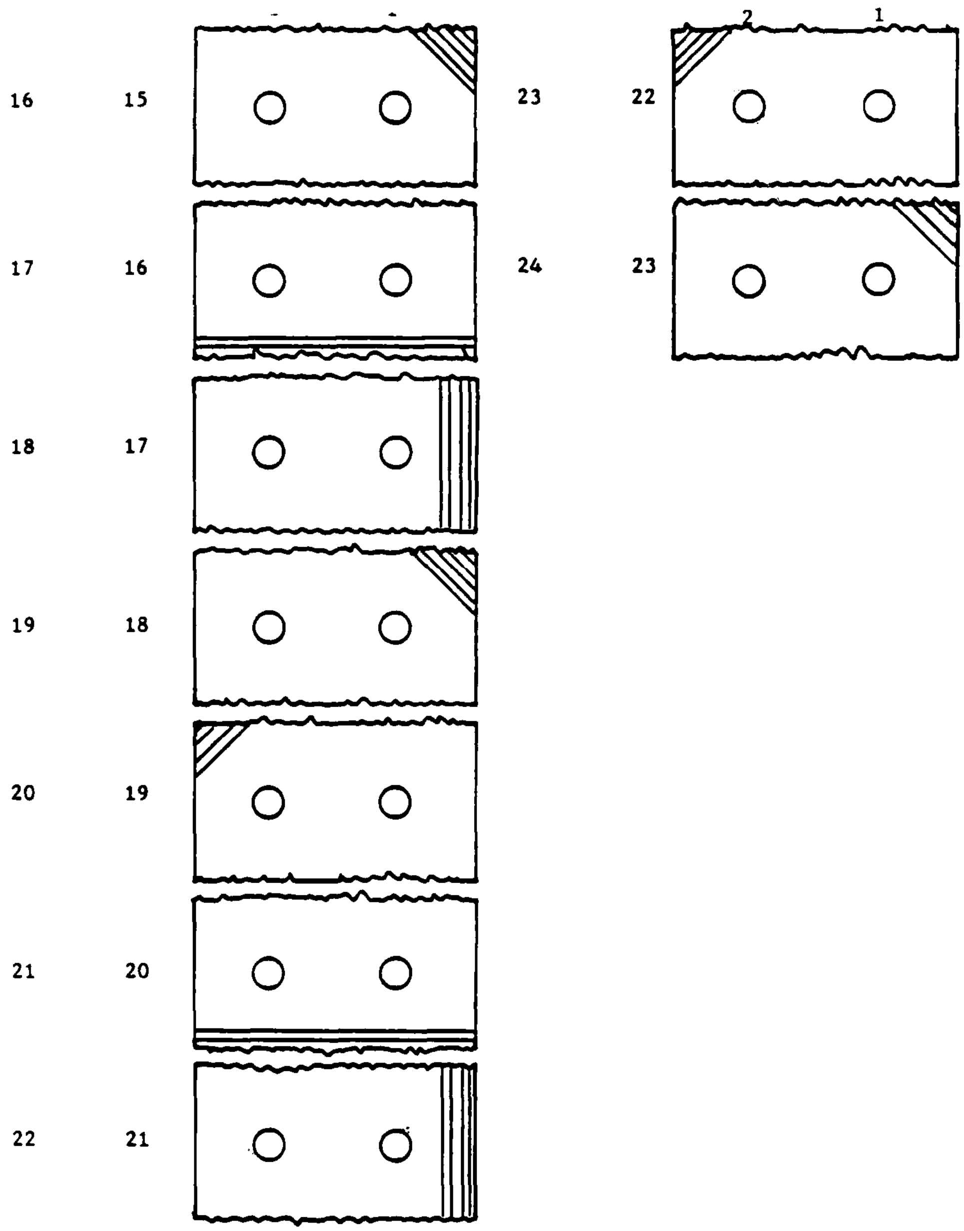


Figure C-39. Lamina Damage Characterization Chart for Specimen I-C-20 Load Level D

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - C($\pm 45^\circ$, 0°, 90°, $\mp 45^\circ$, 0°, 90°, $\pm 45^\circ$, 0°, 90°)s

LOAD LEVEL - D

POUNDS LOAD - 13,742   PERCENT OF ULTIMATE - 87

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-40. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-7.

BEFORE LOADING

AFTER LOADING

FIGURE C-41. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-7.

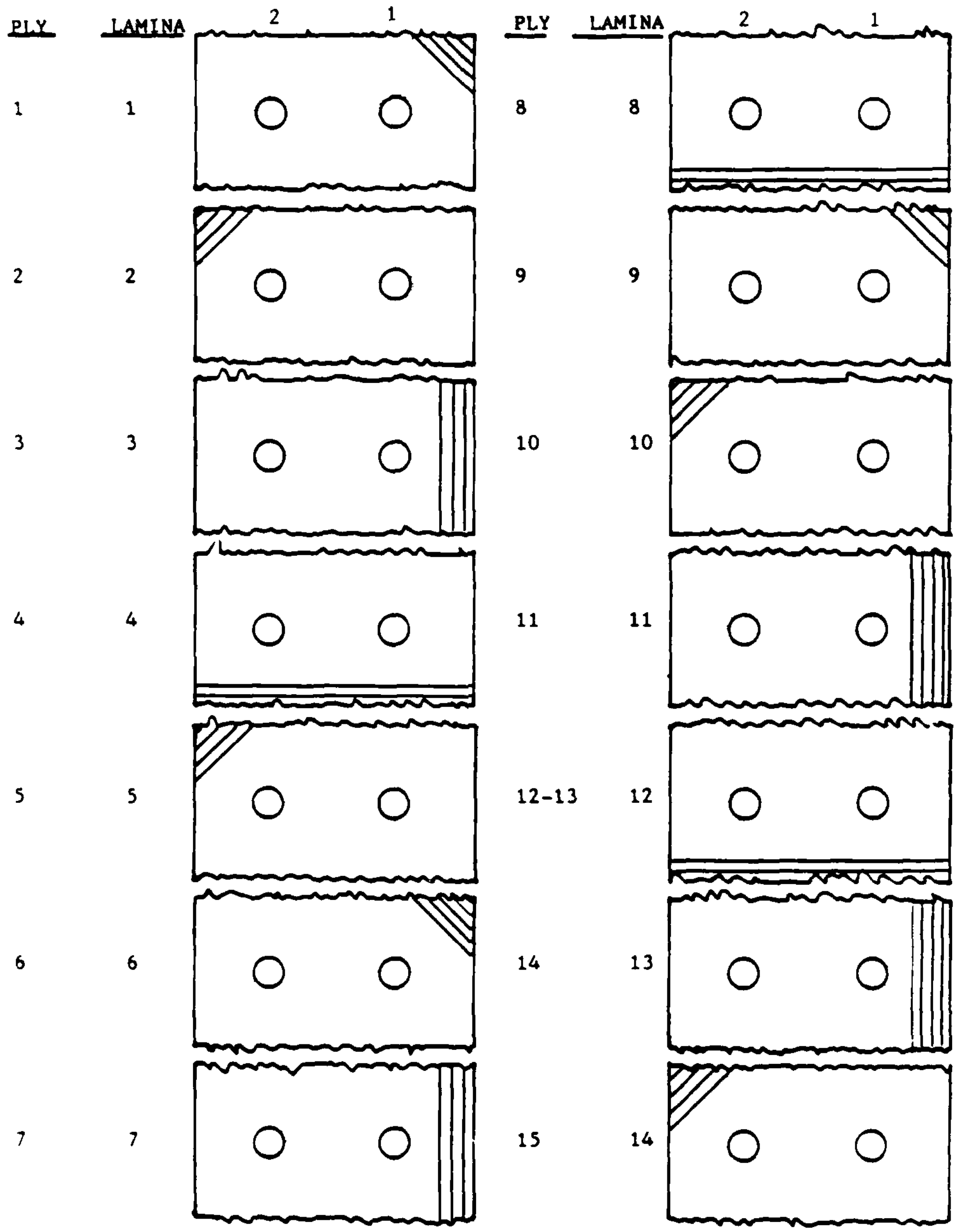


Figure C-42. Lamina Damage Characterization Chart for Specimen I-C-7 Load Level D (Continued)

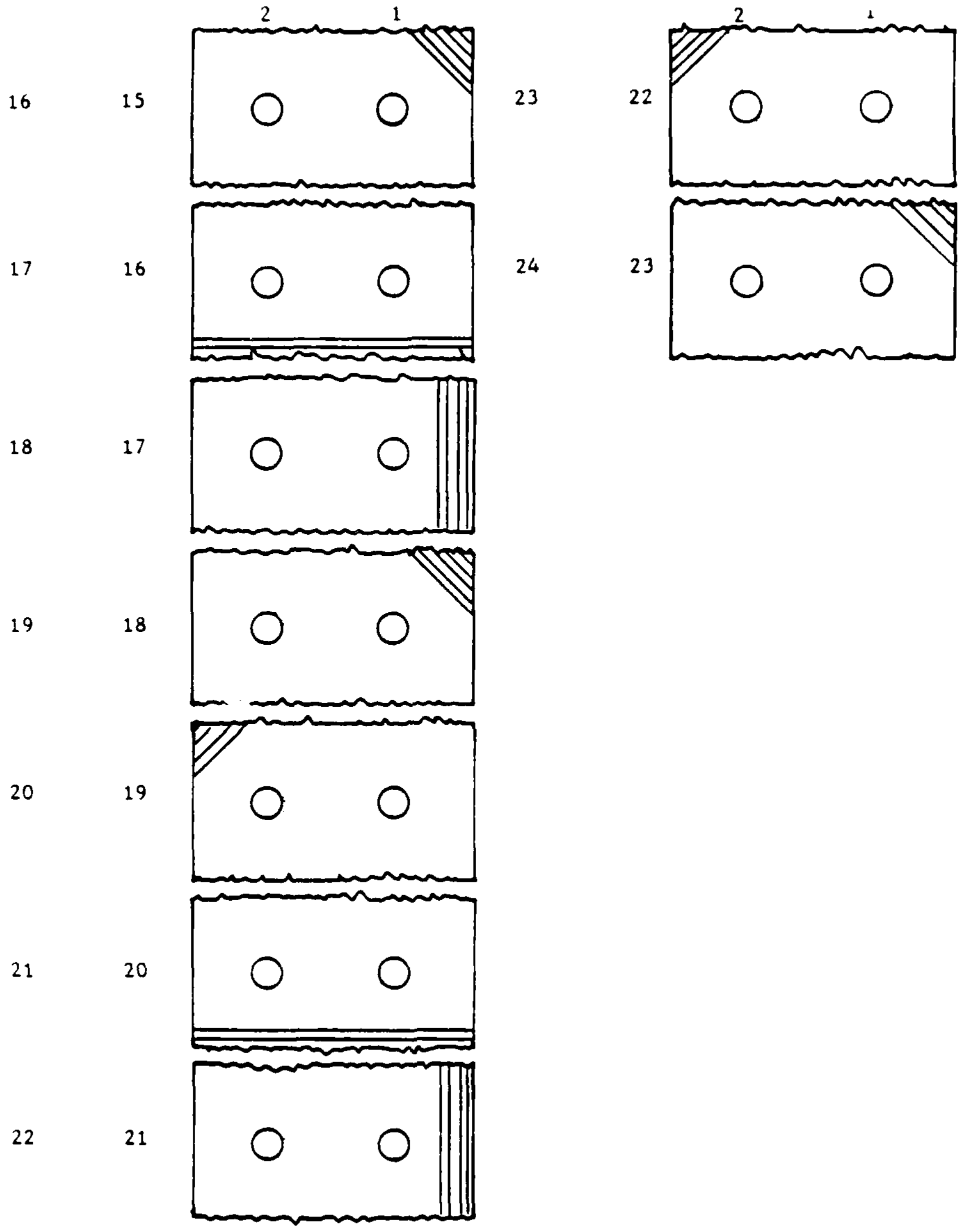


Figure C-42. Lamina Damage Characterization Chart for Specimen I-C-7 Load Level D

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - C($\pm45^\circ$, 0°, 90°, $\mp45^\circ$, 0°, 90°, $\pm45^\circ$, 0°, 90°)s

LOAD LEVEL - D

POUNDS LOAD - 13,742 PERCENT OF ULTIMATE - 87

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES
BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-43. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-17.

BEFORE LOADING

AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE C-44. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-17.

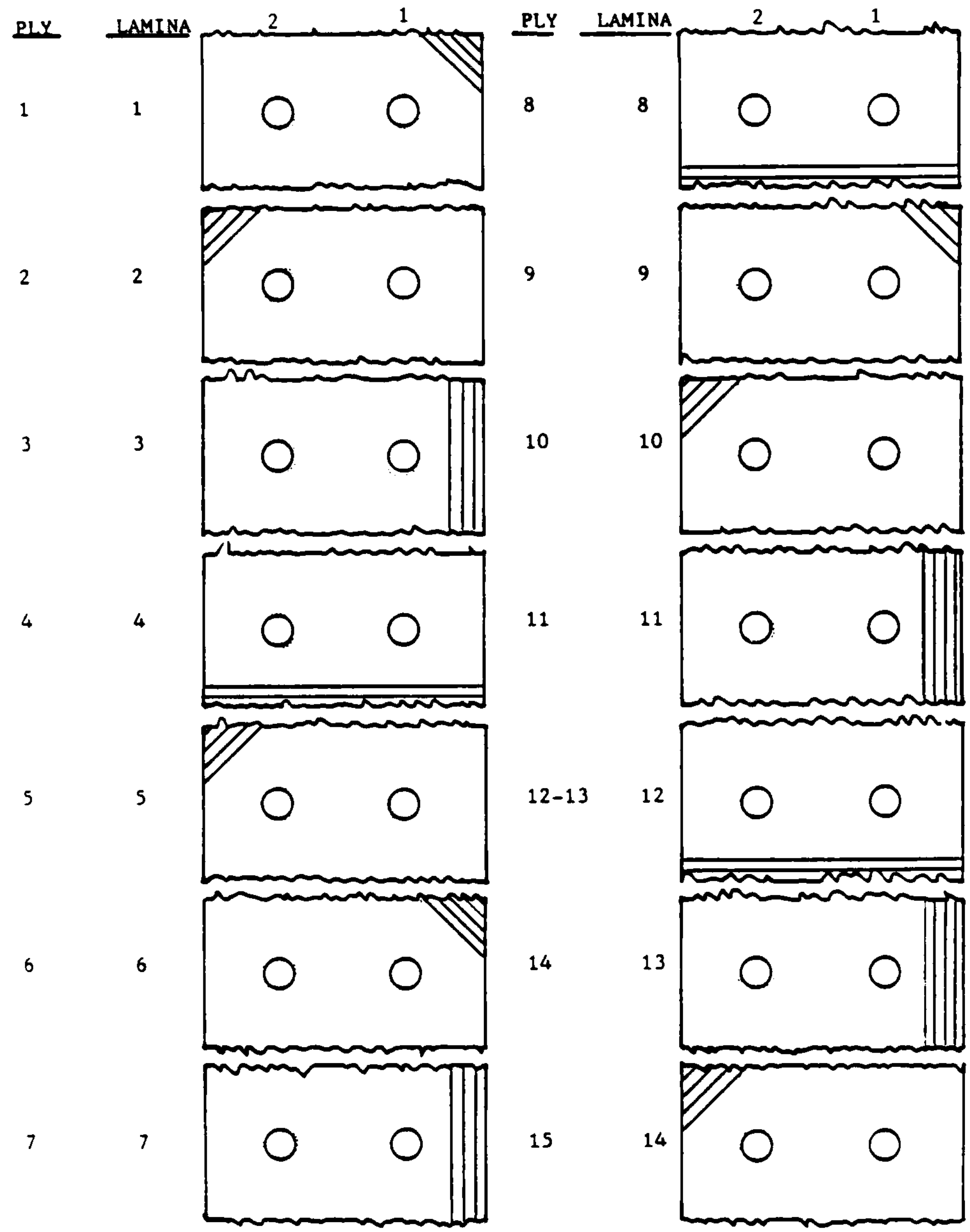


Figure C-45. Lamina Damage Characterization Chart for Specimen I-C-17 Load Level D (Continued)

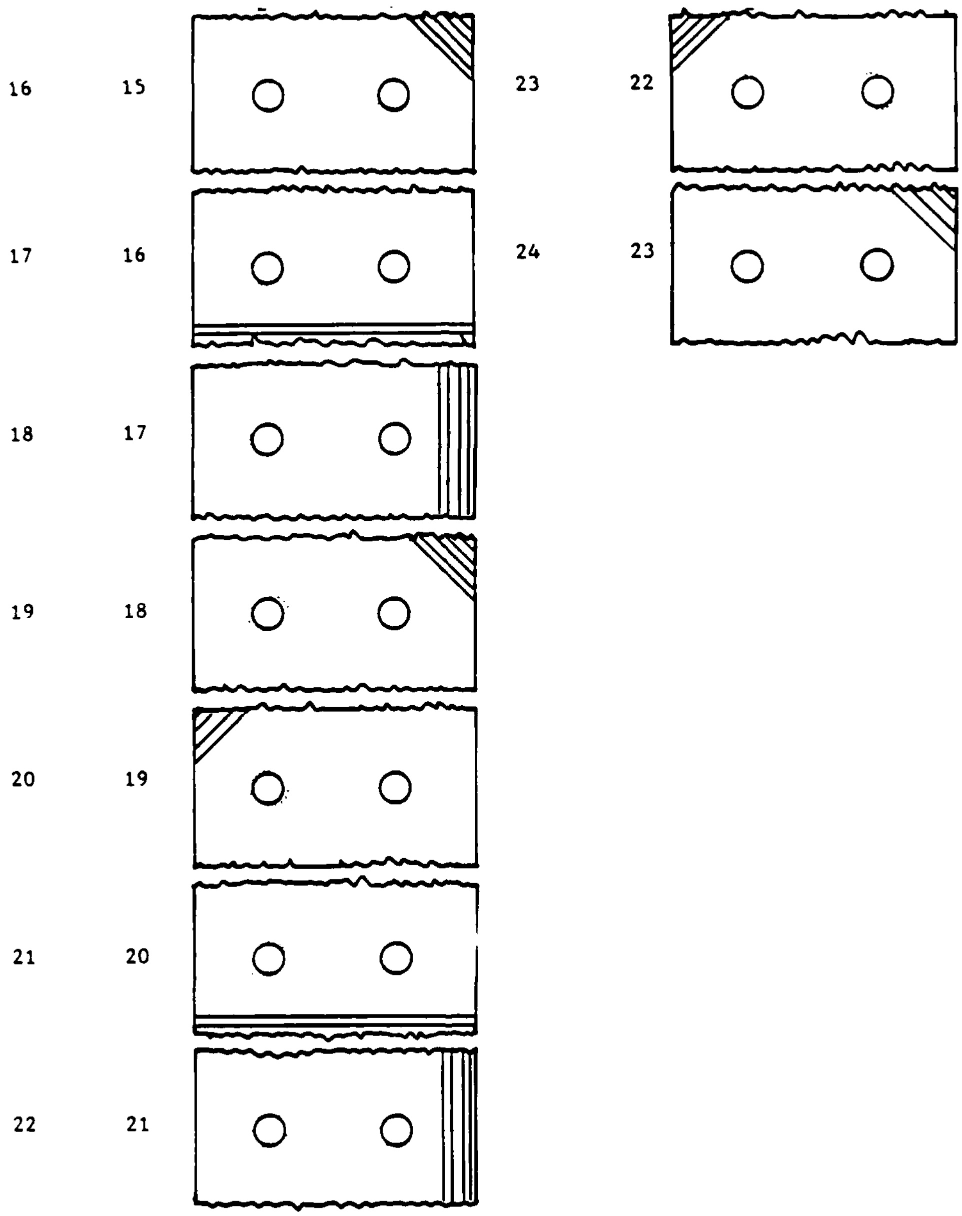


Figure C-45. Lamina Damage Characterization Chart for Specimen
I-C-17 Load Level D

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - C($\pm45^\circ$, 0°, 90°, $\mp45^\circ$, 0°, 90°, $\pm45^\circ$, 0°, 90°)s

LOAD LEVEL - B

POUNDS LOAD - 13,937 PERCENT OF ULTIMATE - 88

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-46. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-14.

BEFORE LOADING AFTER LOADING

FIGURE C-47. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-14.

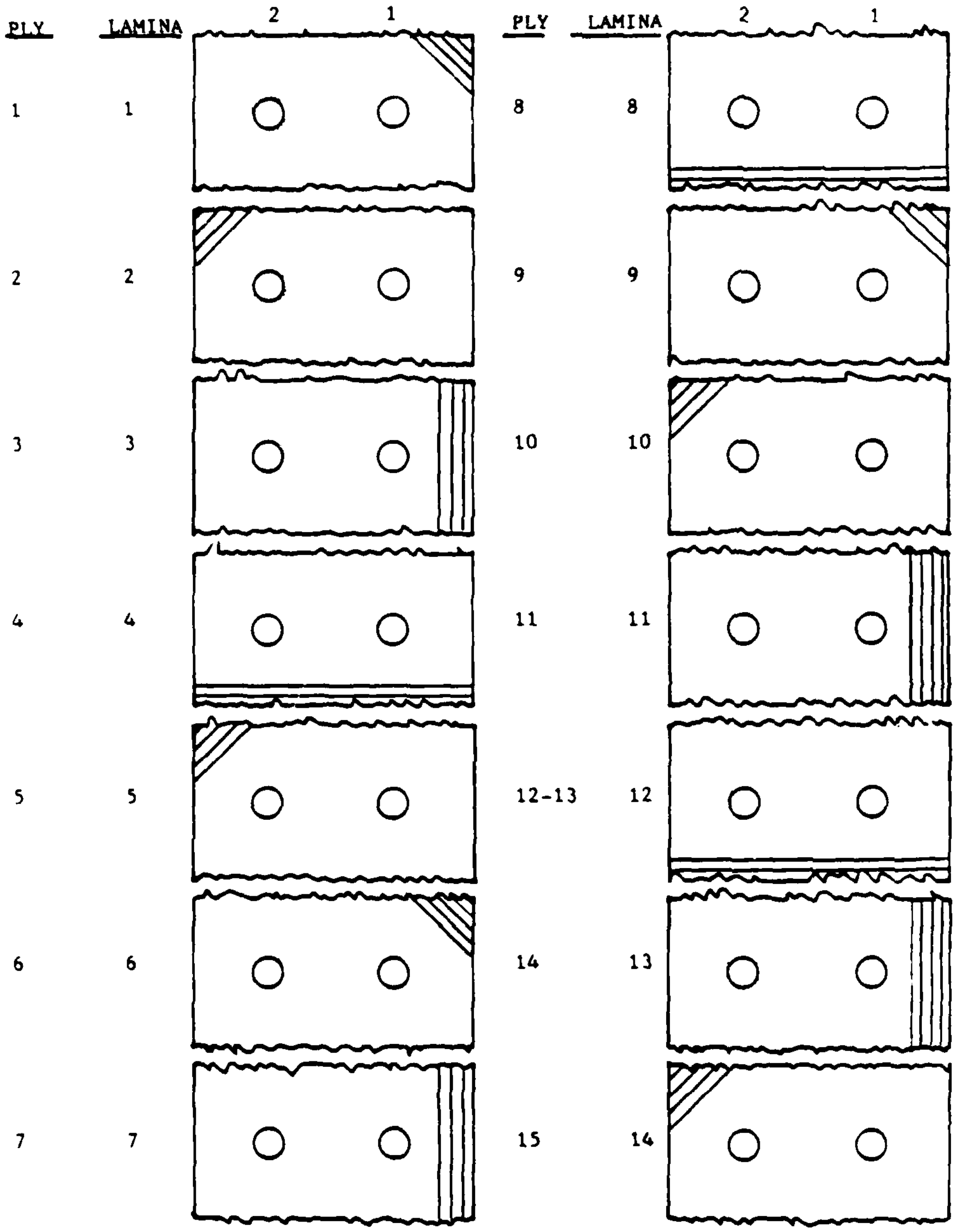


Figure C-48. Lamina Damage Characterization Chart for Specimen I-C-14 Load Level B (Continued)

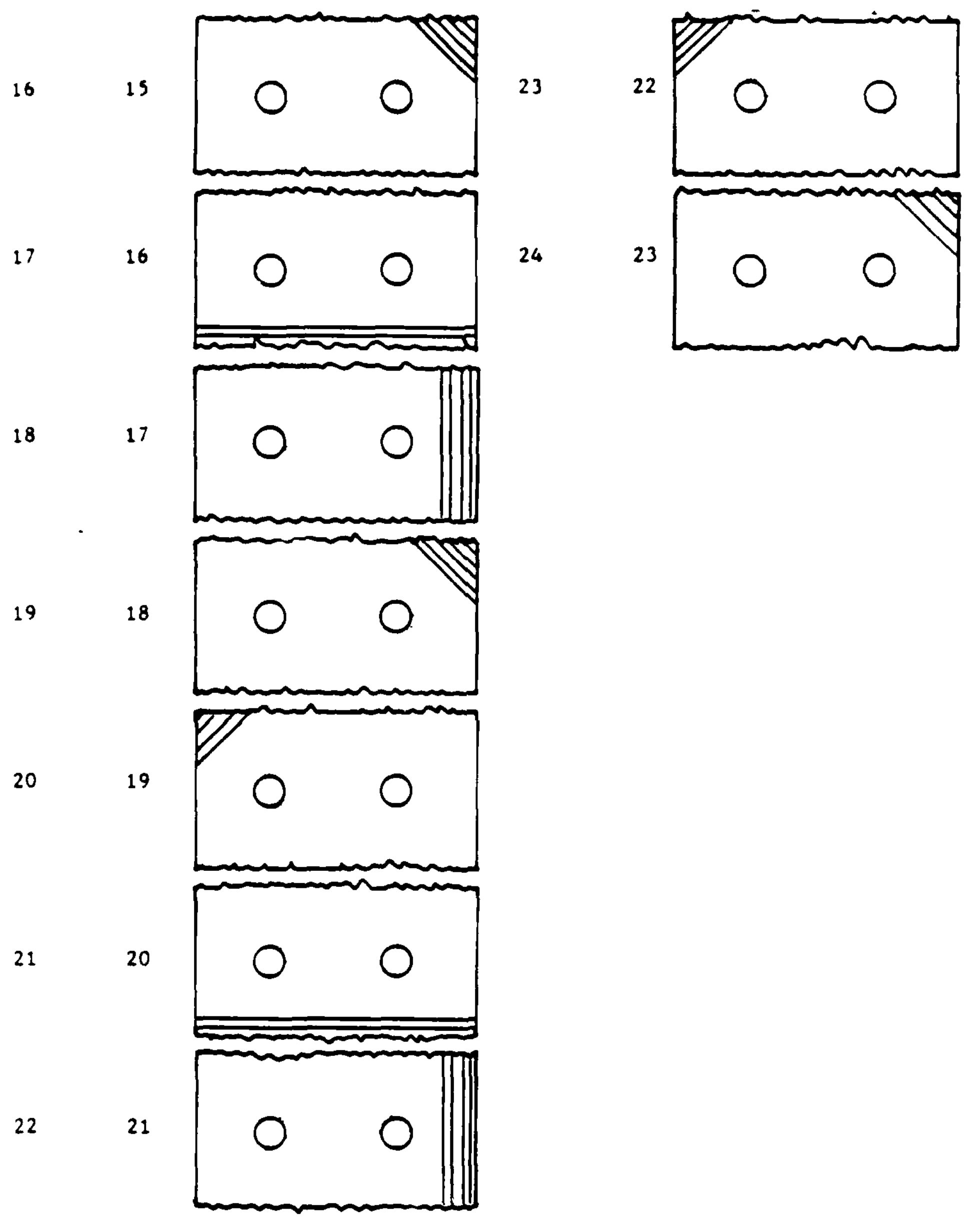


Figure C-48. Lamina Damage Characterization Chart for Specimen
I-C- 14 Load Level B

SPECIMEN TYPE - I(OPEN HOLE)

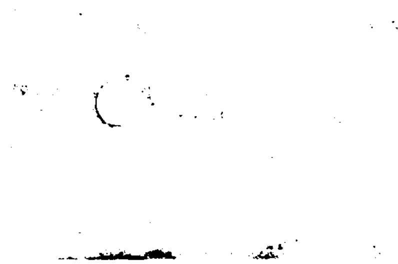
LAMINATE - C($\pm 45^\circ$, 0°, 90°, $\mp 45^\circ$, 0°, 90°, $\pm 45^\circ$, 0°, 90°)s

LOAD LEVEL - B

POUNDS LOAD - 13,937 PERCENT OF ULTIMATE - 88

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-49. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-24.



BEFORE LOADING AFTER LOADING

FIGURE C-50. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-24.

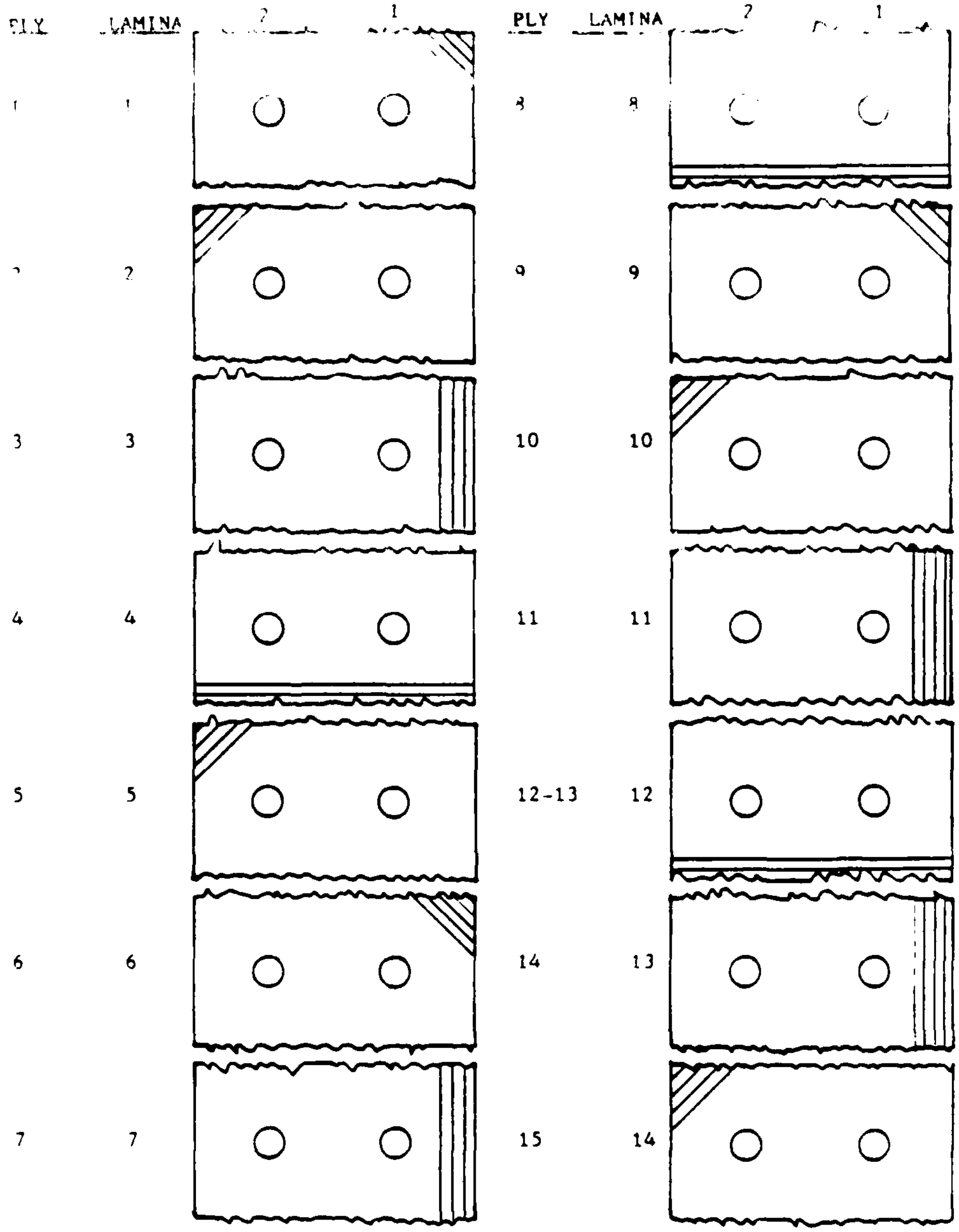


Figure C-51. Lamina Damage Characterization Chart for Specimen I-C-24 Load Level B (Continued)

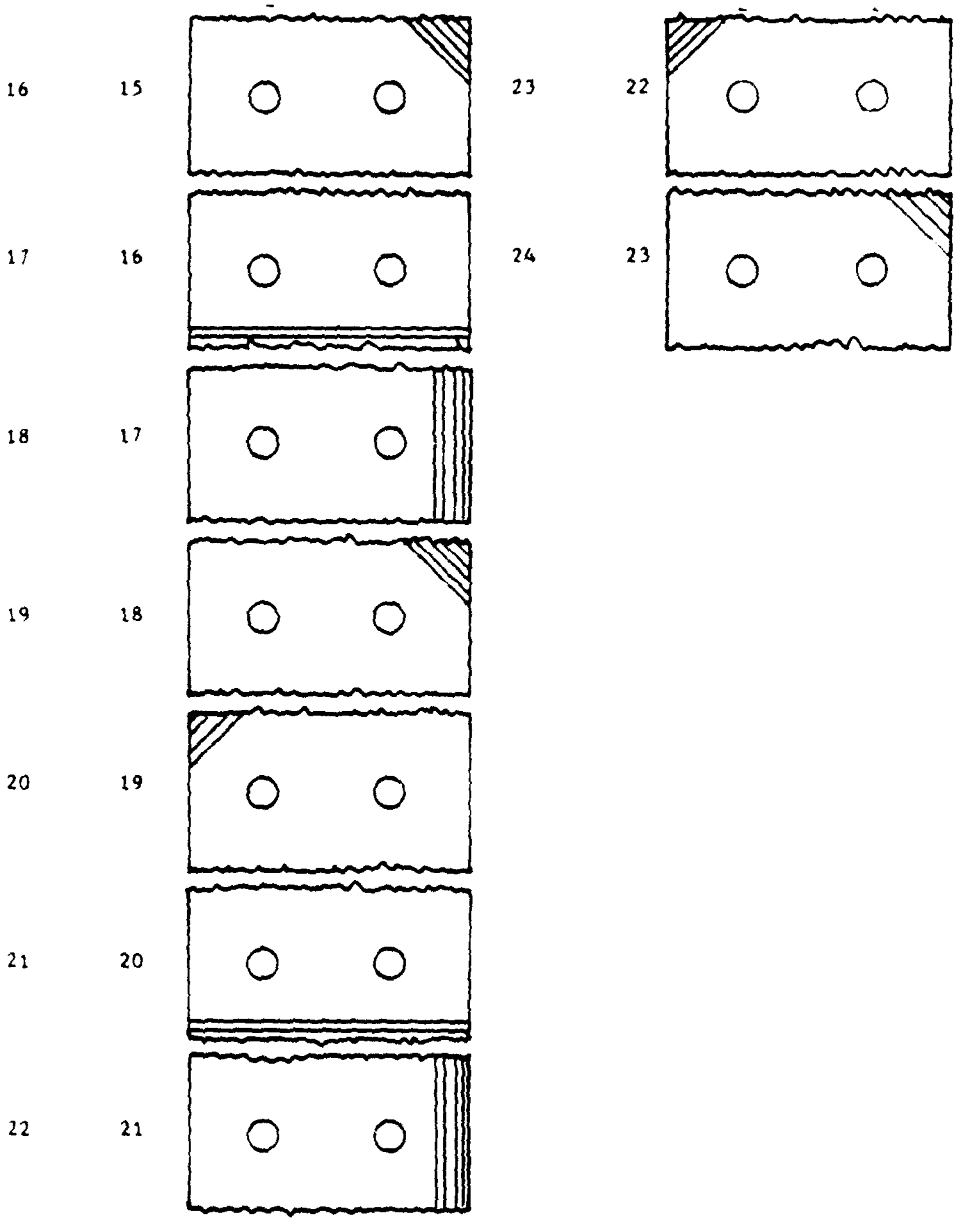


Figure C-51. Lamina Damage Characterization Chart for Specimen I-C-24 Load Level B

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - $C(\pm45^{\circ}, 0^{\circ}, 90^{\circ}, \mp45^{\circ}, 0^{\circ}, 90^{\circ}, \pm45^{\circ}, 0^{\circ}, 90^{\circ})_s$

LOAD LEVEL - B

POUNDS LOAD - 13,937   PERCENT OF ULTIMATE - 88

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-52. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-6.

BEFORE LOADING

AFTER LOADING

FIGURE C-53. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-6.

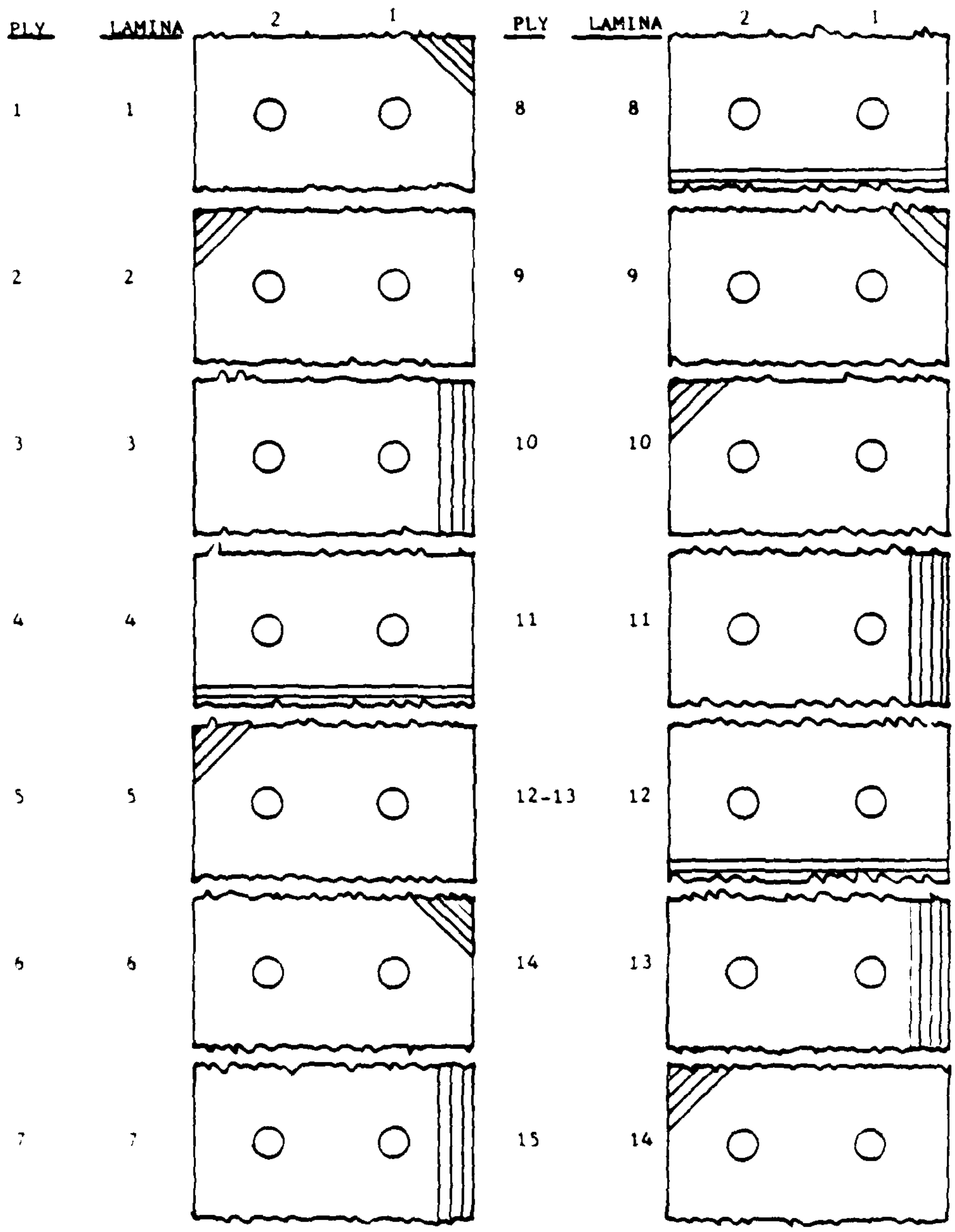


Figure C-54. Lamina Damage Characterization Chart for Specimen I-C-6 Load Level B (Continued)

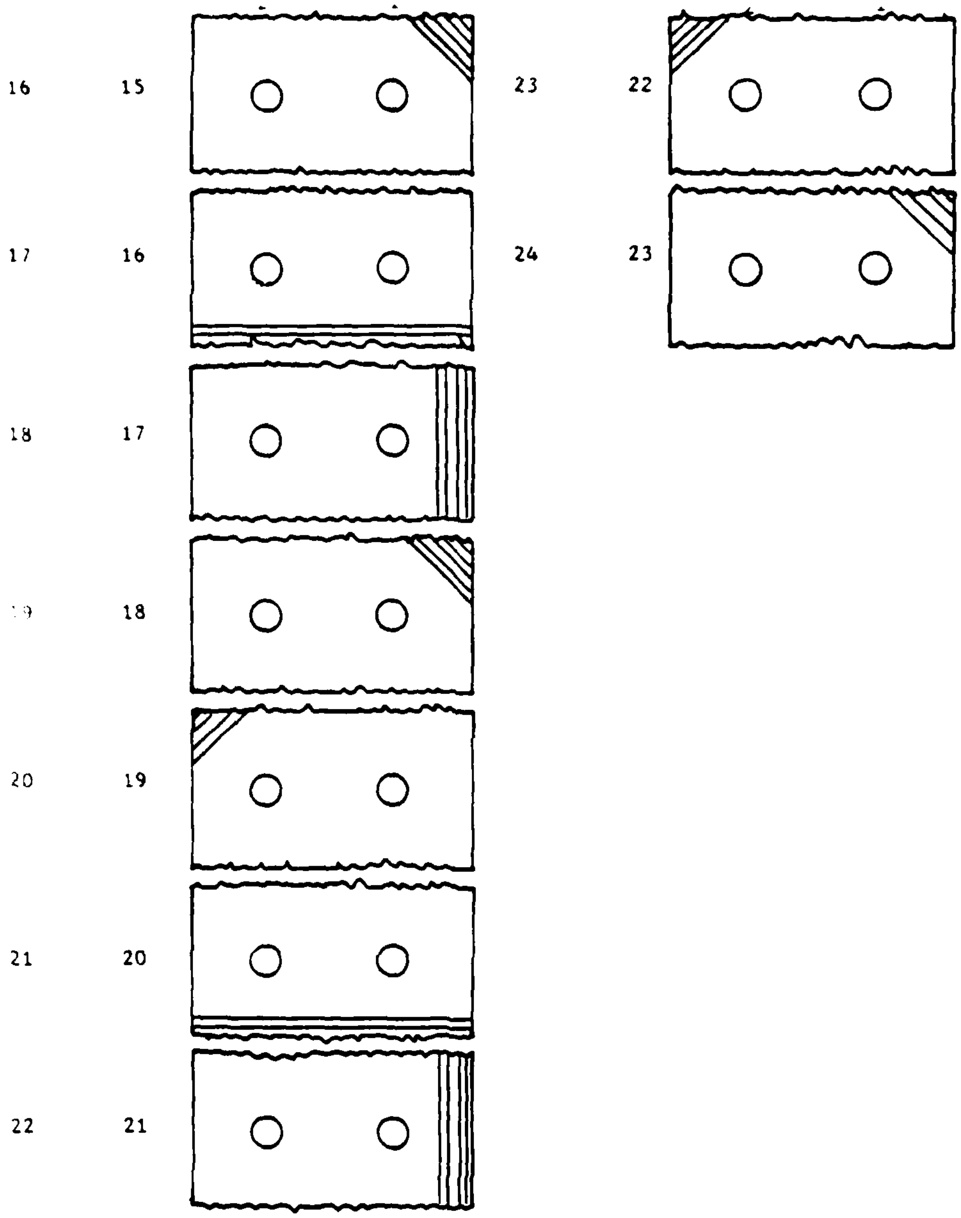


Figure C-54. Lamina Damage Characterization Chart for Specimen
I-C- 6 Load Level B

SPECIMEN TYPE - I(OPEN HOLE)

LAMINATE - C($\pm 45^\circ$, 0°, 90°, $\mp 45^\circ$, 0°, 90°, $\pm 45^\circ$, 0°, 90°)$_s$

LOAD LEVEL - B

POUNDS LOAD - 13,937 PERCENT OF ULTIMATE - 88

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES BASED ON ACOUSTIC EMISSION MONITORING - 1

FIGURE C-55. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-27.

BEFORE LOADING AFTER LOADING

FIGURE C-56. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-27.

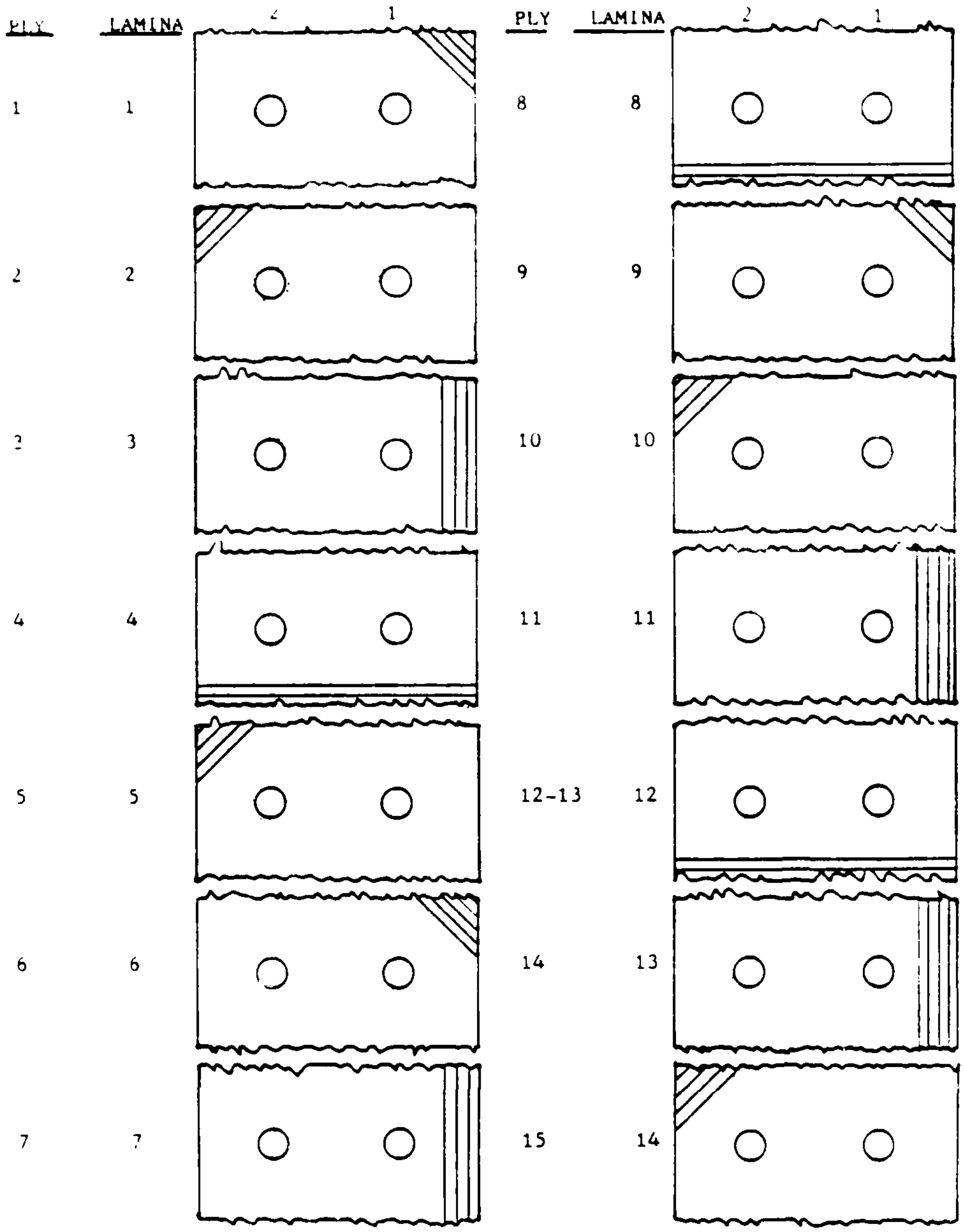


Figure C-57. Lamina Damage Characterization Chart for Specimen I C 27 Load Level B (Continued)

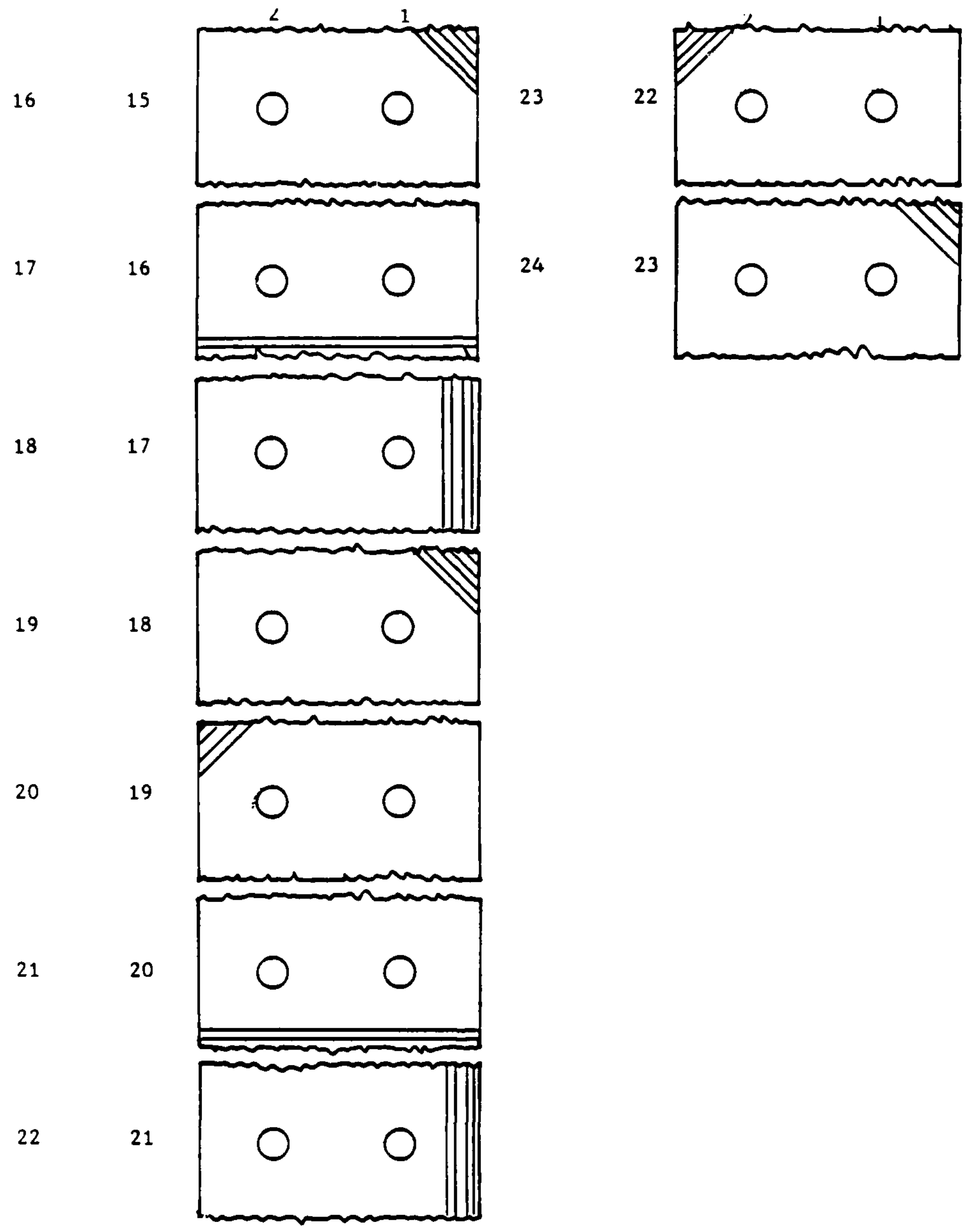


Figure C-57. Lamina Damage Characterization Chart for Specimen I-C-27 Load Level B

SPECIMEN TYPE - I(OPEN HOLE)

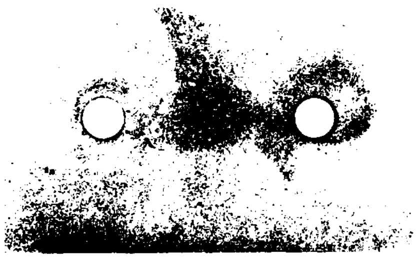
LAMINATE - C($\pm 45^\circ$, 0°, 90°, $\mp 45^\circ$, 0°, 90°, $\pm 45^\circ$, 0°, 90°)s

LOAD LEVEL - B

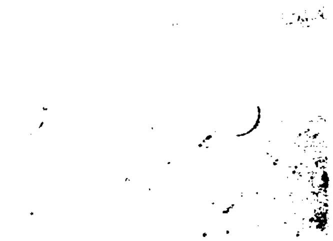
POUNDS LOAD - 13,937 PERCENT OF ULTIMATE - 88

EXPECTED NUMBER OF FIBER BUNDLE FRACTURES
BASED ON ACOUSTIC EMISSION MONITORING - 0

FIGURE C-58. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE TEST LOAD AND EXPECTED FIBER BUNDLE FRACTURES FOR SPECIMEN I-C-18.



BEFORE LOADING



AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE C-59. PRINTS OF RADIOGRAPHS FOR SPECIMEN I-C-18.

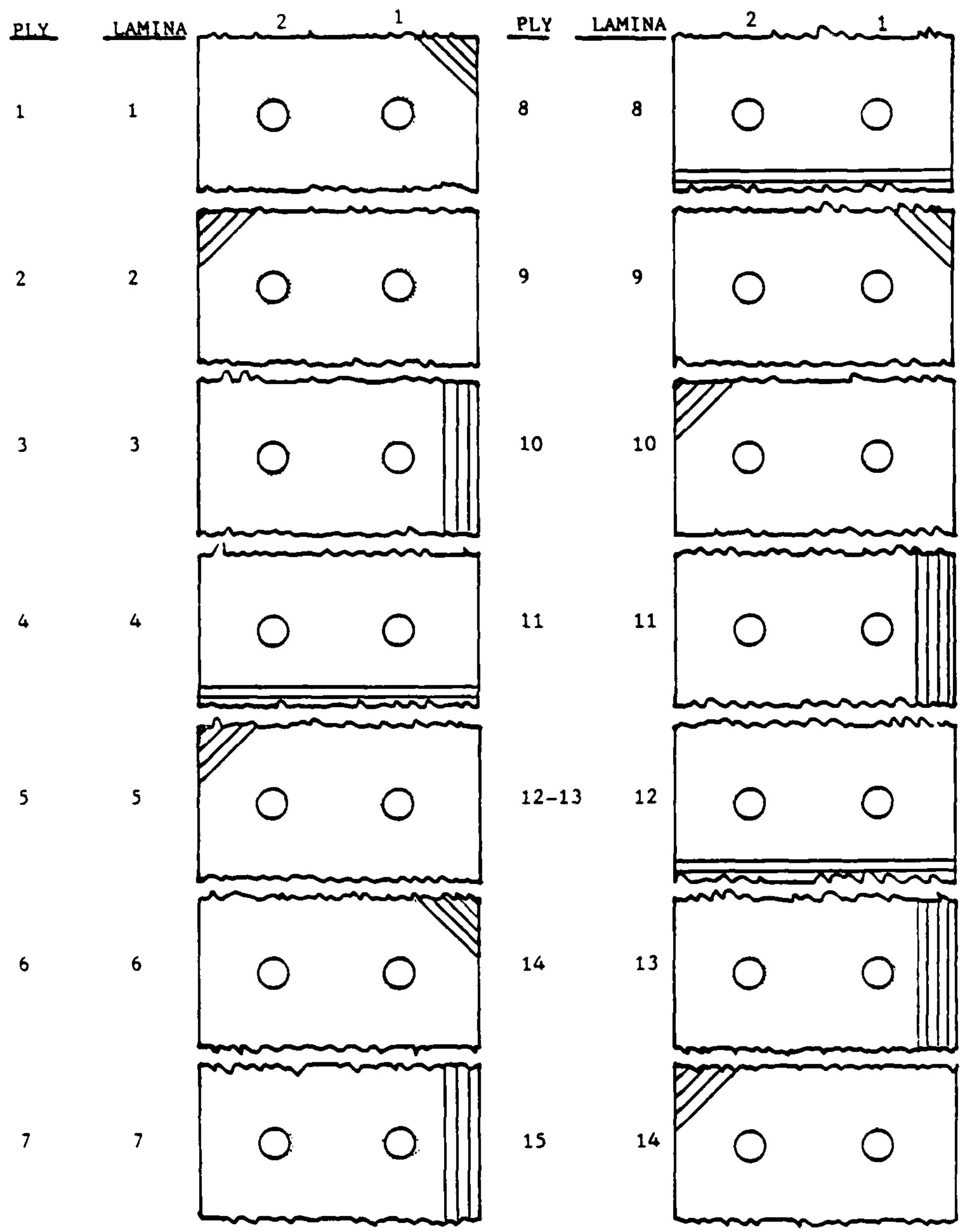


Figure C-60. Lamina Damage Characterization Chart for Specimen I-C-18 Load Level B (Continued)

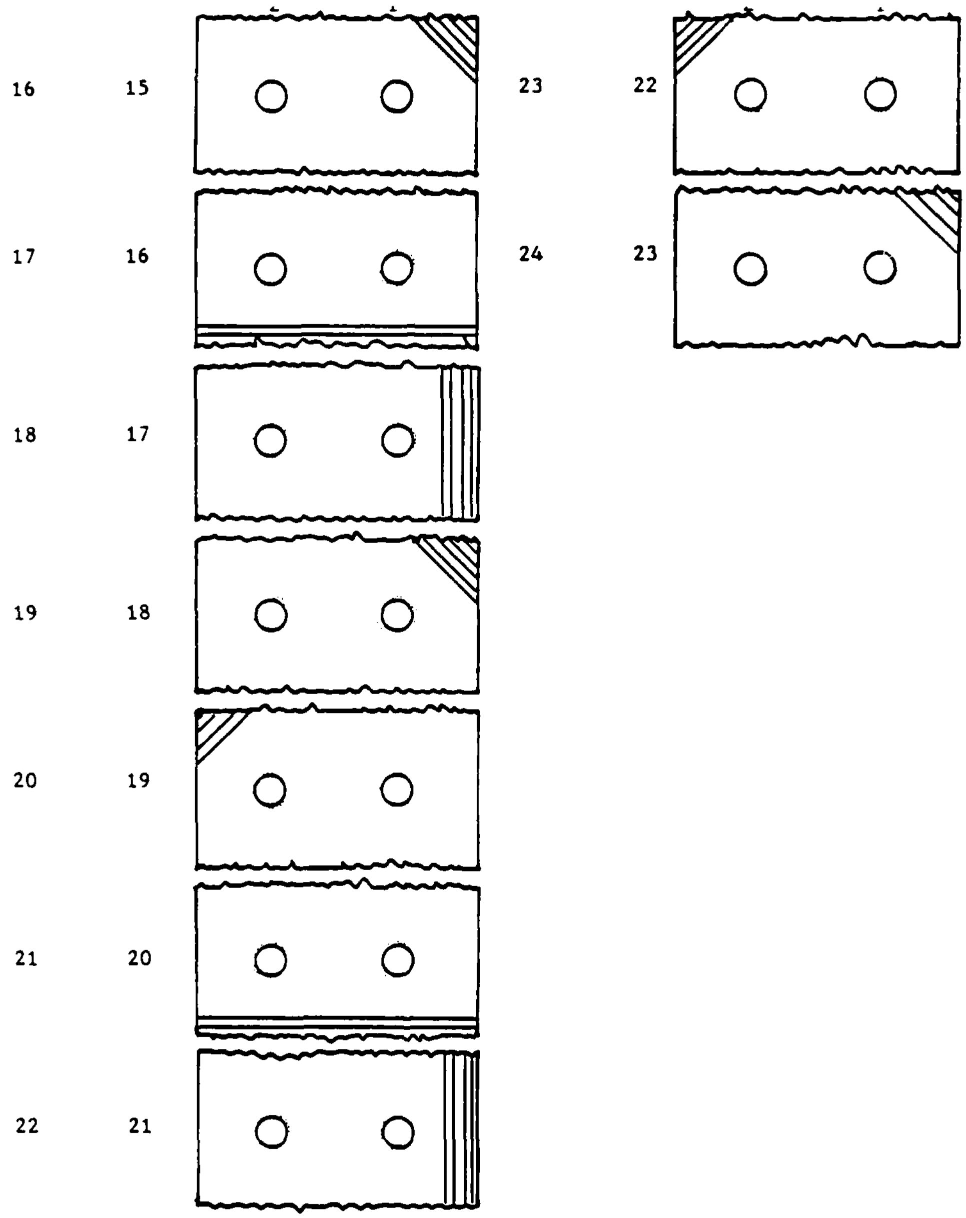


Figure C-60. Lamina Damage Characterization Chart for Specimen I-C-18 Load Level B

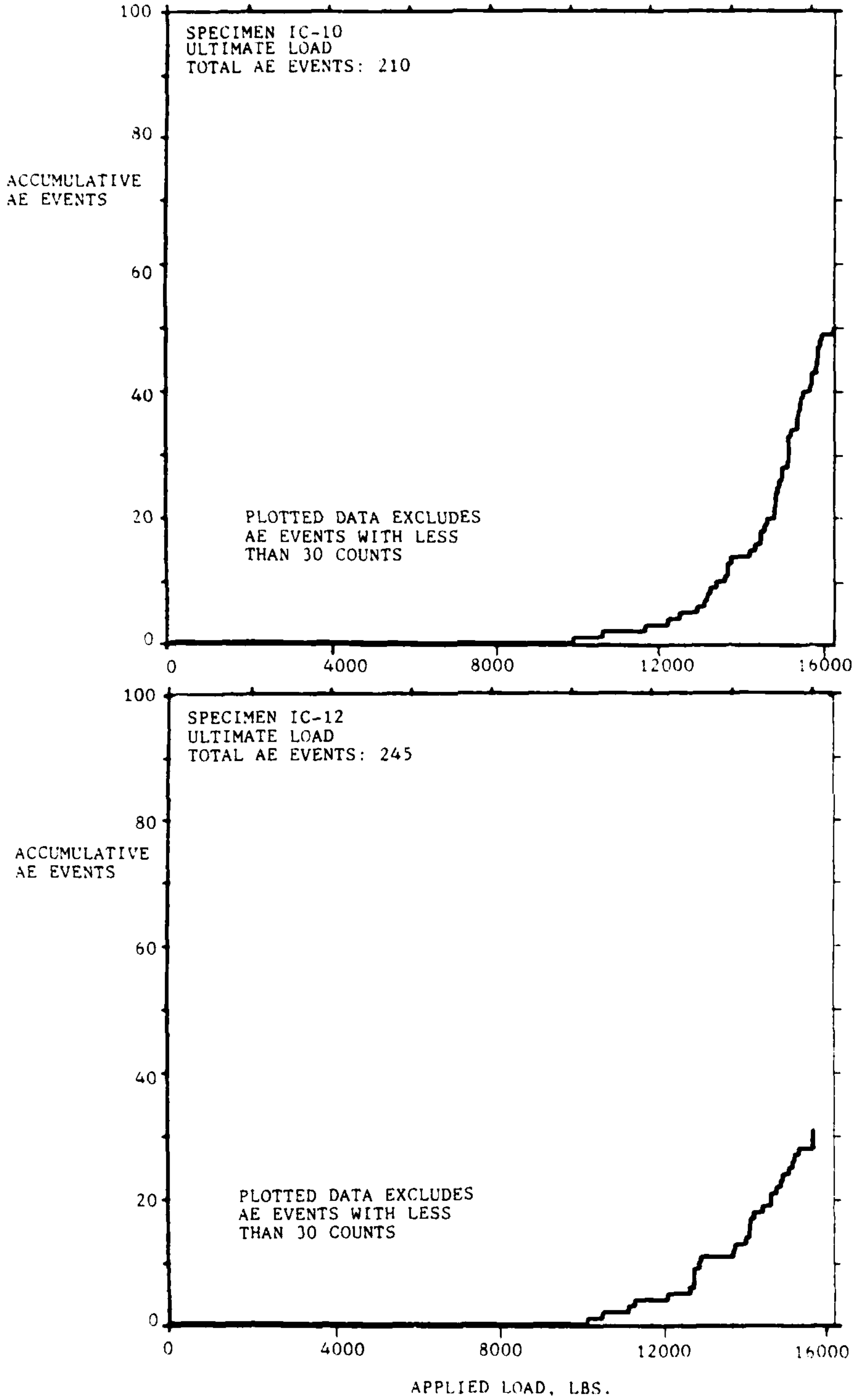
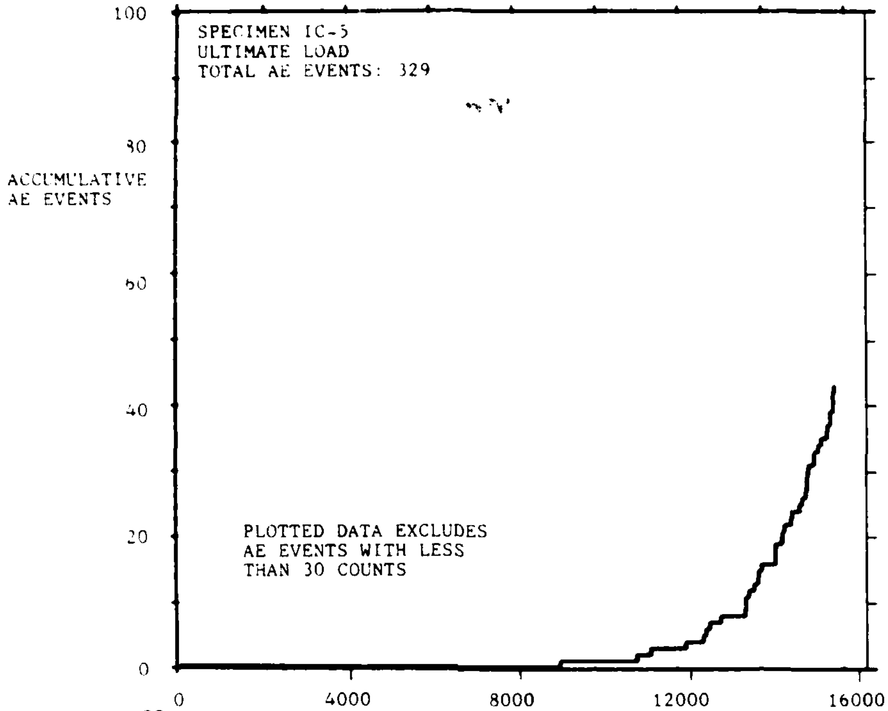


Figure C-61. Plots of Accumulative AE Events vs Applied Loads for Type I-C Ultimate Specimens.



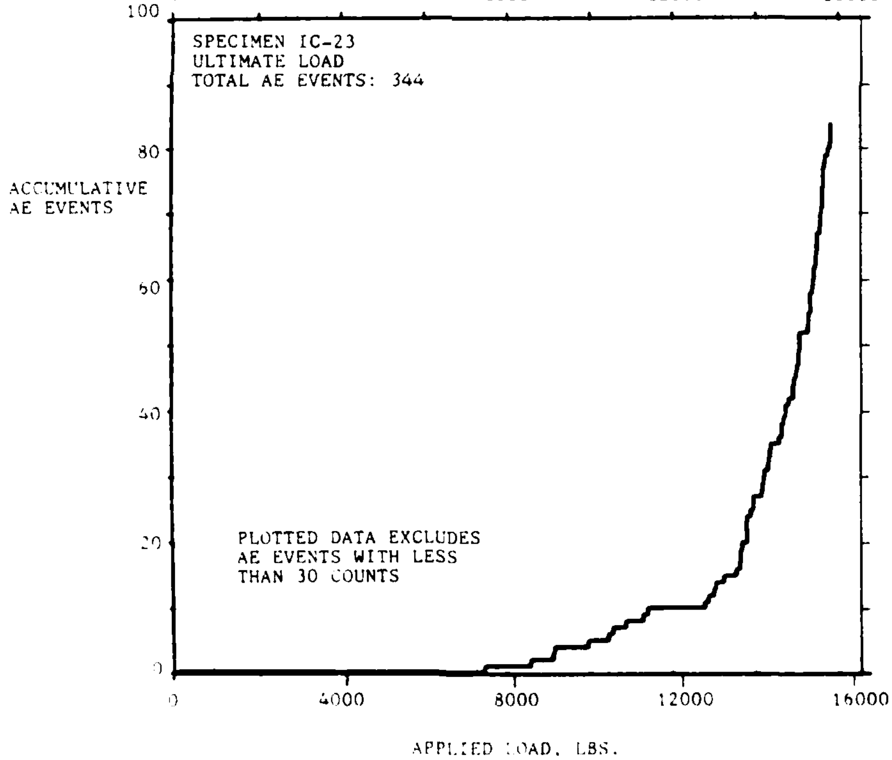


Figure C-62. Plots of Accumulative AE Events vs Applied Load for Type I-C Ultimate Specimens.

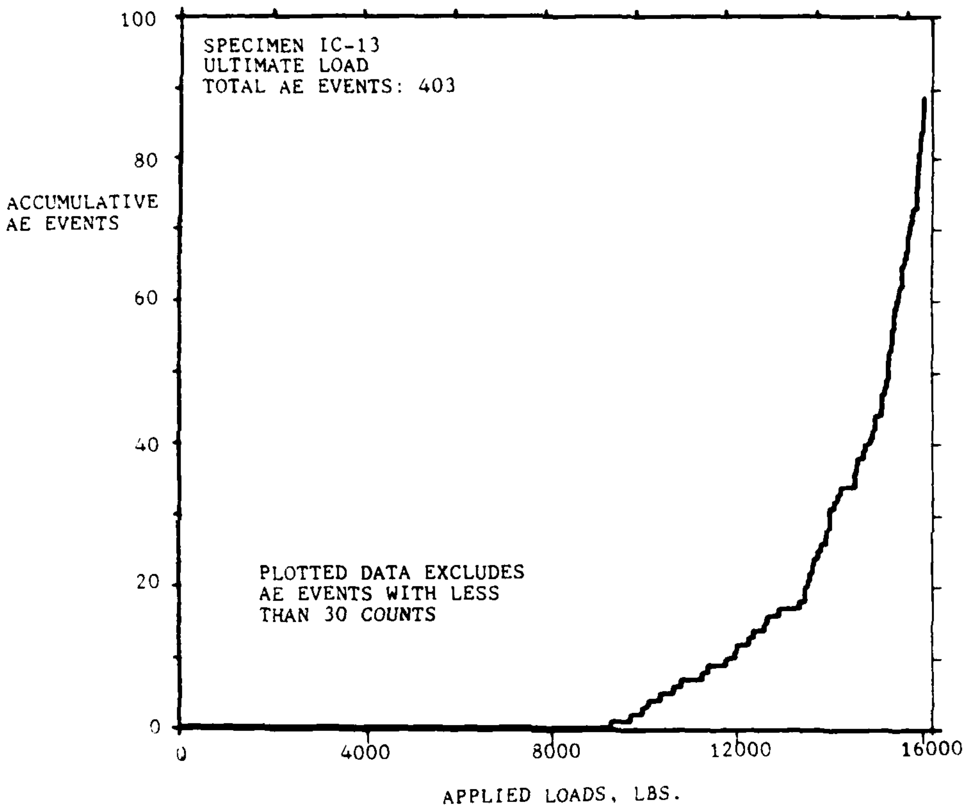


Figure C-63. Plots of Accumulative AE Events VS Applied Load for Type I-C Ultimate Specimens.

APPENDIX D

DETAIL DAMAGE INFORMATION FOR TYPE IIA-A SPECIMENS

The detail information for the Type IIA specimens of Laminate A is presented in this appendix. It is presented in the order of increasing load levels. All specimens of the same load level are grouped together. Three figures are presented for each specimen. The first figure gives specimen type, laminate information and load conditions. The second figure consists of positive prints of enhanced x-ray radiographs made before and after loading. In addition, prints of a stereo x-ray pair are included for one specimen of each load level. The third figure consists of a Lamina Damage Characterization Chart. This chart contains a pictorial sketch for each lamina with fiber orientations indicated on one side or edge of each sketch. Also an outline of the fastener head is shown on these sketches to provide a visual reference as to the magnitude of the damage. The damage observed on each lamina is recorded on the appropriate sketch in a manner to indicate size and location relative to the fastener hole. As shown in these charts lamina No. 1 was adjacent to the joint interface and lamina No. 17 was adjacent to the fastener head.

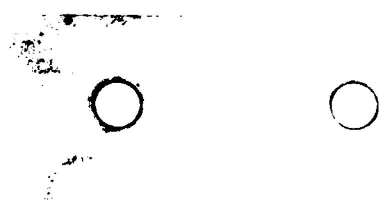
SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - A

POUNDS LOAD - 5000 PERCENT OF ULTIMATE - 61

FIGURE D-1. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, AND TEST LOAD FOR SPECIMEN IIA-A-9.



BEFORE LOADING AFTER LOADING

FIGURE D-2. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-9.

PRECEDING PAGE BLANK-NOT FILMED

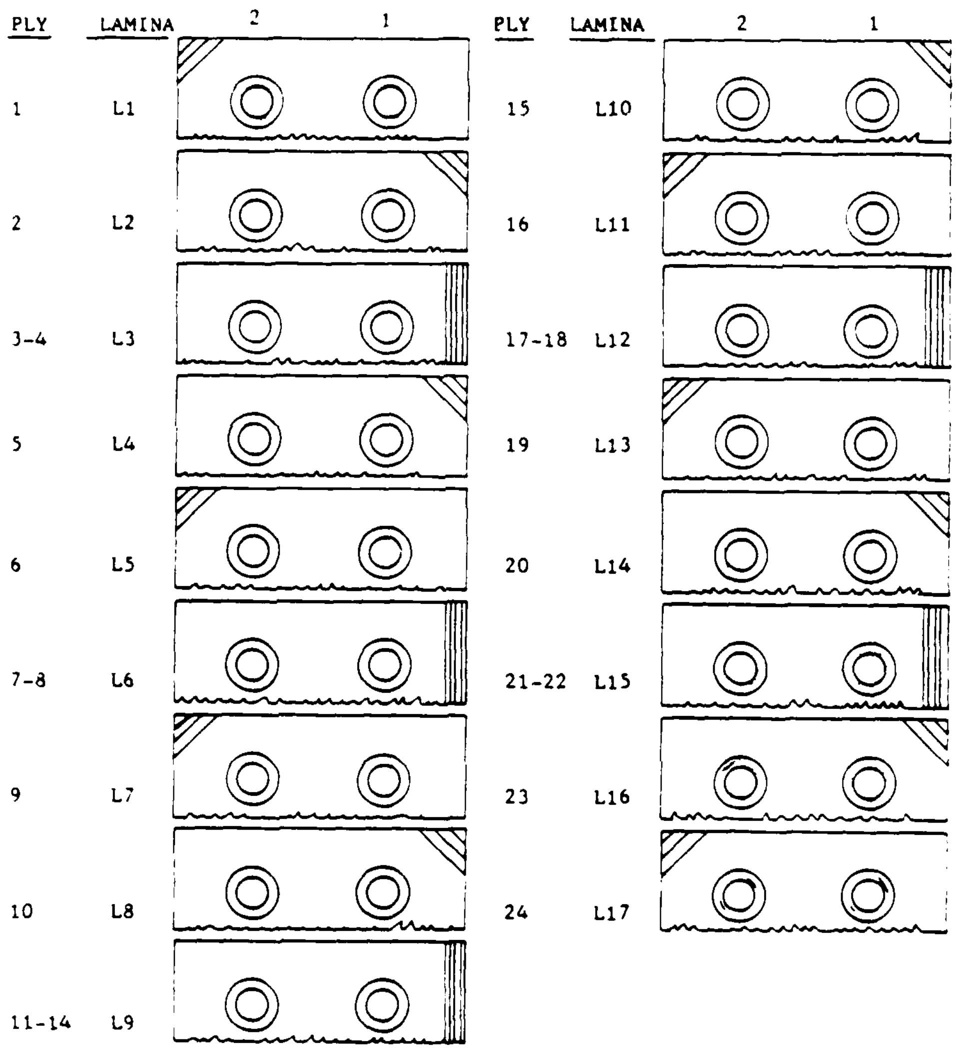


Figure D-3. Lamina Damage Characterization Chart for Specimen

IIA-A-9 Strap A Load Level A

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - A($\pm45^\circ$, 0_2°, $\mp45^\circ$, 0_2°, $\pm45^\circ$, 0_2°)s

LOAD LEVEL - A

POUNDS LOAD - 5000 PERCENT OF ULTIMATE - 61

FIGURE D-4. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, AND TEST LOAD FOR SPECIMEN IIA-A-3.

BEFORE LOADING AFTER LOADING

FIGURE D-5. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-3.

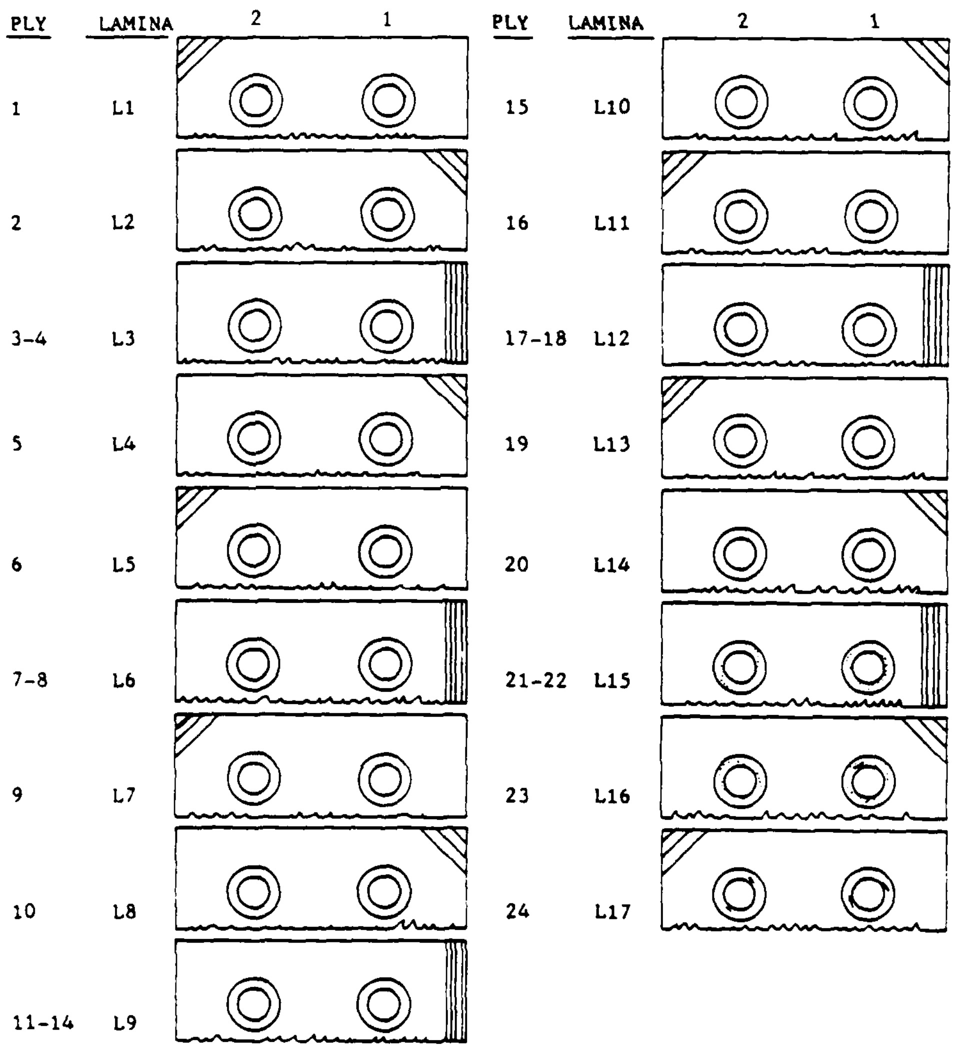


Figure D-6. Lamina Damage Characterization Chart for Specimen

IIA-A-3 Strap A Load Level A

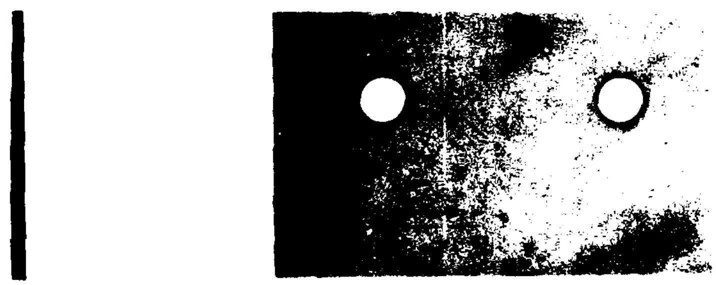
SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - A

POUNDS LOAD - 5000 PERCENT OF ULTIMATE - 61

FIGURE D-7. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, AND TEST LOAD FOR SPECIMEN IIA-A-12.



BEFORE LOADING AFTER LOADING

FIGURE D-8. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-12.

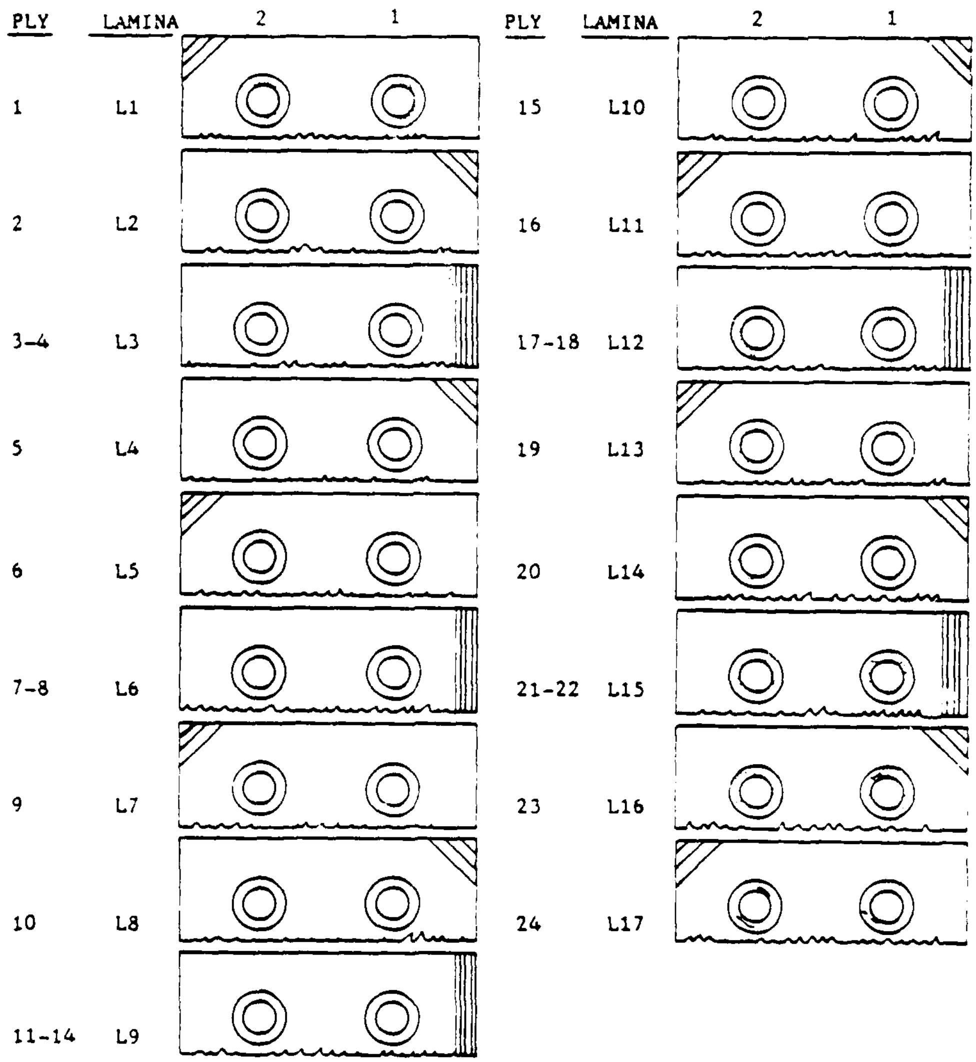


Figure D-9. Lamina Damage Characterization Chart for Specimen IIA-A-12 Strap A Load Level A

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - A($\pm 45^\circ$, 0_2°, $\mp 45^\circ$, 0_2°, $\pm 45^\circ$, 0_2°)s

LOAD LEVEL - A

POUNDS LOAD - 5000 PERCENT OF ULTIMATE - 61

FIGURE D-10. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, AND TEST LOAD FOR SPECIMEN IIA-A-8.

BEFORE LOADING AFTER LOADING

FIGURE D-11. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-8.

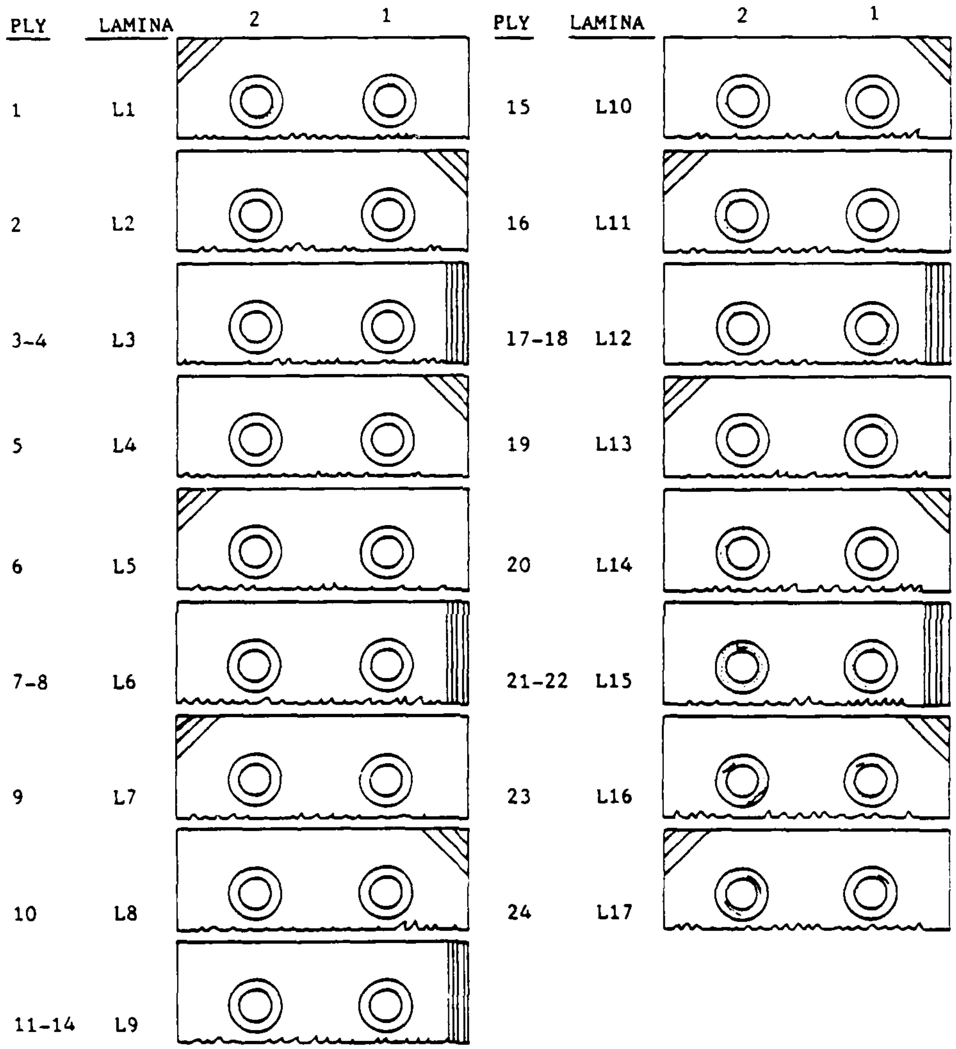


Figure D-12. Lamina Damage Characterization Chart for Specimen

IIA-A-8 Strap B Load Level A

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - A

POUNDS LOAD - 5000 PERCENT OF ULTIMATE - 61

FIGURE D-13. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-A-18.

BEFORE LOADING

AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE D-14. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-18.

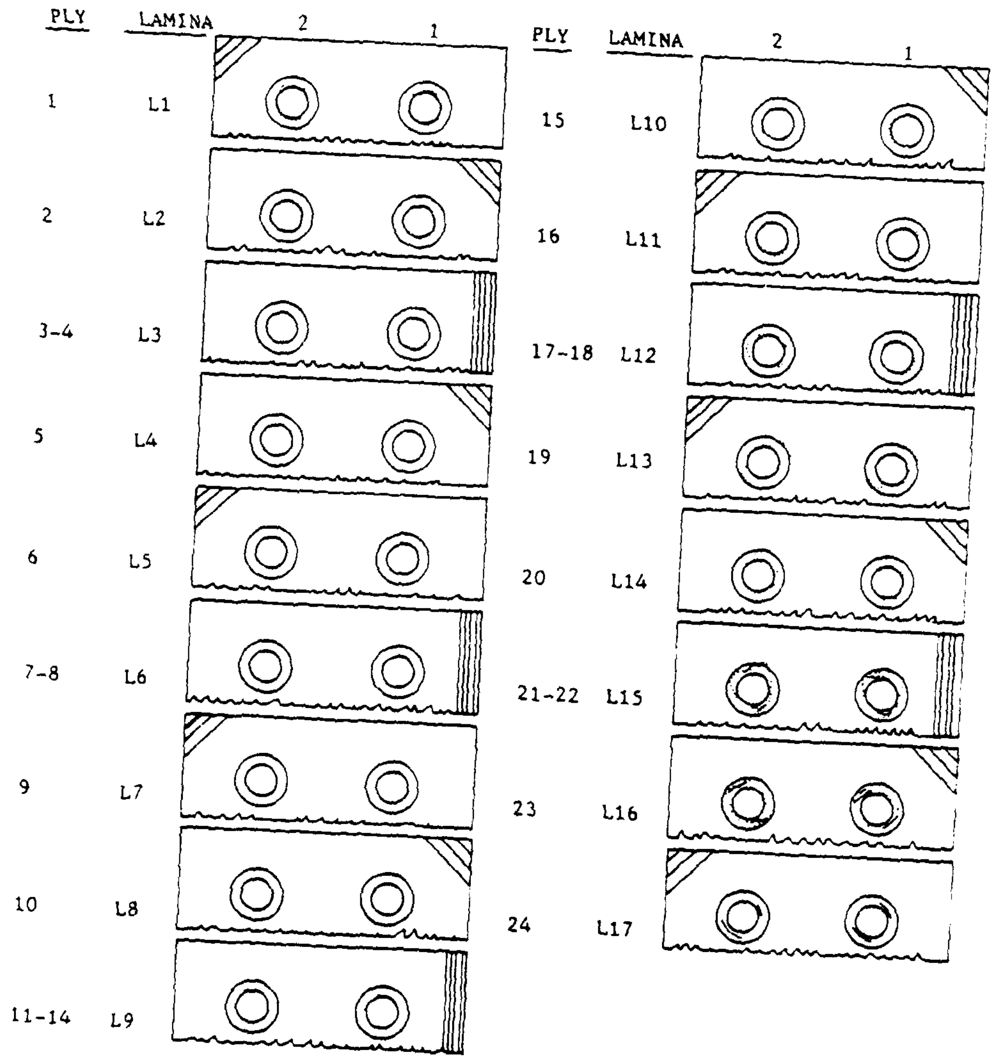


Figure D-15. Lamina Damage Characterization Chart for Specimen IIA-A-18 Strap A Load Level A

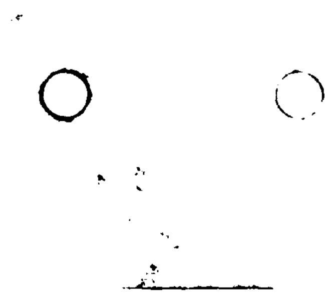
SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - A($\pm 45^\circ$, 0_2°, $\mp 45^\circ$, 0_2°, $\pm 45^\circ$, 0_2°)s

LOAD LEVEL - C

POUNDS LOAD - 5686 PERCENT OF ULTIMATE - 69

FIGURE D-16. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, AND TEST LOAD FOR SPECIMEN IIA-A-24.



BEFORE LOADING AFTER LOADING

FIGURE D-17. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-24.

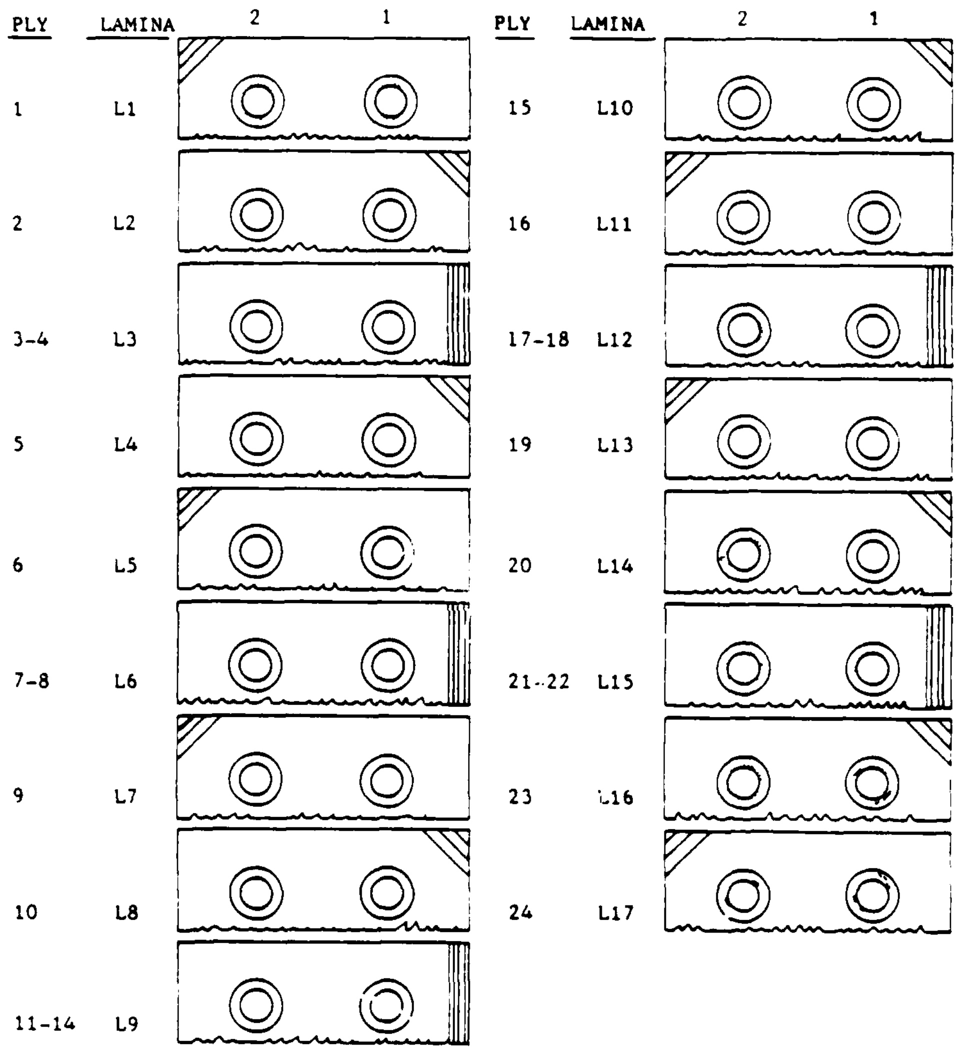


Figure D-18. Lamina Damage Characterization Chart for Specimen

IIA-A-24 Strap A Load Level C

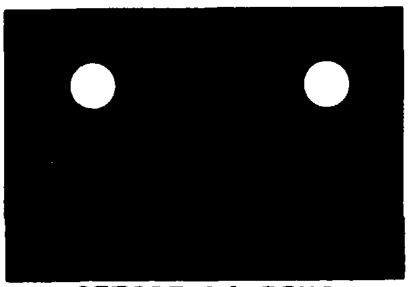
SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

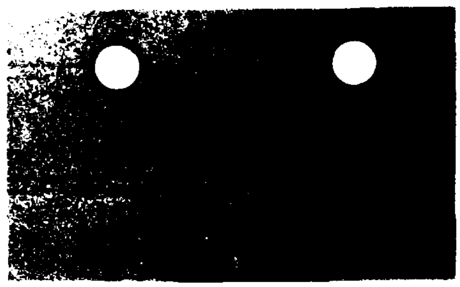
LOAD LEVEL - C

POUNDS LOAD - 5686 PERCENT OF ULTIMATE - 69

FIGURE D-19. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, AND TEST LOAD FOR SPECIMEN IIA-A-14.



BEFORE LOADING



AFTER LOADING

FIGURE D-20. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-14.

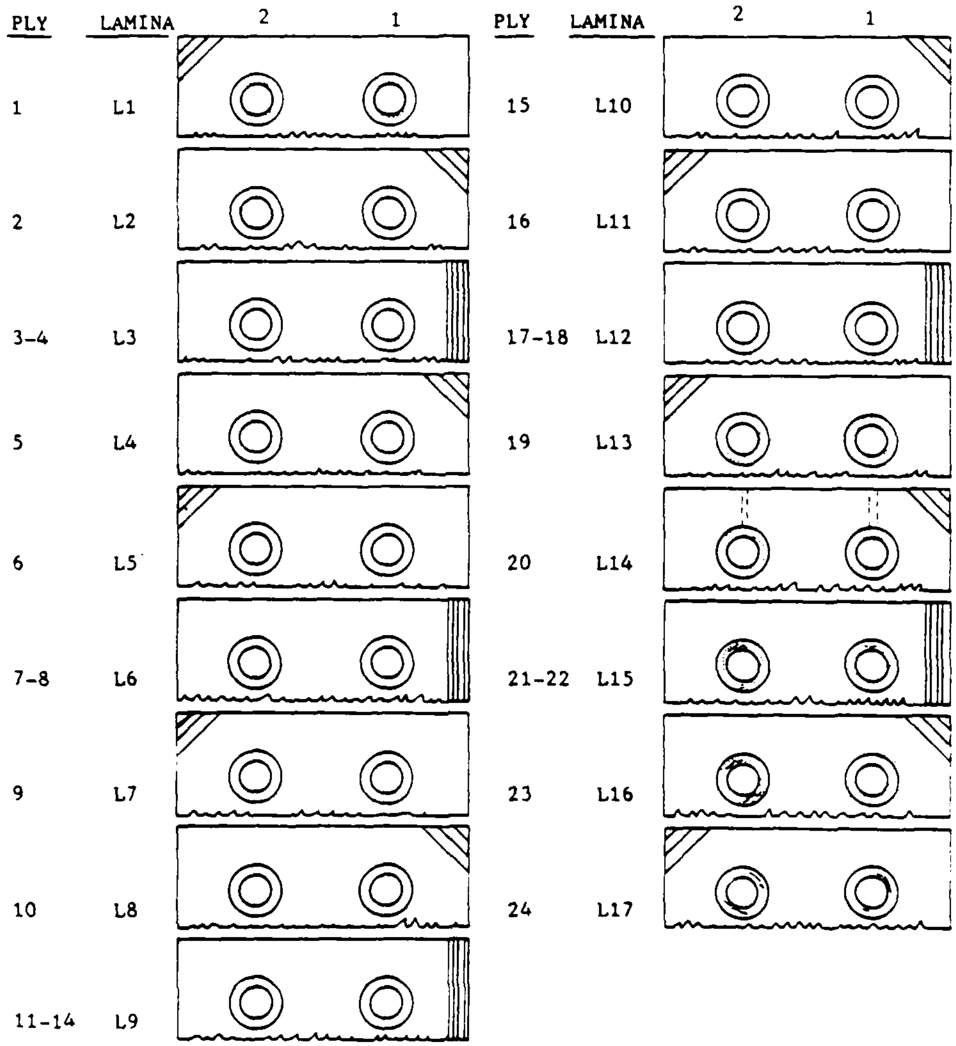


Figure D-21. Lamina Damage Characterization Chart for Specimen

IIA-A-14 Strap A Load Level C

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - A($\pm45^{\circ}$, 0_2°, $\mp45^{\circ}$, 0_2°, $\pm45^{\circ}$, 0_2°)s

LOAD LEVEL - C

POUNDS LOAD - 5686 PERCENT OF ULTIMATE - 69

FIGURE D-22. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, AND TEST LOAD FOR SPECIMEN IIA-A-21.

BEFORE LOADING AFTER LOADING

FIGURE D-23. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-21.

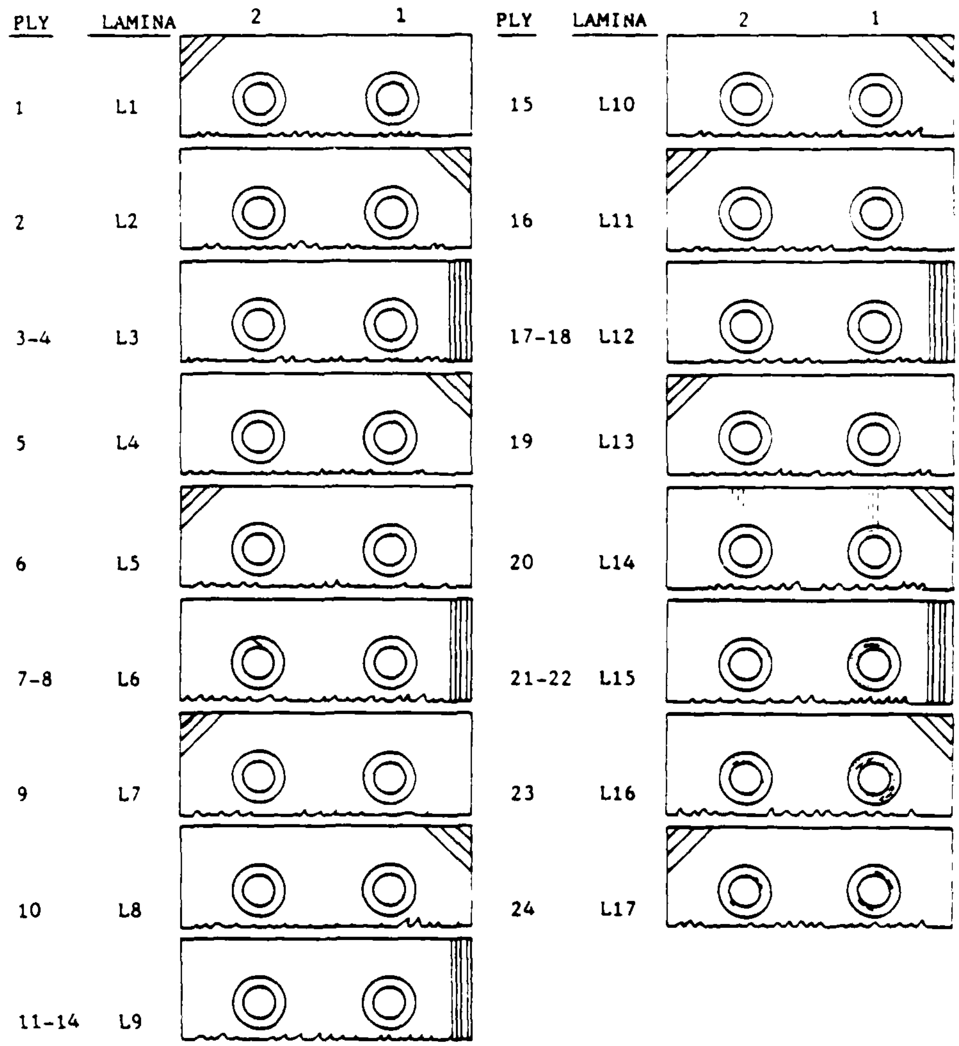


Figure D-24. Lamina Damage Characterization Chart for Specimen

IIA-A-21 Strap A Load Level C

SPECIMEN TYPE - [illegible] (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - C

POUNDS LOAD - 5686 PERCENT OF ULTIMATE - 69

FIGURE D-25. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, AND TEST LOAD FOR SPECIMEN IIA-A-22.

BEFORE LOADING AFTER LOADING

FIGURE D-26. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-22.

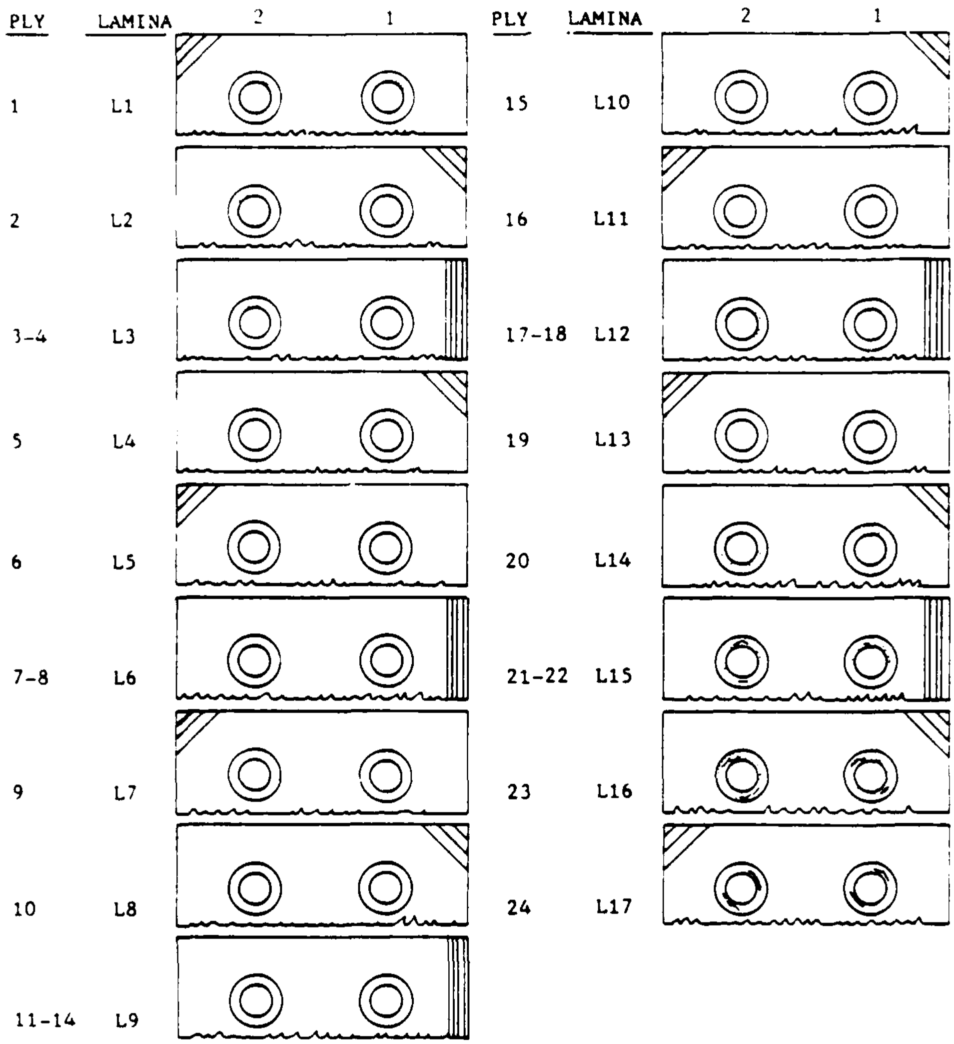


Figure D-27. Lamina Damage Characterization Chart for Specimen IIA-A-22 Strap A Load Level C

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - $A(\pm 45^\circ, 0_2{}^\circ, \mp 45^\circ, 0_2{}^\circ, \pm 45^\circ, 0_2{}^\circ)s$

LOAD LEVEL - C

POUNDS LOAD - 5686 PERCENT OF ULTIMATE - 69

FIGURE D-28. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-A-16.

BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE D-29. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-16.

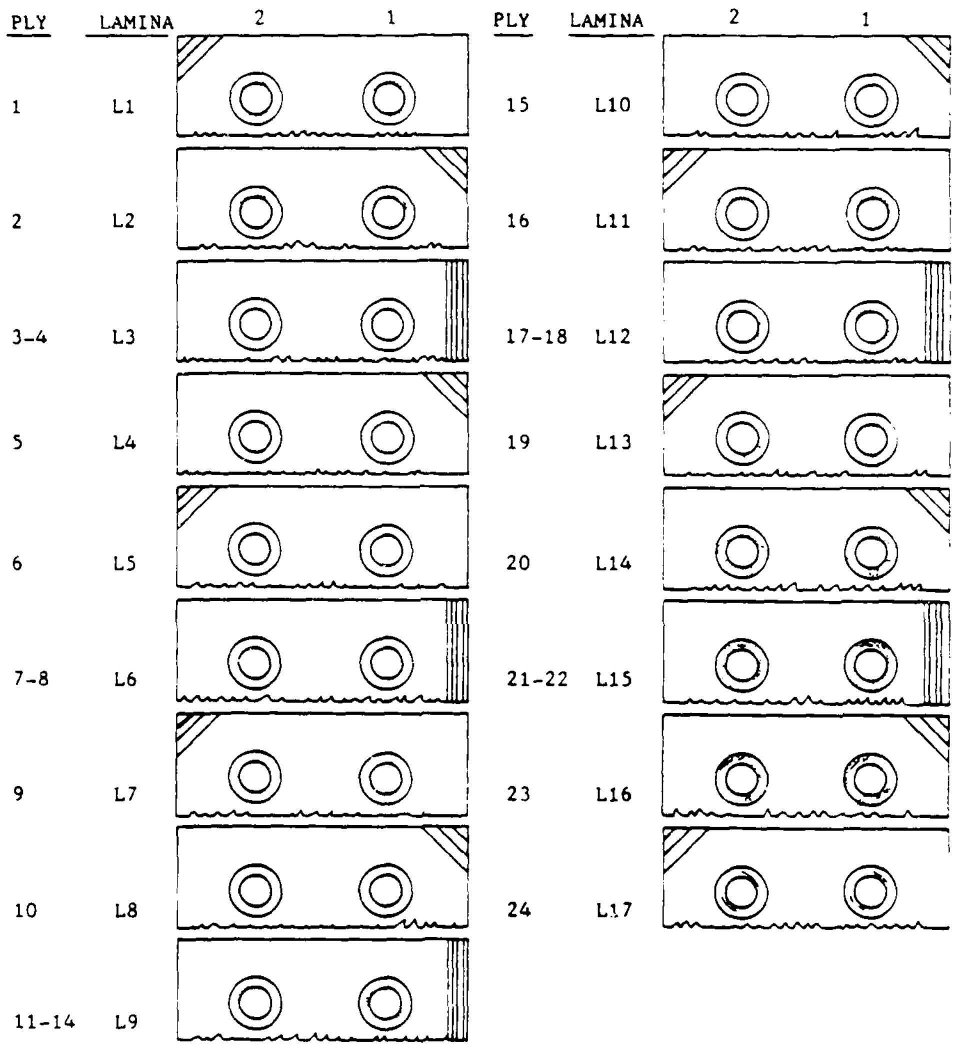


Figure D-30. Lamina Damage Characterization Chart for Specimen

IIA-A-16 Strap B Load Level C

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - A($\pm45^\circ$, $0_2{}^\circ$, $\mp45^\circ$, $0_2{}^\circ$, $\pm45^\circ$, $0_2{}^\circ$)s

LOAD LEVEL - D

POUNDS LOAD - 6345 PERCENT OF ULTIMATE - 77

FIGURE D-31. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, AND TEST LOAD FOR SPECIMEN IIA-A-15.

BEFORE LOADING AFTER LOADING

FIGURE D-32. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-15.

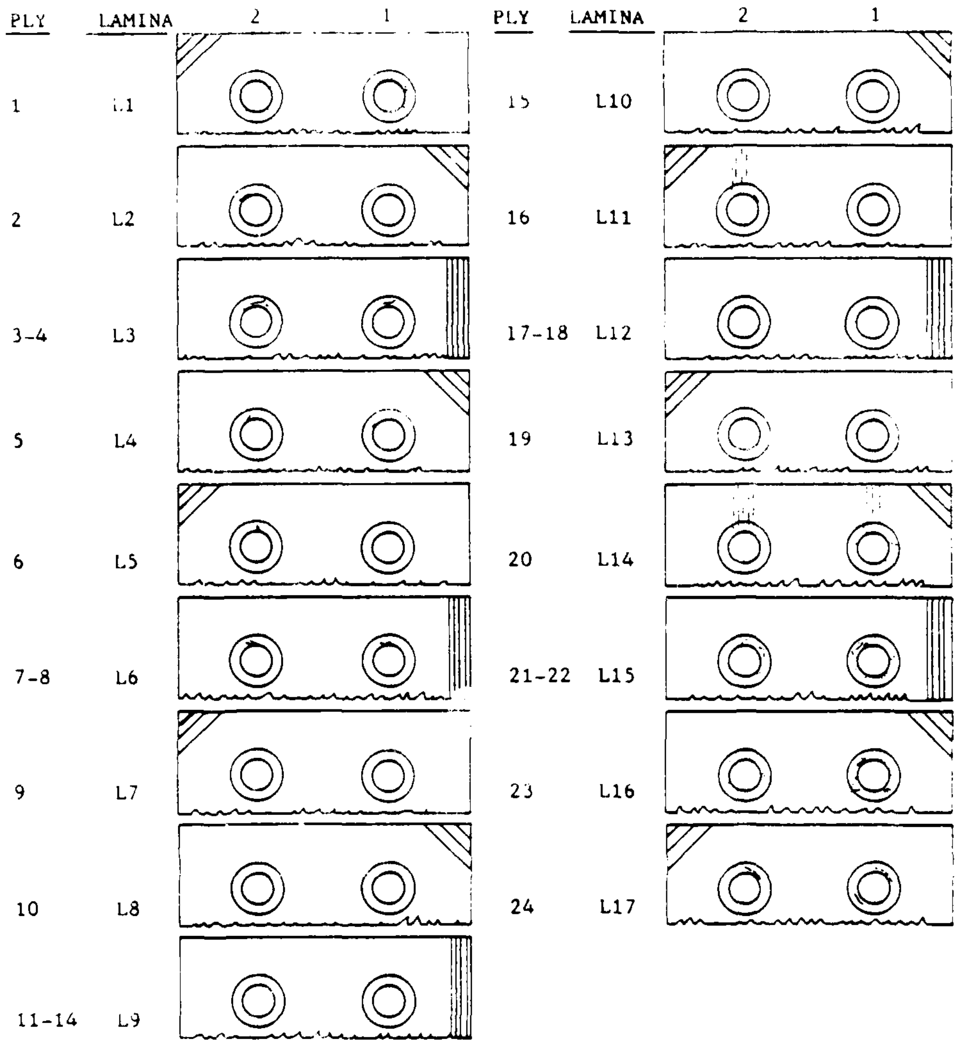


Figure D 33. Lamina Damage Characterization Chart for Specimen

IIA-A-15 Strap A Load Level D

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - D

POUNDS LOAD - 6345 PERCENT OF ULTIMATE - 77

FIGURE D-34. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, AND TEST LOAD FOR SPECIMEN IIA-A-20.

BEFORE LOADING AFTER LOADING

FIGURE D-35. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-20.

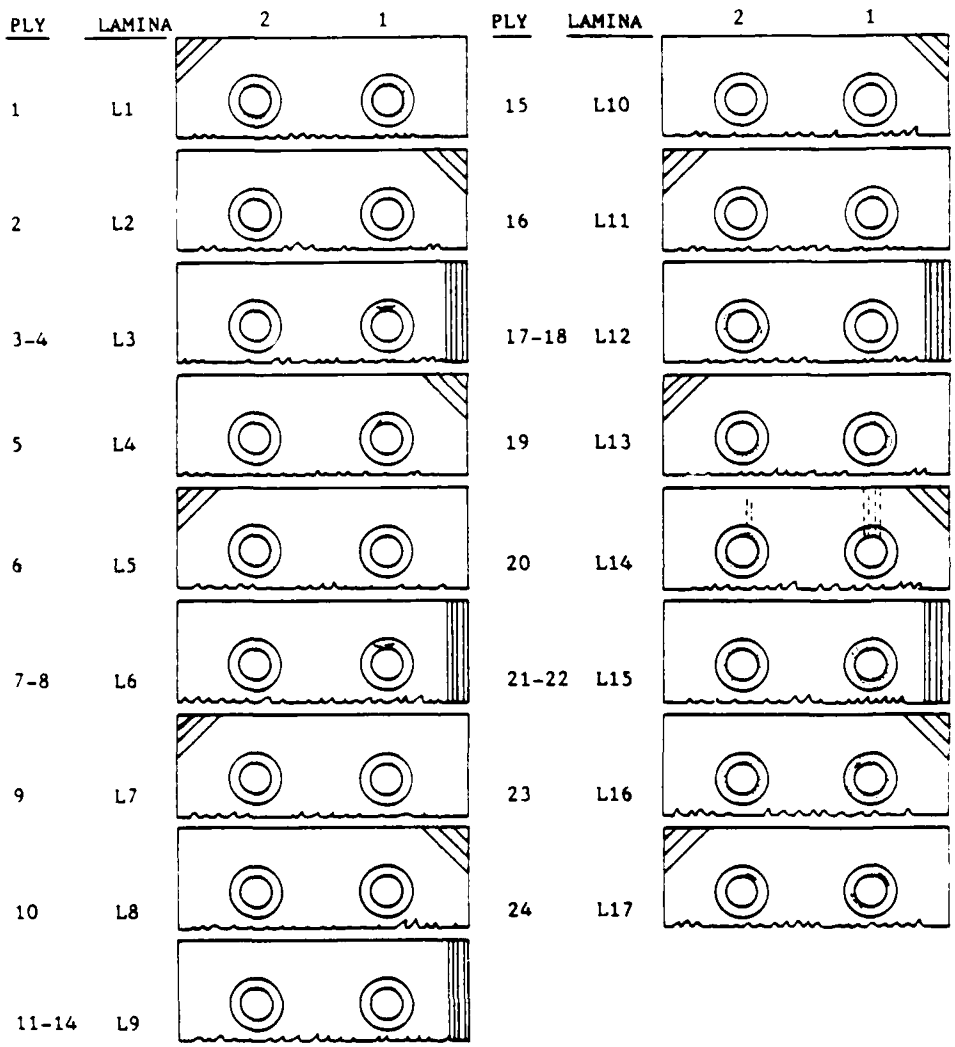


Figure D-36. Lamina Damage Characterization Chart for Specimen

IIA-A-20 Strap B Load Level D

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, $0_2{}^{\circ}$, $\mp 45^{\circ}$, $0_2{}^{\circ}$, $\pm 45^{\circ}$, $0_2{}^{\circ}$)s

LOAD LEVEL - D

POUNDS LOAD - 6345 PERCENT OF ULTIMATE - 77

FIGURE D-37. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, AND TEST LOAD FOR SPECIMEN IIA-A-13.

BEFORE LOADING AFTER LOADING

FIGURE D-38. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-13.

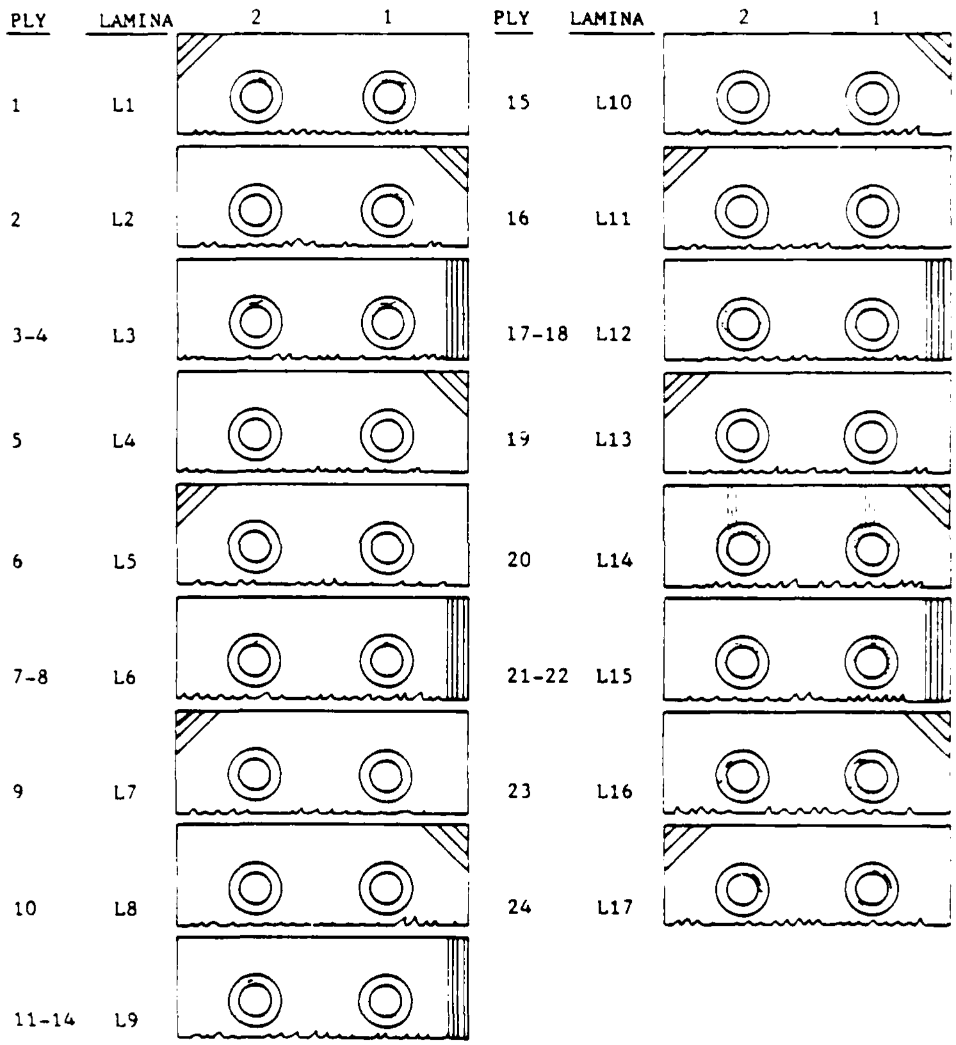


Figure D-39. Lamina Damage Characterization Chart for Specimen

IIA-A-13 Strap B Load Level D

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - A($\pm45^\circ$, $0_2{}^\circ$, $\mp45^\circ$, $0_2{}^\circ$, $\pm45^\circ$, $0_2{}^\circ$)s

LOAD LEVEL - D

POUNDS LOAD - 6345 PERCENT OF ULTIMATE - 77

FIGURE D-40. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, AND TEST LOAD FOR SPECIMEN IIA-A-7.

BEFORE LOADING AFTER LOADING

FIGURE D-41. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-7.

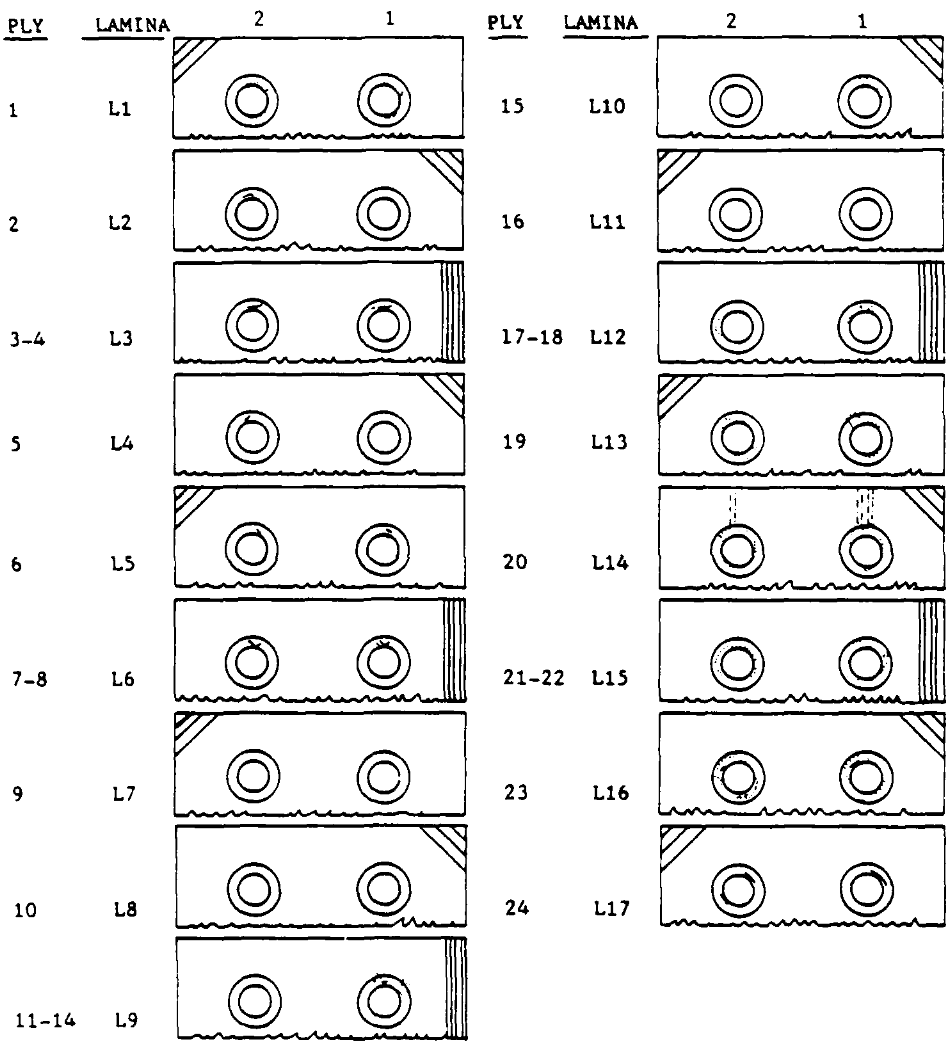


Figure D-42. Lamina Damage Characterization Chart for Specimen

IIA-A-7 Strap B Load Level D

SPECIMEN TYPE - IIA (BOLTED JOINT)

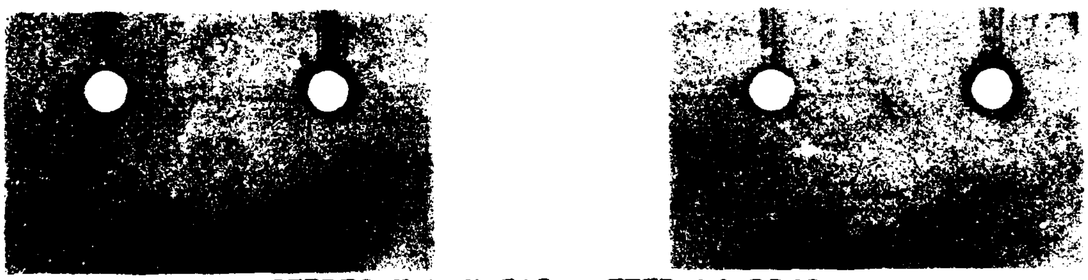
LAMINATE - A($\pm 45^\circ$, $0_2{}^\circ$, $\mp 45^\circ$, $0_2{}^\circ$, $\pm 45^\circ$, $0_2{}^\circ$)s

LOAD LEVEL - D

POUNDS LOAD - 6345 PERCENT OF ULTIMATE - 77

FIGURE D-43. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-A-1.

BEFORE LOADING AFTER LOADING



STEREO X-RAY PAIR AFTER LOADING

FIGURE D-44. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-1.

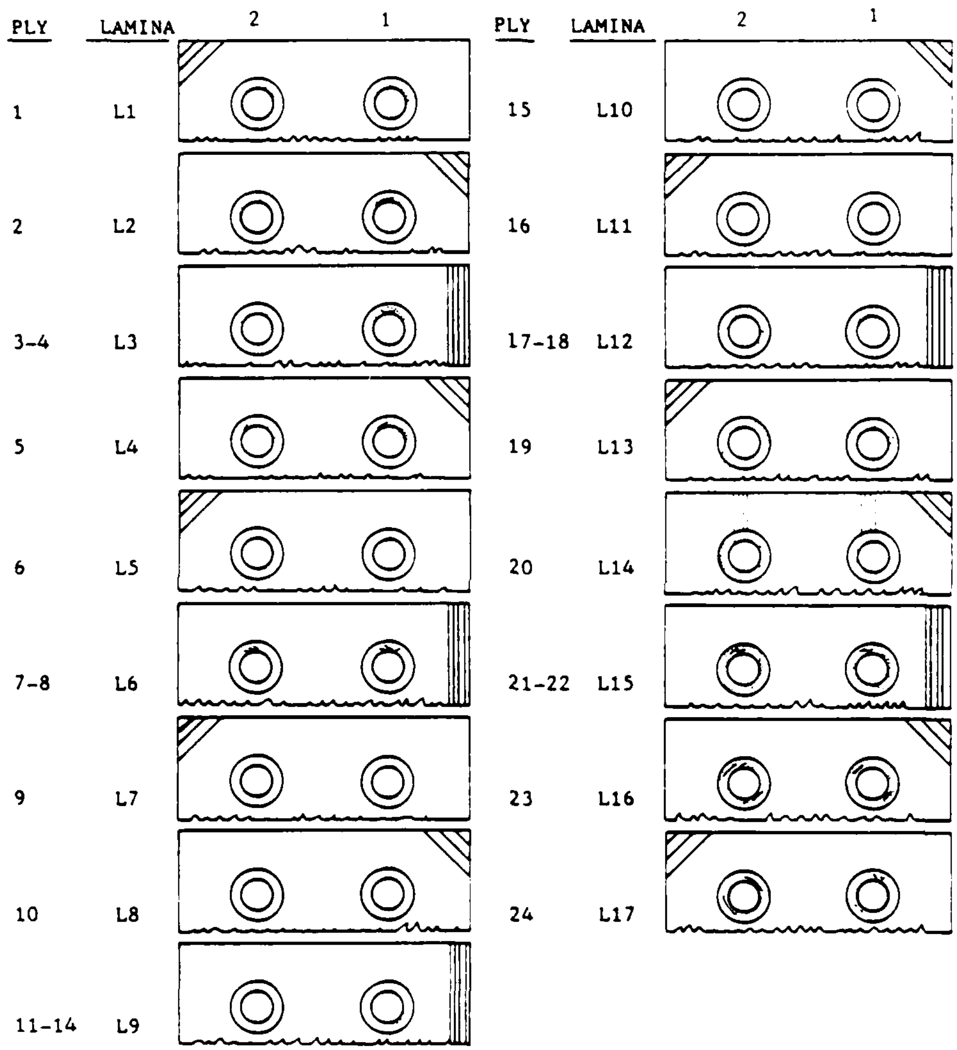


Figure D-45. Lamina Damage Characterization Chart for Specimen

IIA-A-1 Strap B Load Level D

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - B

POUNDS LOAD - 7038 PERCENT OF ULTIMATE - 85

FIGURE D-46. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, AND TEST LOAD FOR SPECIMEN IIA-A-2.

BEFORE LOADING AFTER LOADING

FIGURE D-47. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-2.

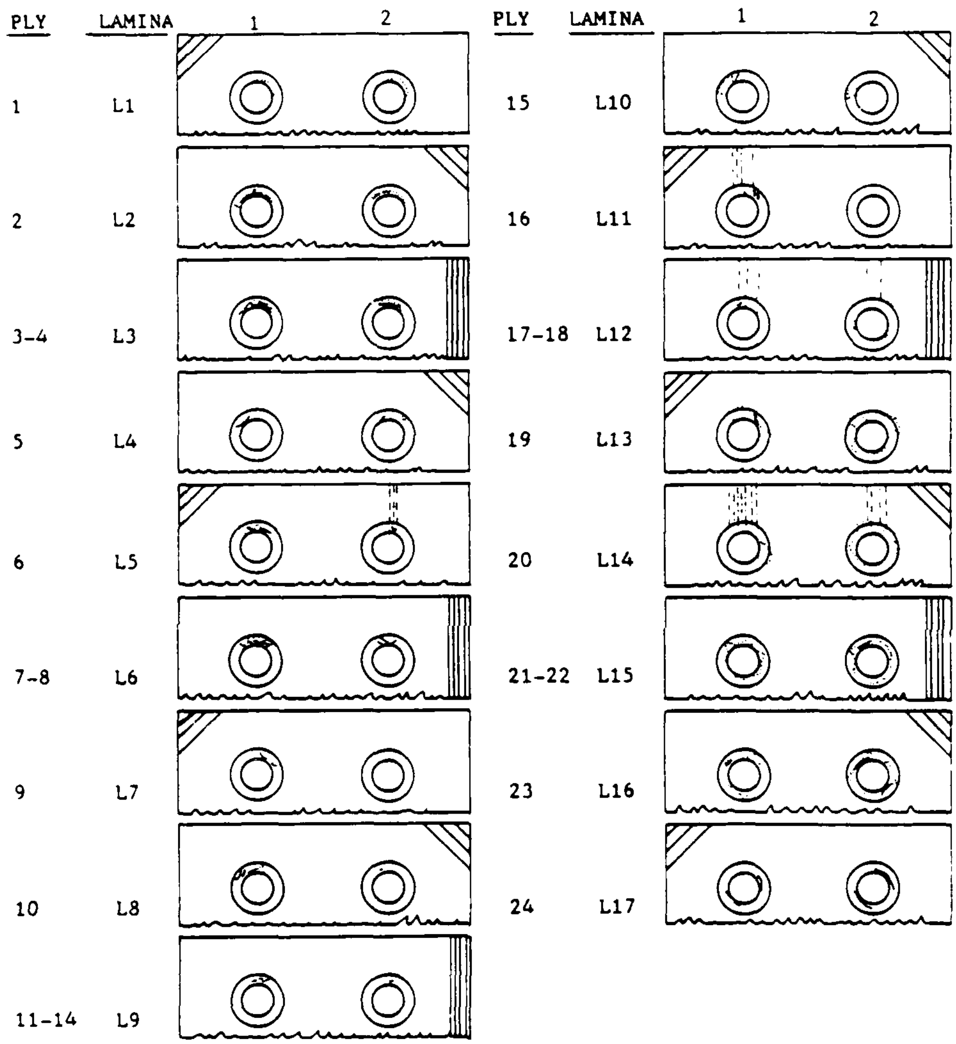


Figure D-48. Lamina Damage Characterization Chart for Specimen

IIA-A-2 Strap B Load Level B

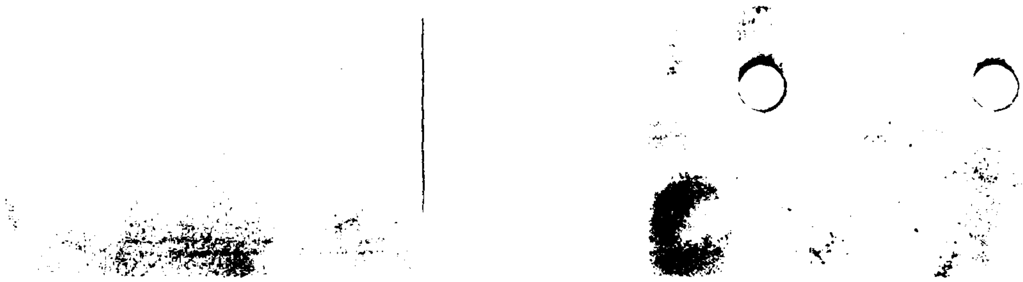
SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, $0_2{}^{\circ}$, $\mp 45^{\circ}$, $0_2{}^{\circ}$, $\pm 45^{\circ}$, $0_2{}^{\circ}$)s

LOAD LEVEL - B

POUNDS LOAD - 7038 PERCENT OF ULTIMATE - 85

FIGURE D-49. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, AND TEST LOAD FOR SPECIMEN IIA-A-6.



BEFORE LOADING AFTER LOADING

FIGURE D-50. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-6.

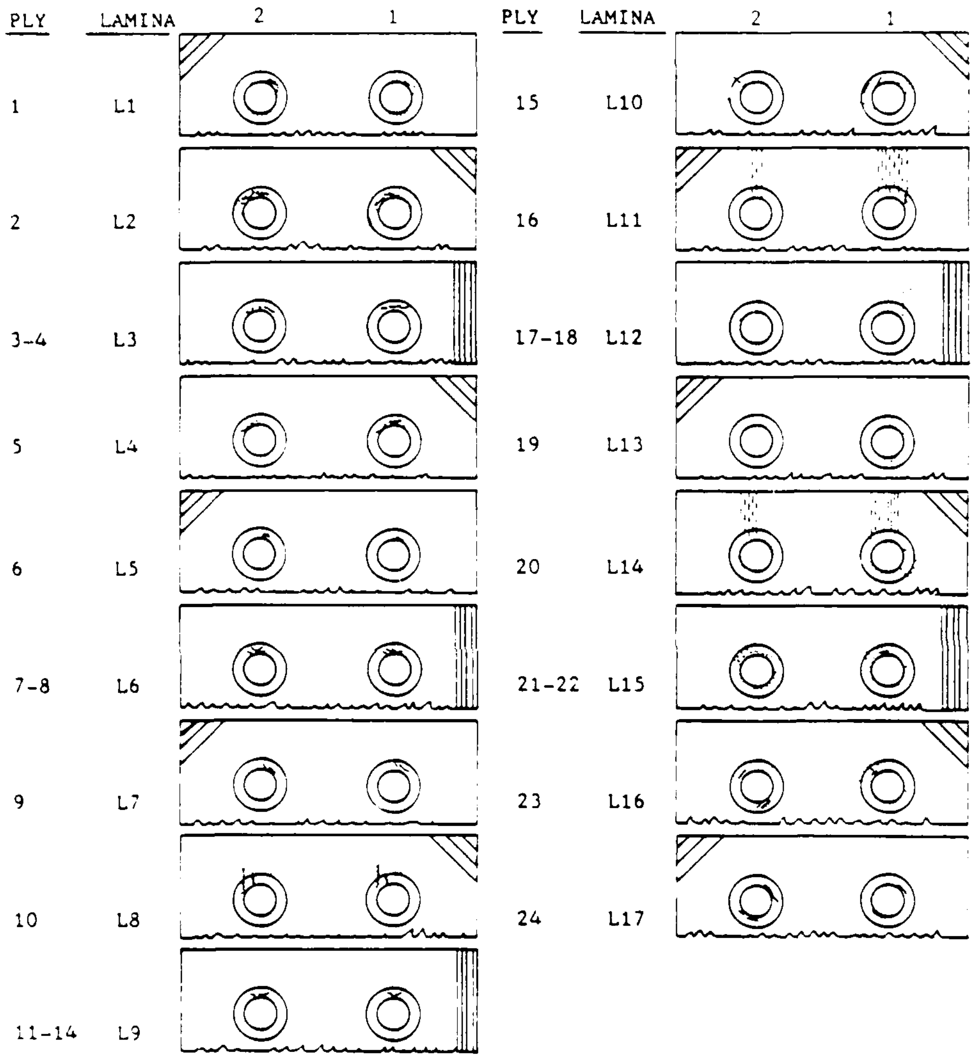


Figure D-51. Lamina Damage Characterization Chart for Specimen IIA-A-6 Strap A Load Level B

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - A($\pm 45^\circ$, 0_2°, $\mp 45^\circ$, 0_2°, $\pm 45^\circ$, 0_2°)s

LOAD LEVEL - B

POUNDS LOAD - 7038 PERCENT OF ULTIMATE - 85

FIGURE D-52. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, AND TEST LOAD FOR SPECIMEN IIA-A-11.

BEFORE LOADING AFTER LOADING

FIGURE D-53. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-11.

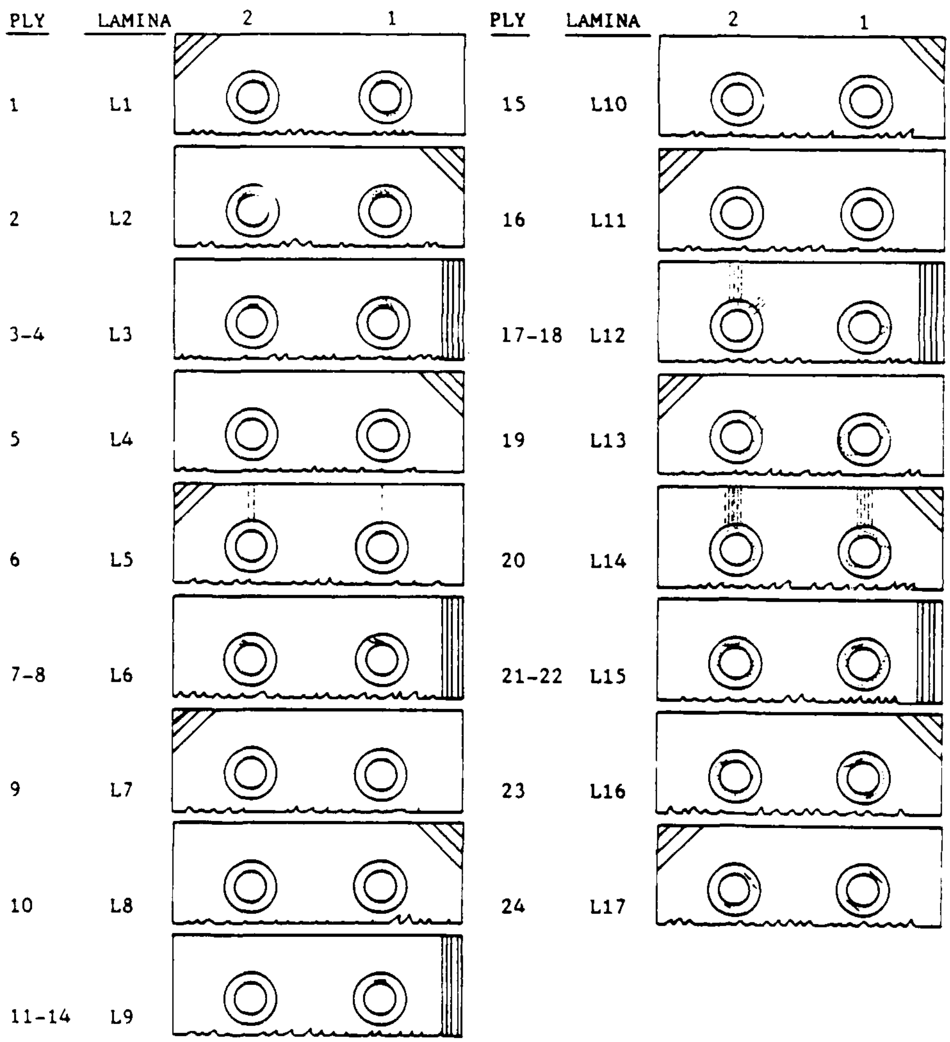


Figure D-54. Lamina Damage Characterization Chart for Specimen

IIA-A-11 Strap A Load Level B

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - $A(\pm45^{\circ}, 0_2^{\circ}, \mp45^{\circ}, 0_2^{\circ}, \pm45^{\circ}, 0_2^{\circ})s$

LOAD LEVEL - B

POUNDS LOAD - 7038 PERCENT OF ULTIMATE - 85

FIGURE D-55. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE, AND TEST LOAD FOR SPECIMEN IIA-A-10.

BEFORE LOADING AFTER LOADING

FIGURE D-56. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-10.

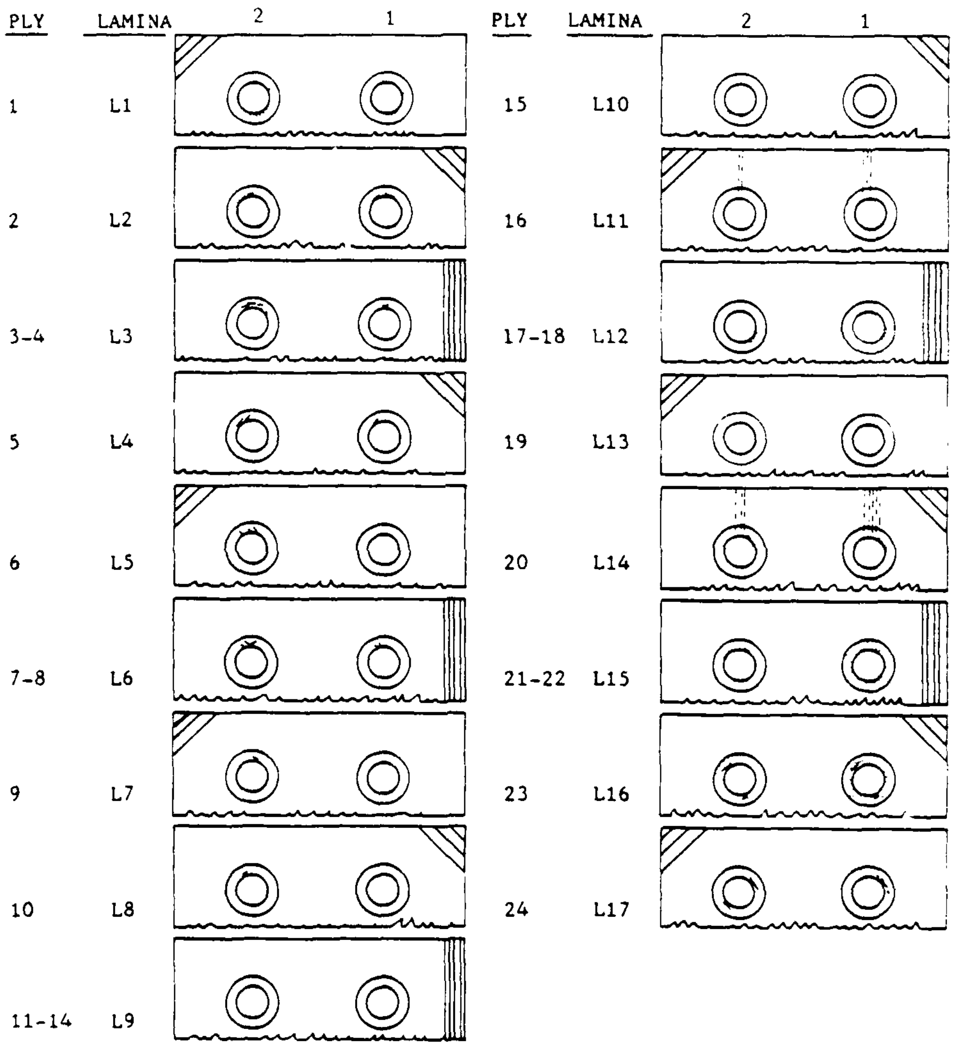


Figure D-57. Lamina Damage Characterization Chart for Specimen
IIA-A-10 Strap A Load Level B

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - B

POUNDS LOAD - 7038 PERCENT OF ULTIMATE - 85

FIGURE D-58. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-A-27.

BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE D-59. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-A-27.

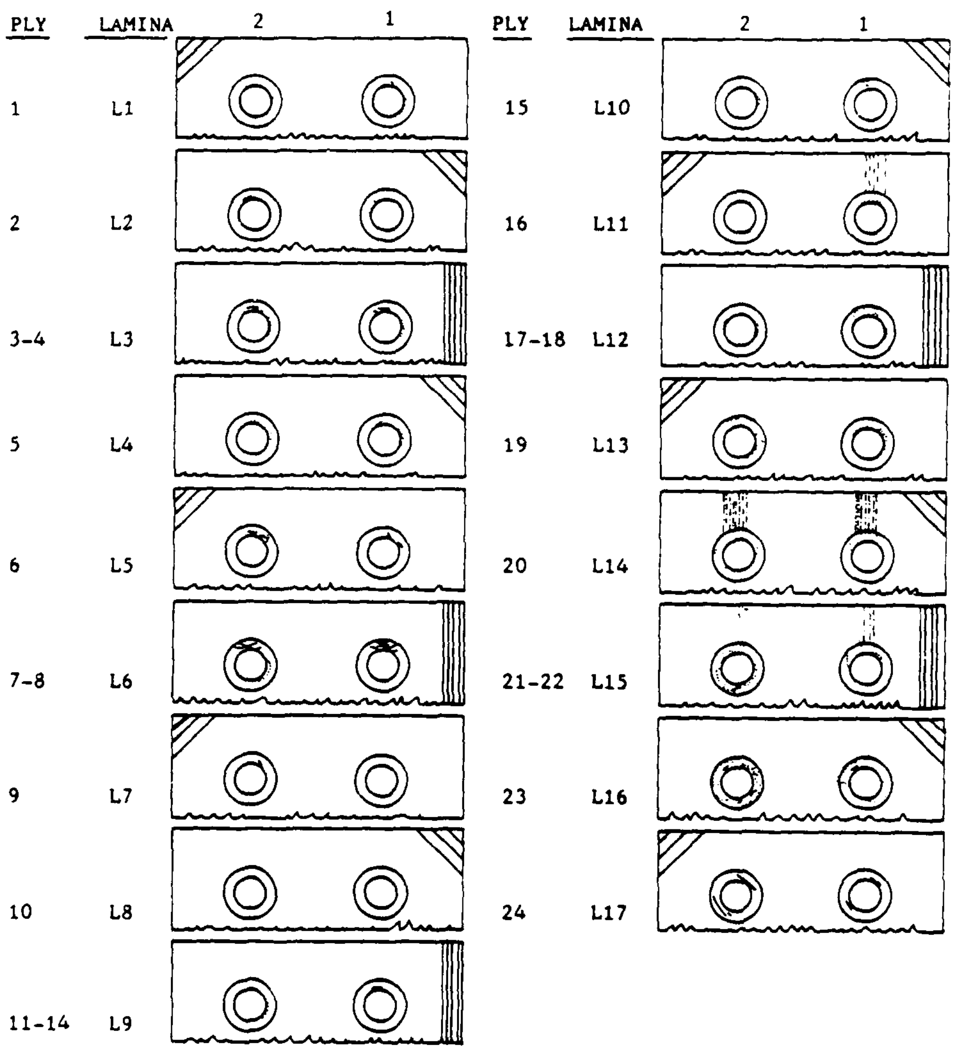
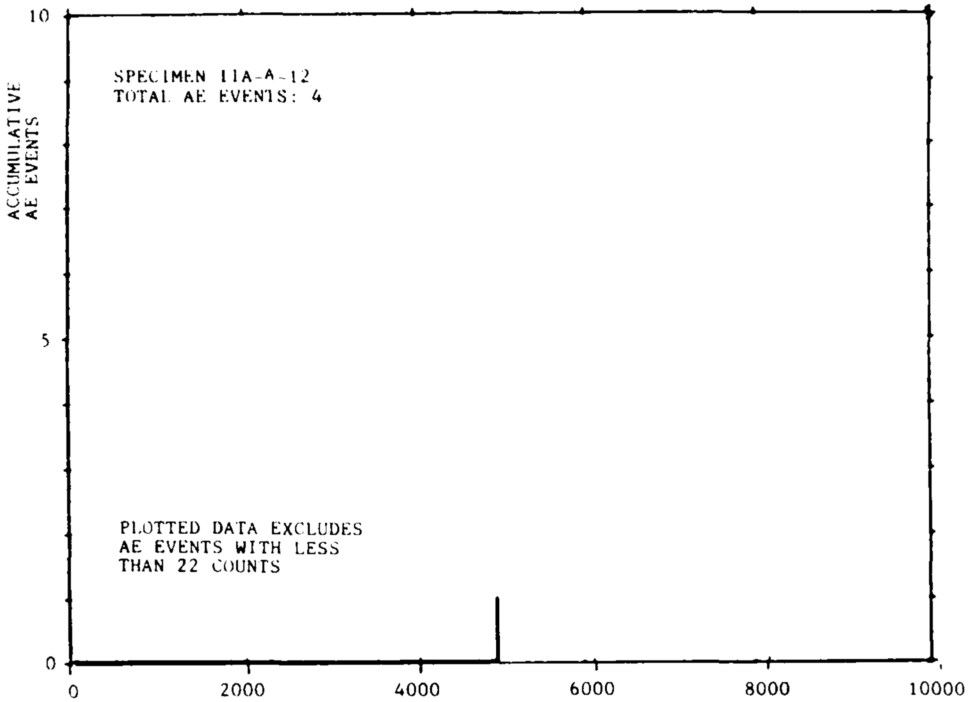


Figure D-60. Lamina Damage Characterization Chart for Specimen IIA-A-27 Strap A Load Level B



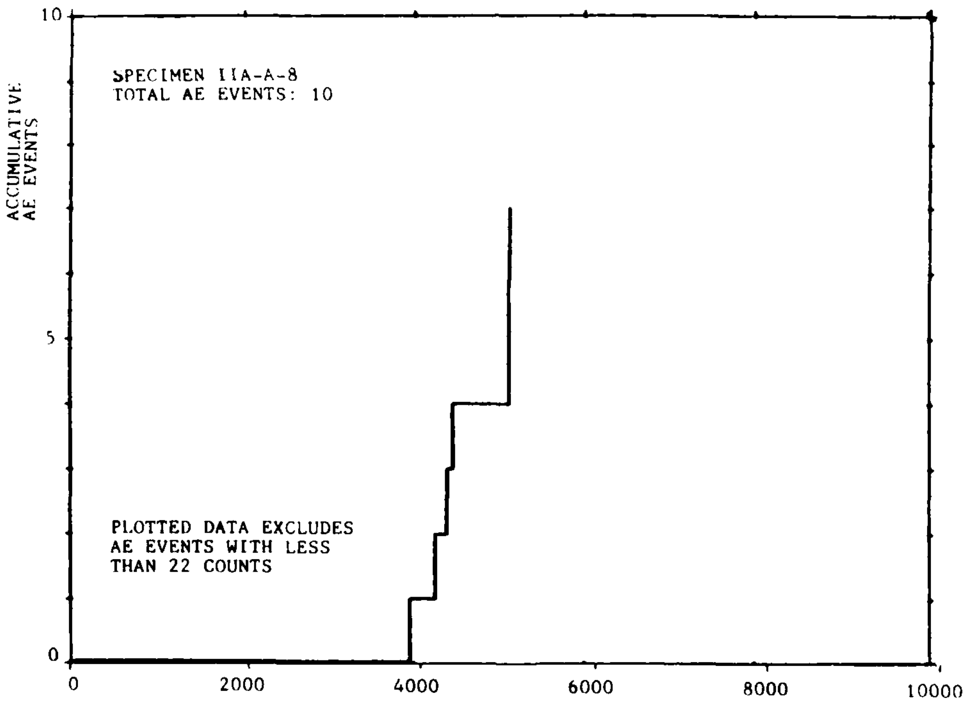
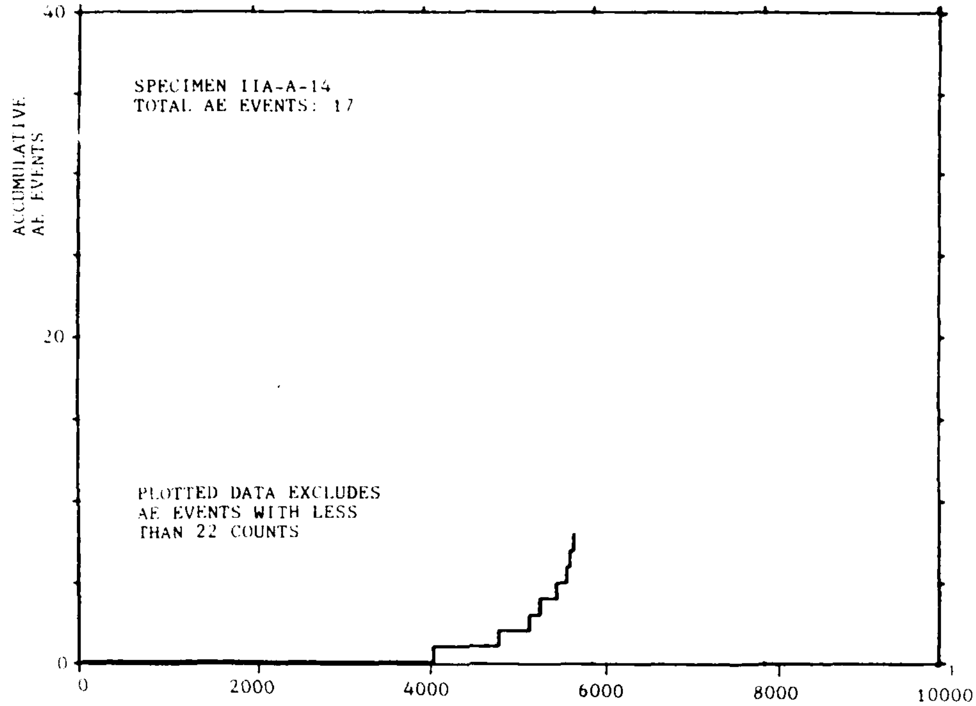


Figure D-61. Plots of Accumulative AE Events vs Applied Load for Type IIA-A Specimens with Minimum and Maximum Response for Load Level A.



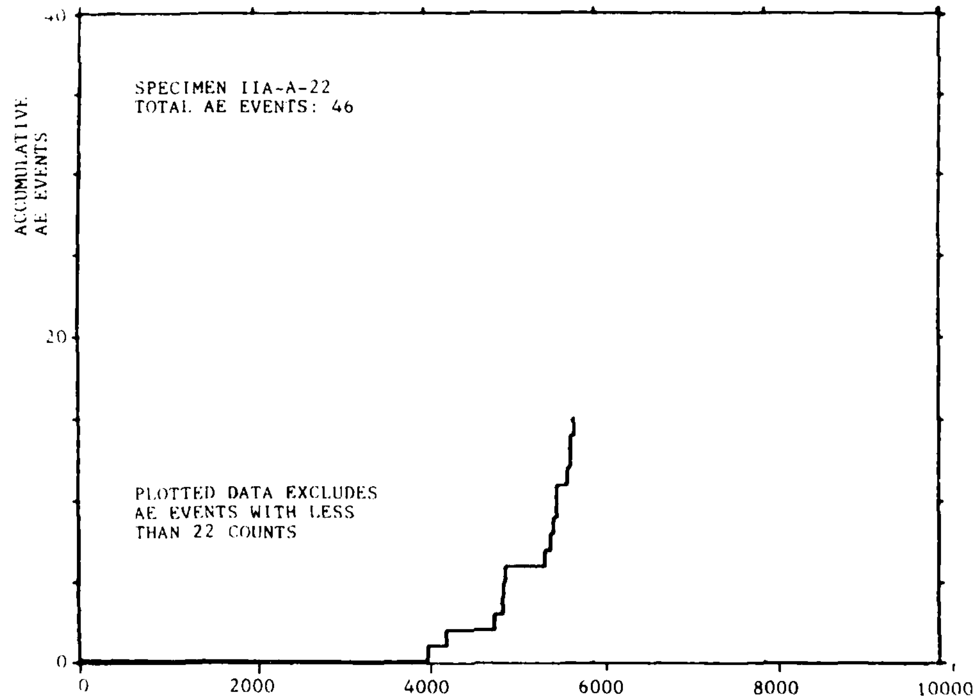
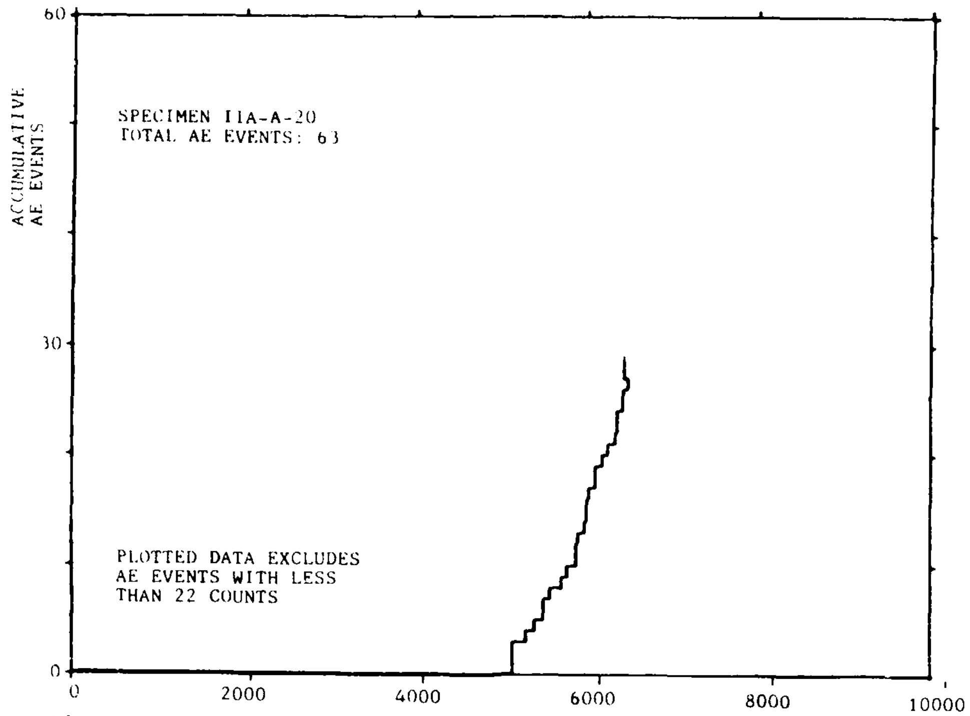


Figure D-62. Plots of Accumulative AE Events vs Applied Load for Type IIA-A Specimens with Minimum and Maximum Response for Load Level C.



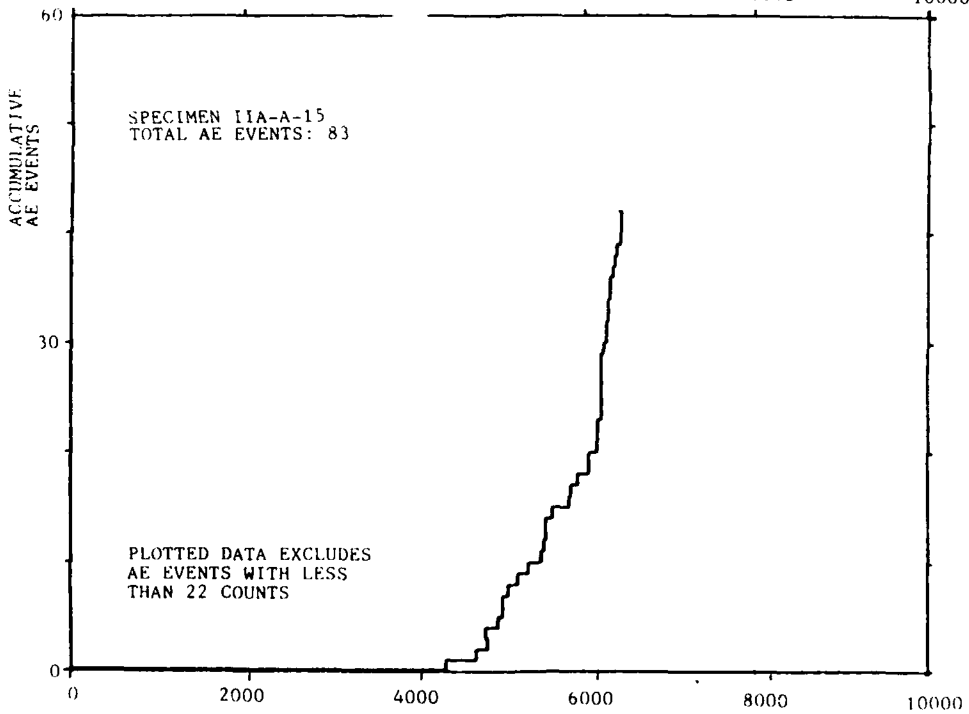


Figure D-63. Plots of Accumulative AE Events vs Applied Load for Type IIA-A Specimens with Minimum and Maximum Response for Load Level D.

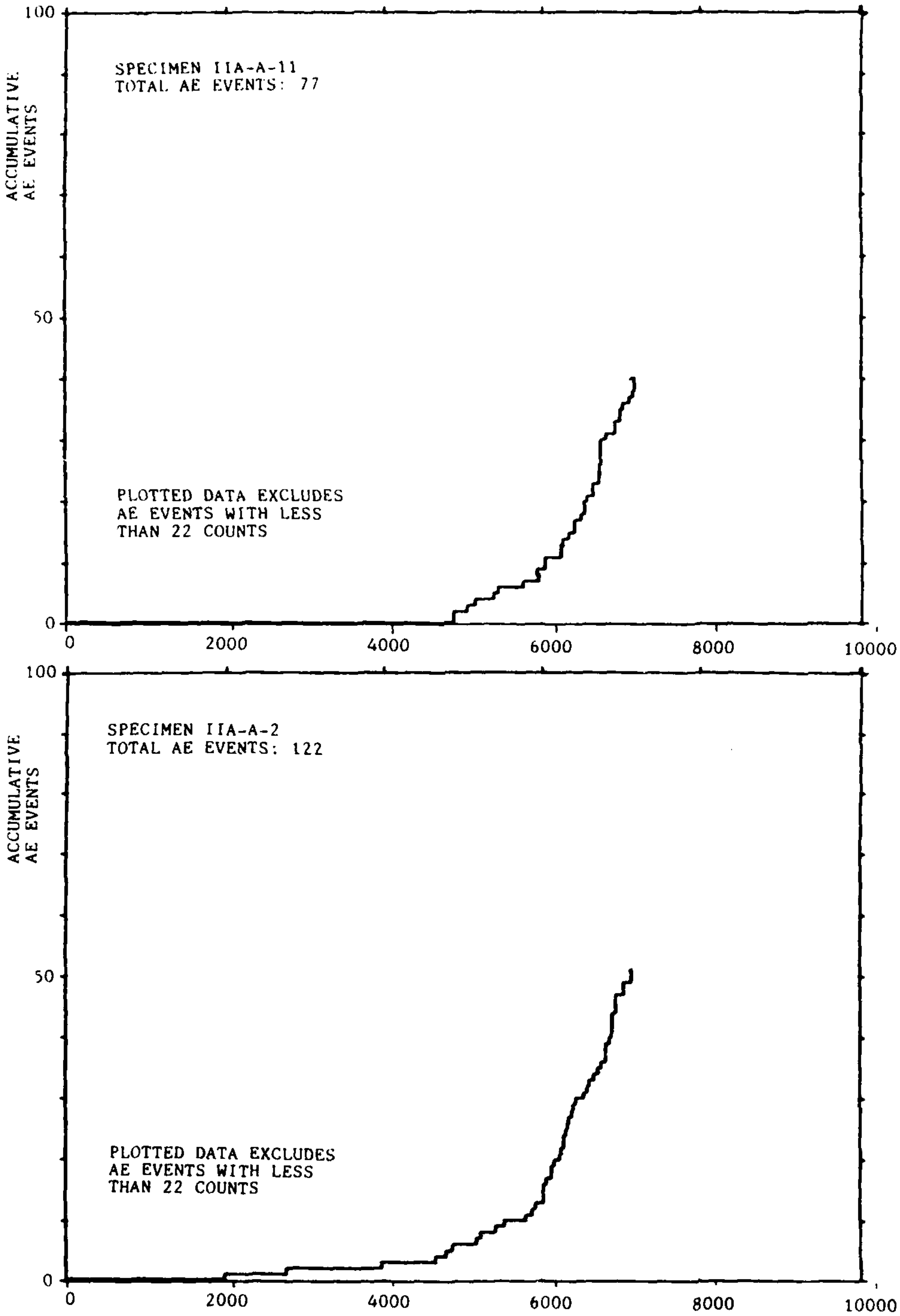


Figure D-64. Plots of Accumulative AE Events vs Applied Load for Type IIA-A Specimens with Minimum and Maximum Response for Load Level B.

APPENDIX E

DETAIL DAMAGE INFORMATION FOR TYPE IIA-B SPECIMENS

The detail information for the Type IIA specimens of Laminate B is presented in this appendix. It is presented in the order of increasing load levels. All specimens of the same load level are grouped together. Three figures are presented for each specimen. The first figure gives specimen type, laminate information and load conditions. The second figure consists of positive prints of enhanced x-ray radiographs made before and after loading. In addition, prints of a stereo x-ray pair are included for one specimen of each load level. The third figure consists of a Lamina Damage Characterization Chart. This chart contains a pictorial sketch for each lamina with fiber orientations indicated on one side or edge of each sketch. Also an outline of the fastener head is shown on these sketches to provide a visual reference as to the magnitude of the damage. The damage observed on each lamina is recorded on the appropriate sketch in a manner to indicate size and location relative to the fastener hole. As shown in these charts lamina No. 1 was adjacent to the joint interface and lamina No. 9 was adjacent to the fastener head.

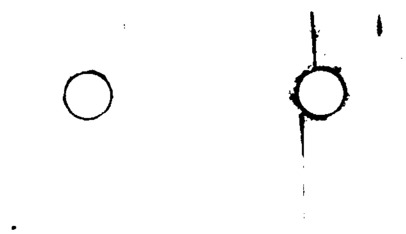
SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm45^\circ$, $\mp45^\circ$, $\pm45^\circ$, $0_6{}^\circ$)s

LOAD LEVEL - A

POUNDS LOAD - 3100 PERCENT OF ULTIMATE - 59

FIGURE E-1. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-9.



BEFORE LOADING AFTER LOADING

FIGURE E-2. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-9.

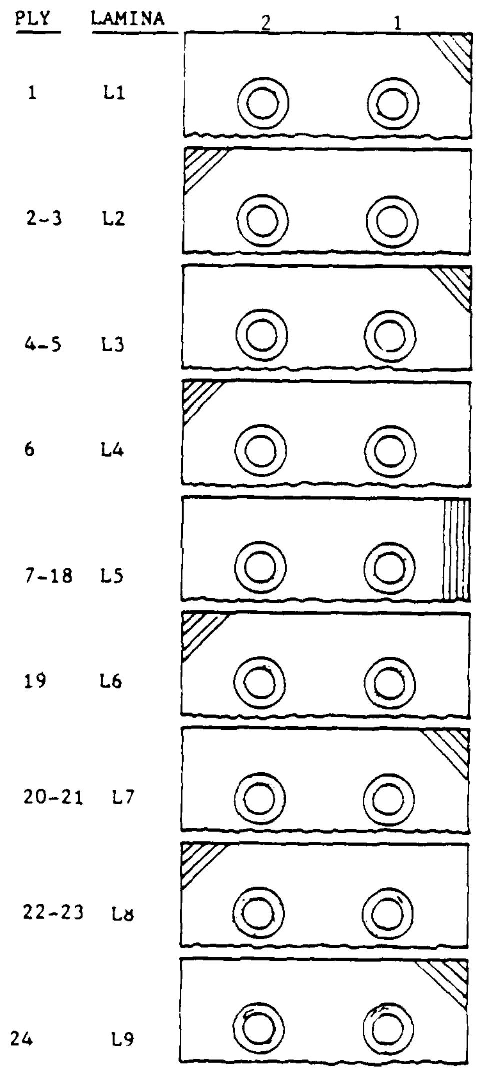


Figure E-3. Lamina Damage Characterization Chart for Specimen IIA-B-9 Strap A Load Level A

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm 45^{\circ}$, $\mp 45^{\circ}$, $\pm 45^{\circ}$, 0_6°)s

LOAD LEVEL - A

POUNDS LOAD - 3100 PERCENT OF ULTIMATE - 59

FIGURE E-4. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-18.

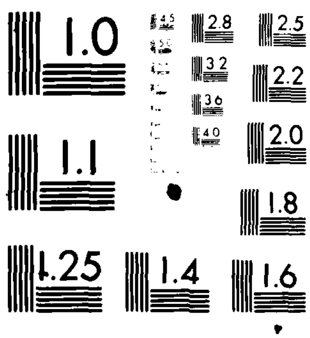
BEFORE LOADING AFTER LOADING

FIGURE E-5. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-18.

AD-A116 120 LOCKHEED-GEORGIA CO MARIETTA F/G 11/4
DAMAGE PROGRESSION IN GRAPHITE-EPOXY BY A DEPLYING TECHNIQUE.(U)
DEC 81 S M FREEMAN F33615-80-C-3224
UNCLASSIFIED LG-81ER0245 AFWAL-TR-81-3157 NL

4 of 6
AD
A116120

116120



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

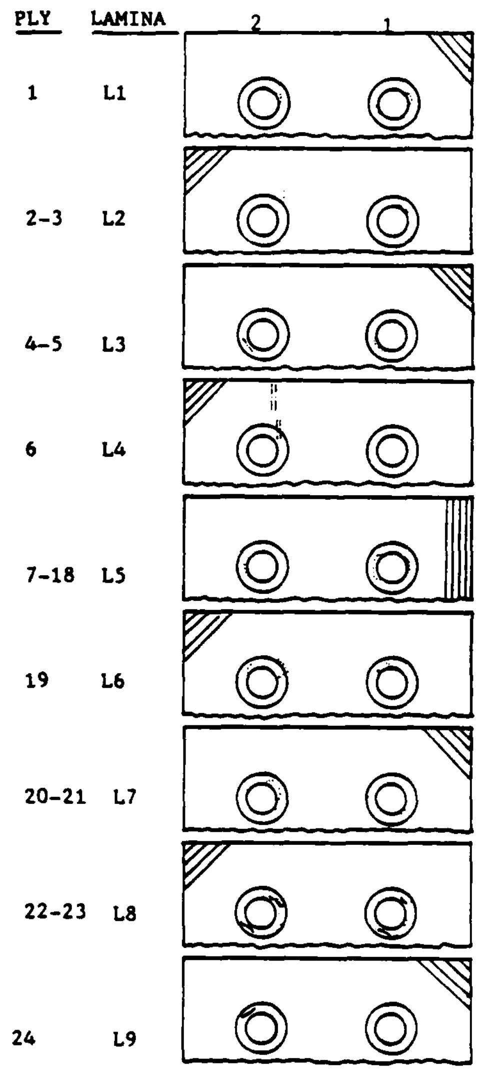


Figure E-6. Lamina Damage Characterization Chart for Specimen IIA-B-18 Strap A Load Level A

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm 45^{\circ}$, $\mp 45^{\circ}$, $\pm 45^{\circ}$, $0_6{}^{\circ}$)s

LOAD LEVEL - A

POUNDS LOAD - 3100 PERCENT OF ULTIMATE - 59

FIGURE E-7. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-12.

BEFORE LOADING AFTER LOADING

FIGURE E-8. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-12.

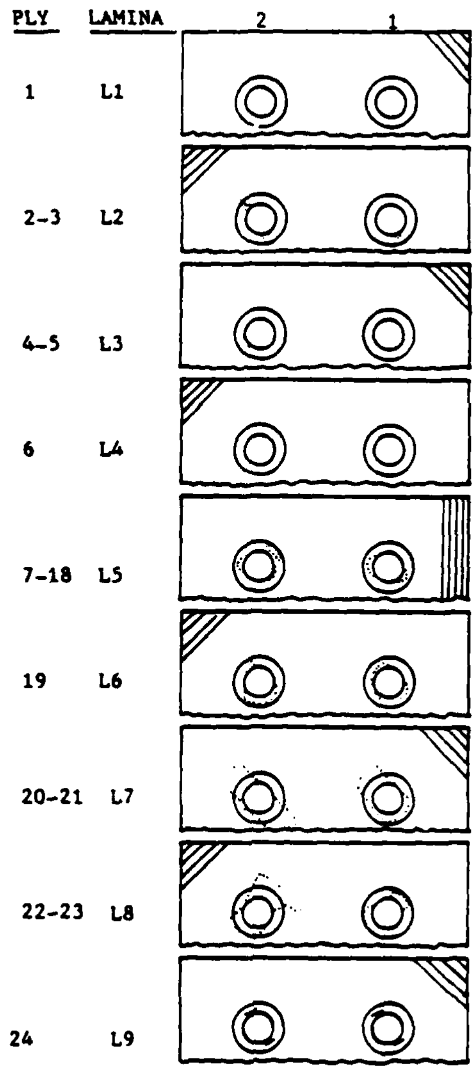


Figure E-9. Lamina Damage Characterization Chart for Specimen IIA-B- 12 Strap A Load Level A

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm 45^{\circ}$, $\mp 45^{\circ}$, $\pm 45^{\circ}$, 0_6°)s

LOAD LEVEL - A

POUNDS LOAD - 3100 PERCENT OF ULTIMATE - 59

FIGURE E-10. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-8.

BEFORE LOADING AFTER LOADING

FIGURE E-11. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-8.

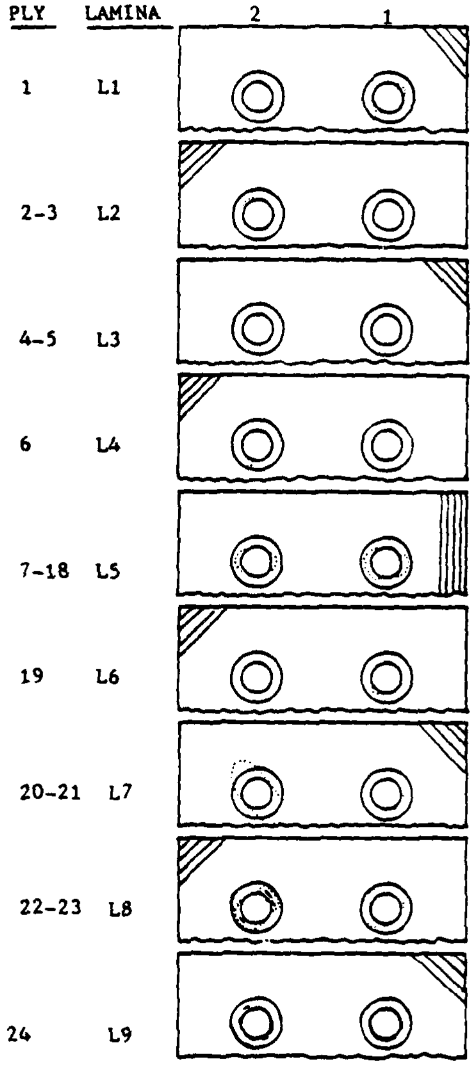


Figure E-12. Lamina Damage Characterization Chart for Specimen IIA-B-8 Strap A Load Level A

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm 45^\circ$, $\mp 45^\circ$, $\pm 45^\circ$, 0_6°)s

LOAD LEVEL - A

POUNDS LOAD - 3100 PERCENT OF ULTIMATE - 59

FIGURE E-13. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-3.

BEFORE LOADING

AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE E-14. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-3.

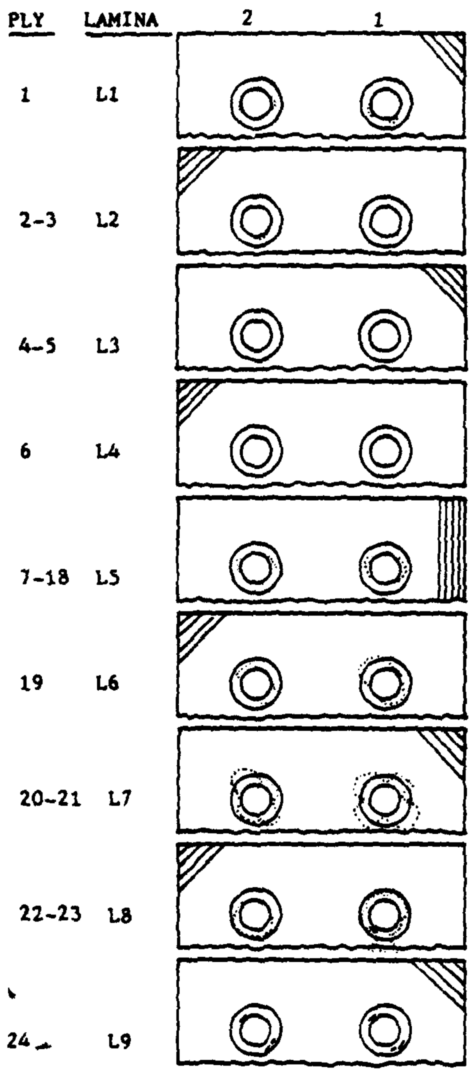


Figure E-15. Lamina Damage Characterization Chart for Specimen IIA-8-3 Strap A Load Level A

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm45^{\circ}$, $\mp45^{\circ}$, $\pm45^{\circ}$, $0_6{}^{\circ}$)s

LOAD LEVEL - C

POUNDS LOAD - 3639 PERCENT OF ULTIMATE - 69

FIGURE E-16. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-14.

BEFORE LOADING AFTER LOADING

FIGURE E-17. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-14.

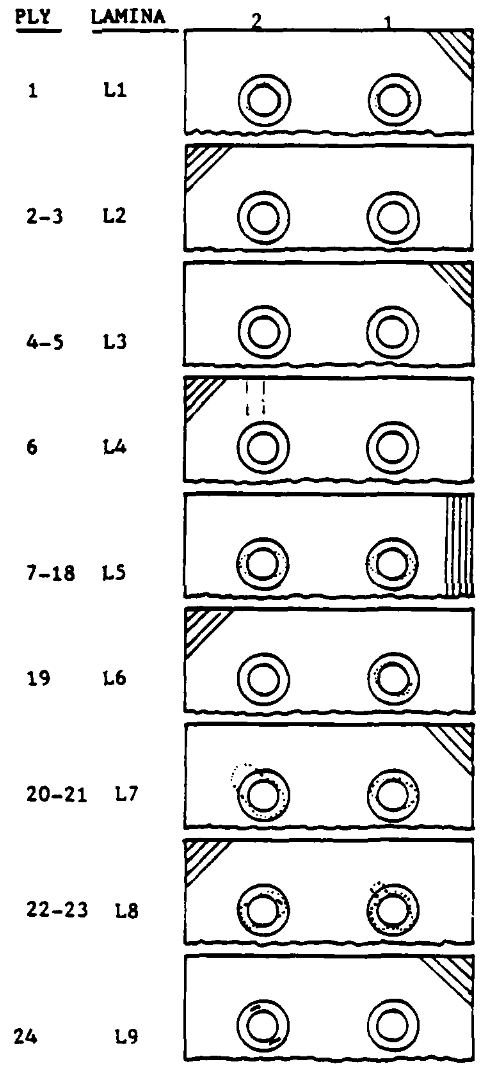


Figure E-18. Lamina Damage Characterization Chart for Specimen
IIA-B-14 Strap A Load Level C

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm 45^\circ$, $\mp 45^\circ$, $\pm 45^\circ$, $0_6{}^\circ$)s

LOAD LEVEL - C

POUNDS LOAD - 3639 PERCENT OF ULTIMATE - 69

FIGURE E-19. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-21.

BEFORE LOADING AFTER LOADING

FIGURE E-20. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-21.

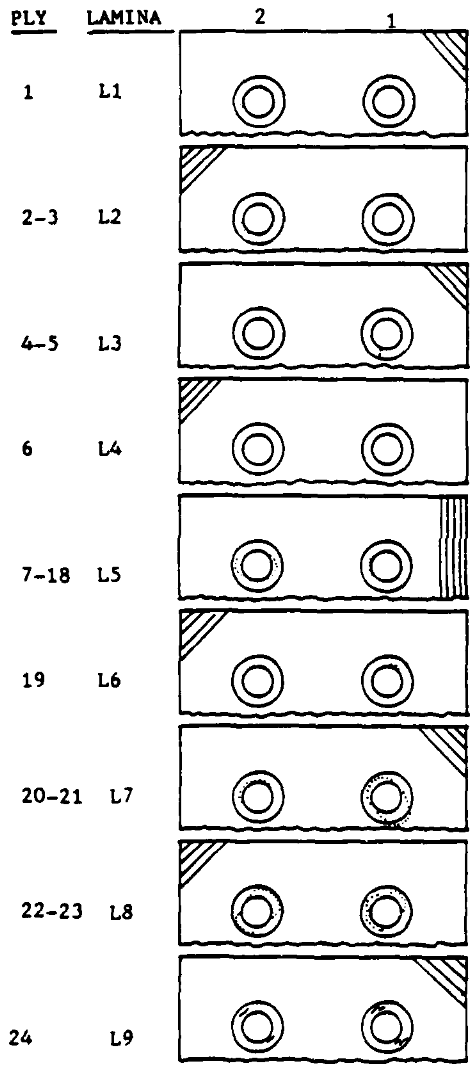


Figure E-21. Lamina Damage Characterization Chart for Specimen IIA-B-21 Strap A Load Level C

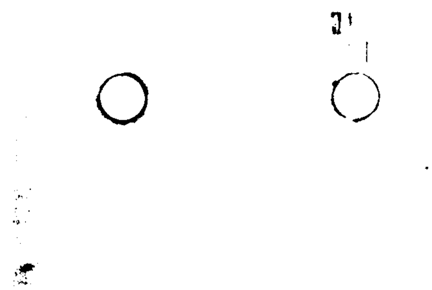
SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm45^\circ$, $\mp45^\circ$, $\pm45^\circ$, $0_6{}^\circ$)s

LOAD LEVEL - C

POUNDS LOAD - 3639 PERCENT OF ULTIMATE - 69

FIGURE E-22. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-16.



BEFORE LOADING AFTER LOADING

FIGURE E-23. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-16.

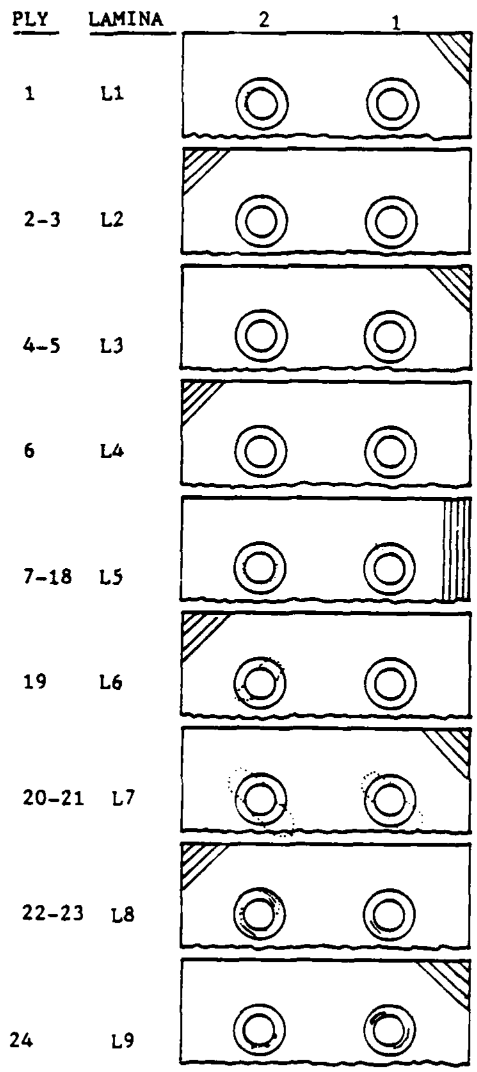


Figure E-24. Lamina Damage Characterization Chart for Specimen IIA-B-16 Strap A Load Level C

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm45^\circ$, $\mp45^\circ$, $\pm45^\circ$, $0_6{}^\circ$)s

LOAD LEVEL - C

POUNDS LOAD - 3639 PERCENT OF ULTIMATE - 69

FIGURE E-25. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-22.

BEFORE LOADING AFTER LOADING

FIGURE E-26. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-22.

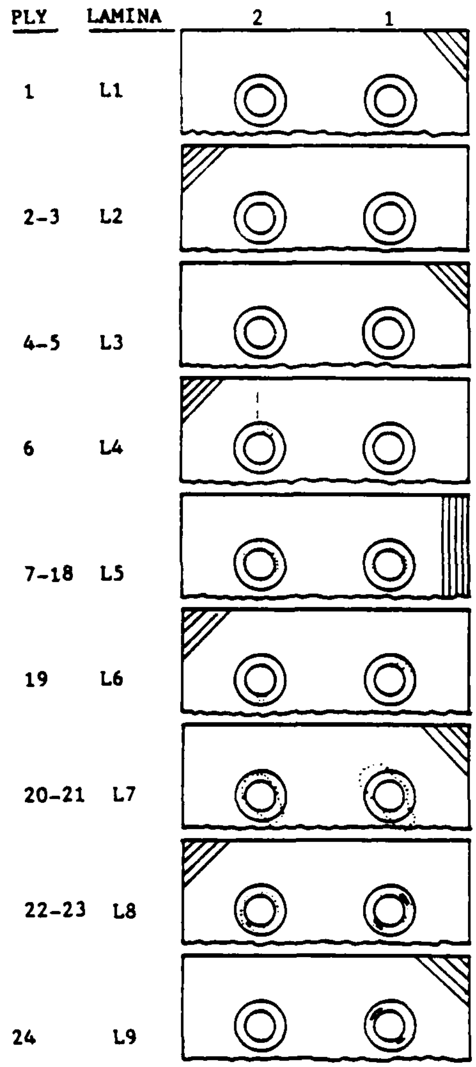


Figure E-27. Lamina Damage Characterization Chart for Specimen IIA-B-22 Strap B Load Level C

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm45^\circ$, $\mp45^\circ$, $\pm45^\circ$, 0_6°)s

LOAD LEVEL - C

POUNDS LOAD - 3639 PERCENT OF ULTIMATE - 69

FIGURE E-28. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-24.

BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE E-29. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-24.

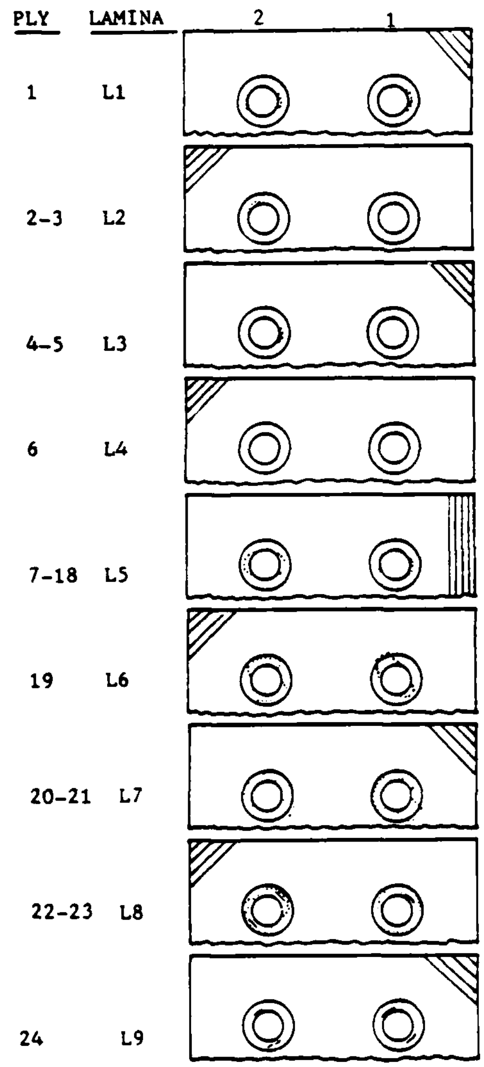


Figure E-30. Lamina Damage Characterization Chart for Specimen IIA-B-24 Strap A Load Level C

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm 45^{\circ}$, $\mp 45^{\circ}$, $\pm 45^{\circ}$, $0_6{}^{\circ}$)s

LOAD LEVEL - D

POUNDS LOAD - 4166 PERCENT OF ULTIMATE - 79

FIGURE E-31. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-15.

BEFORE LOADING AFTER LOADING

FIGURE E-32. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-15.

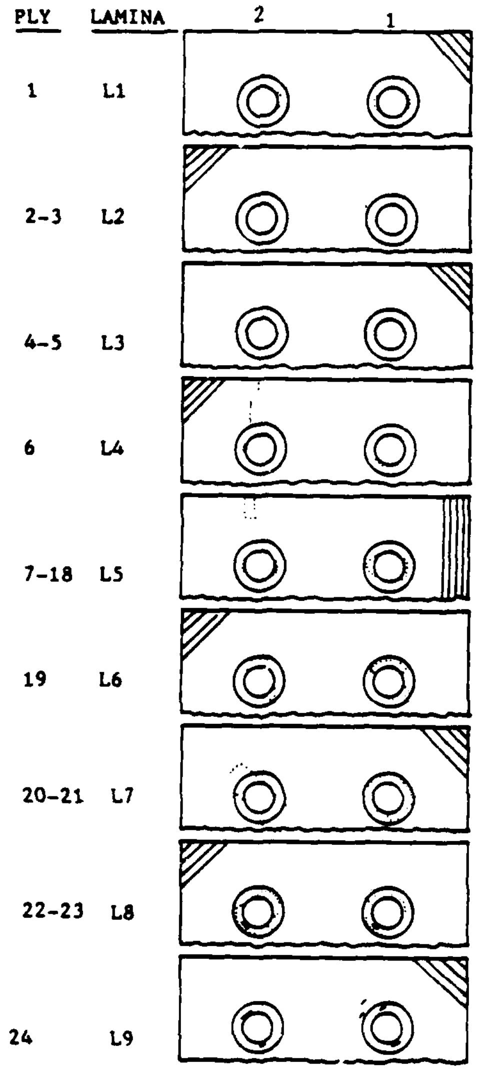


Figure E-33. Lamina Damage Characterization Chart for Specimen IIA-B-15 Strap B Load Level D

SPECIMEN TYPE - IIA (BOLTED JOINT)

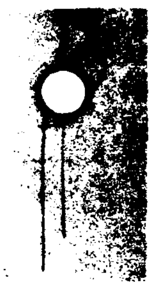
LAMINATE - B($\pm 45^{\circ}$, $\mp 45^{\circ}$, $\pm 45^{\circ}$, 0_5°)s

LOAD LEVEL - D

POUNDS LOAD - 4166 PERCENT OF ULTIMATE - 79

FIGURE E-34. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-20.

BEFORE LOADING



AFTER LOADING

FIGURE E-35. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-20.

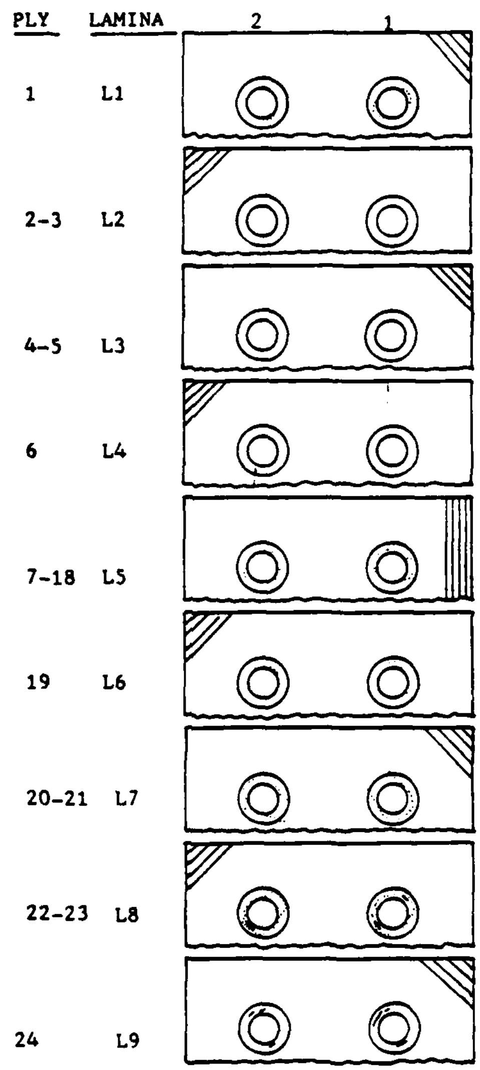


Figure E-36. Lamina Damage Characterization Chart for Specimen IIA-B-20 Strap B Load Level D

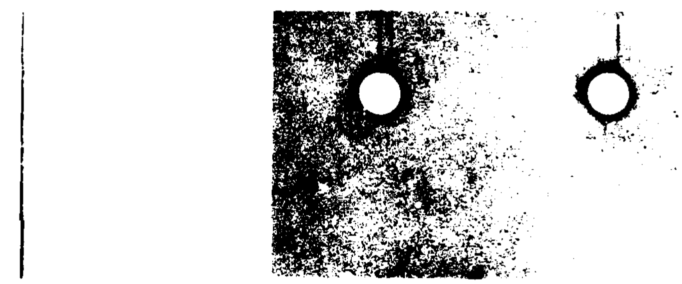
SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - $B(\pm 45^{\circ}, \mp 45^{\circ}, \pm 45^{\circ}, 0_6{}^{\circ})s$

LOAD LEVEL - D

POUNDS LOAD - 4166 PERCENT OF ULTIMATE - 79

FIGURE E-37. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-13.



BEFORE LOADING AFTER LOADING

FIGURE E-38. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-13.

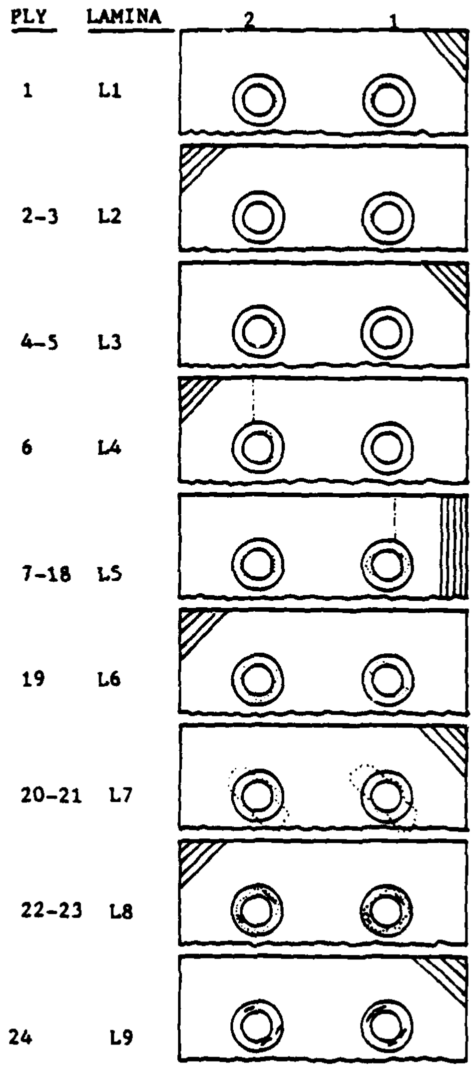


Figure E-39. Lamina Damage Characterization Chart for Specimen IIA-B-13 Strap A Load Level D

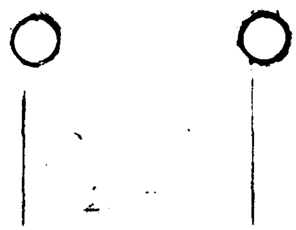
SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm 45^{\circ}$, $\mp 45^{\circ}$, $\pm 45^{\circ}$, $0_6{}^{\circ}$)s

LOAD LEVEL - D

POUNDS LOAD - 4166 PERCENT OF ULTIMATE - 79

FIGURE E-40. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-1.



BEFORE LOADING AFTER LOADING

FIGURE E-41. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-1.

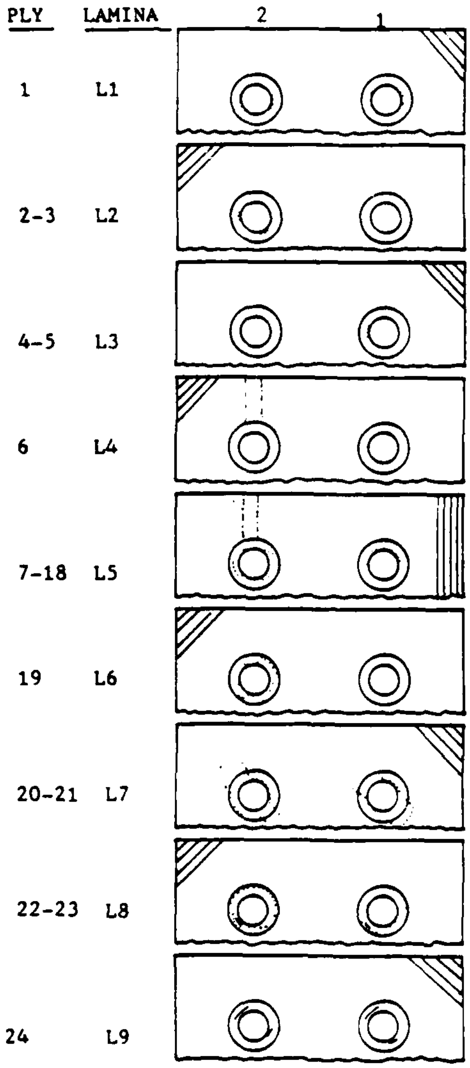


Figure E-42. Lamina Damage Characterization Chart for Specimen IIA-B-1 Strap A Load Level D

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm45^o$, $\mp45^o$, $\pm45^o$, $0_6{}^o$)s

LOAD LEVEL - D

POUNDS LOAD - 4166 PERCENT OF ULTIMATE - 79

FIGURE E-43. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-7.

BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE E-44. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-7.

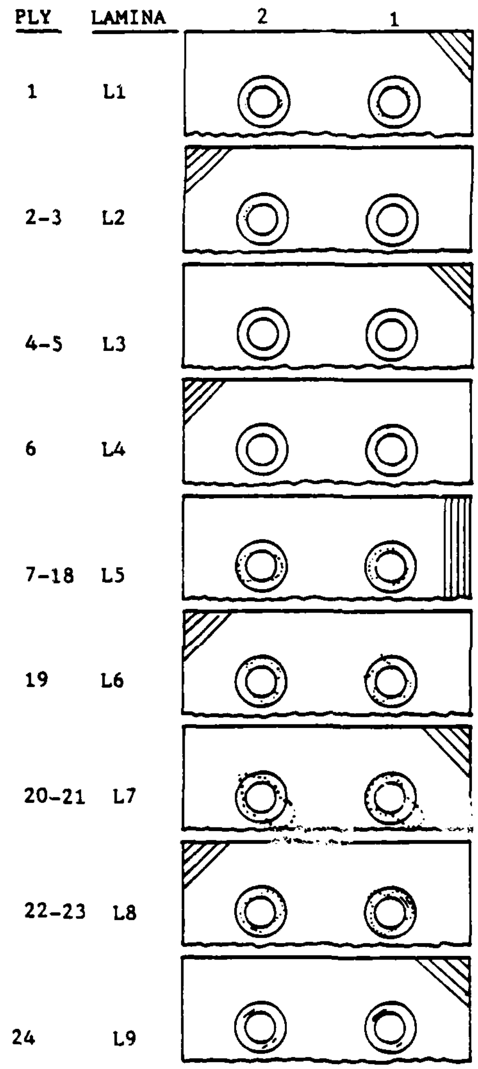


Figure E-45. Lamina Damage Characterization Chart for Specimen IIA-B-7 Strap A Load Level D

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm45^\circ$, $\mp45^\circ$, $\pm45^\circ$, $0_6{}^\circ$)s

LOAD LEVEL - B

POUNDS LOAD - 4642 PERCENT OF ULTIMATE - 88

FIGURE E-46. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-27.

BEFORE LOADING AFTER LOADING

FIGURE E-47. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-27.

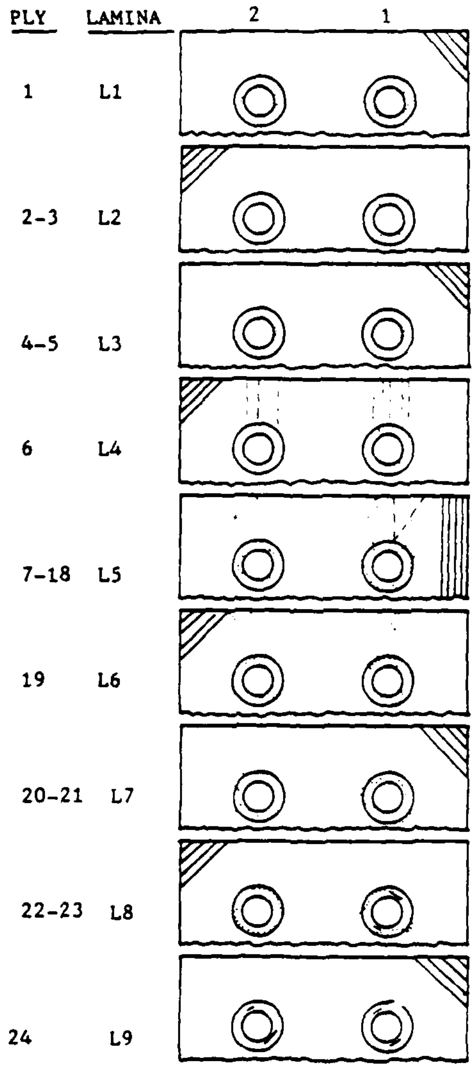


Figure E-48. Lamina Damage Characterization Chart for Specimen IIA-B- 27 Strap A Load Level B

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm45^\circ$, $\mp45^\circ$, $\pm45^\circ$, $0_6{}^\circ$)s

LOAD LEVEL - B

POUNDS LOAD - 4642 PERCENT OF ULTIMATE - 88

FIGURE E-49. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-6.

BEFORE LOADING AFTER LOADING

FIGURE E-50. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-6.

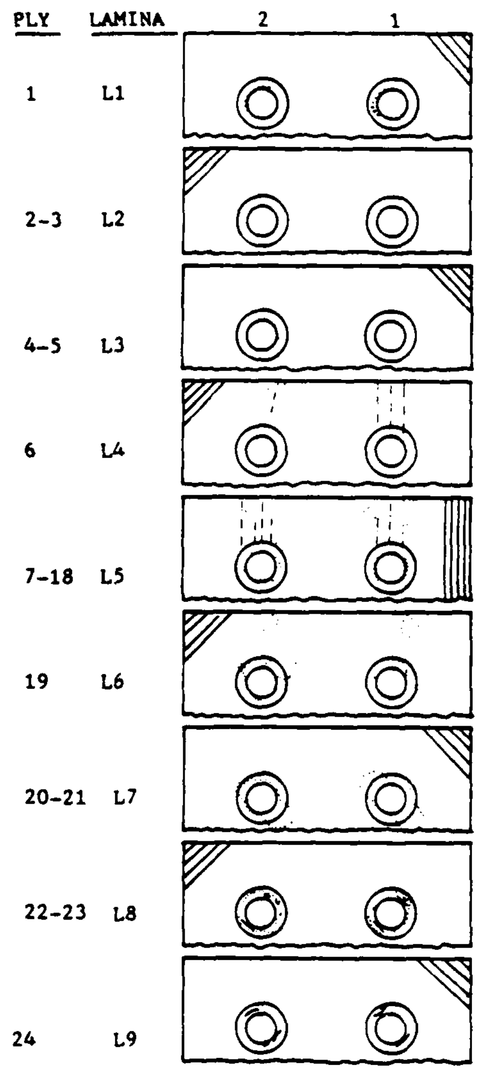


Figure E-51. Lamina Damage Characterization Chart for Specimen IIA-B-6 Strap A Load Level B

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm45^\circ$, $\mp45^\circ$, $\pm45^\circ$, $0_6{}^\circ$)s

LOAD LEVEL - B

POUNDS LOAD - 4642 PERCENT OF ULTIMATE - 88

FIGURE E-52. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-11.

BEFORE LOADING AFTER LOADING

FIGURE E-53. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-11.

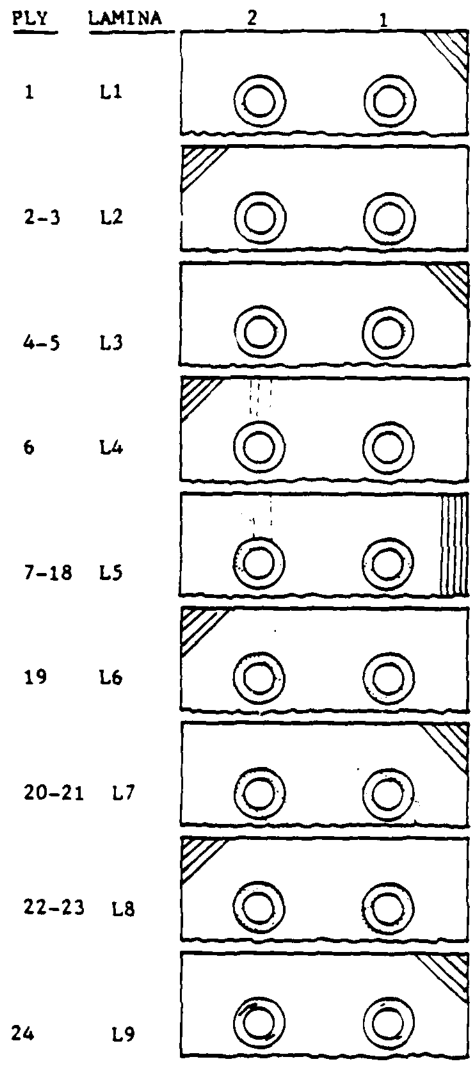


Figure E-54. Lamina Damage Characterization Chart for Specimen

IIA-B-11 Strap B Load Level B

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - B($\pm 45^\circ$, $\mp 45^\circ$, $\pm 45^\circ$, $0_6{}^\circ$)s

LOAD LEVEL - B

POUNDS LOAD - 4642 PERCENT OF ULTIMATE - 88

FIGURE E-55. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-10.

BEFORE LOADING AFTER LOADING

FIGURE E-56. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-10.

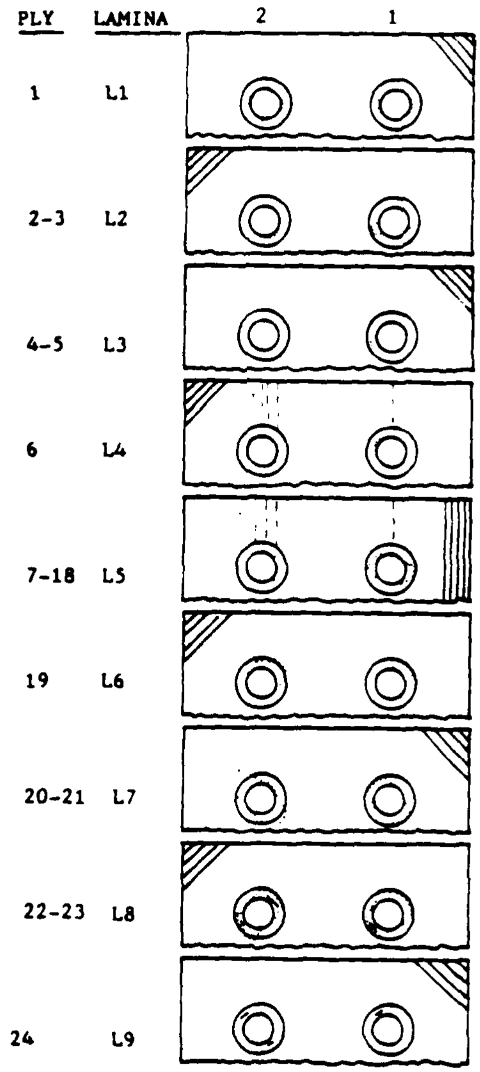


Figure E-57. Lamina Damage Characterization Chart for Specimen IIA-B- 10 Strap A Load Level B

SPECIMEN TYPE - IIA (BOLTED JOINT)

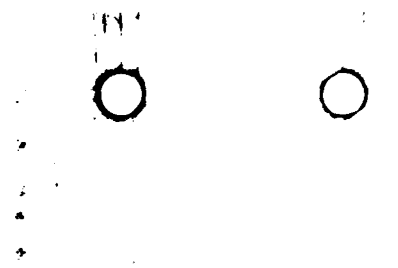
LAMINATE - B($\pm45^{\circ}$, $\mp45^{\circ}$, $\pm45^{\circ}$, 0_6°)s

LOAD LEVEL - B

POUNDS LOAD - 4642 PERCENT OF ULTIMATE - 88

FIGURE E-58. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-B-2.

BEFORE LOADING



AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE E-59. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-B-2.

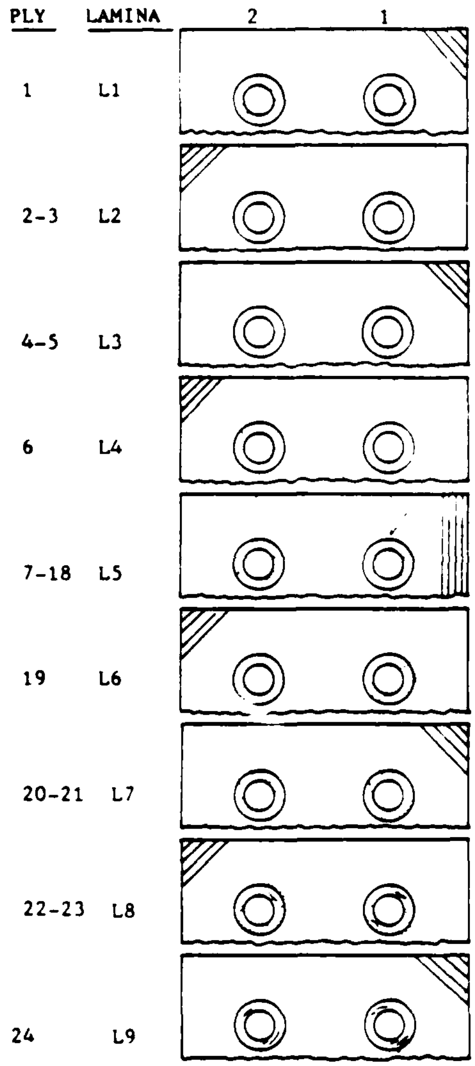
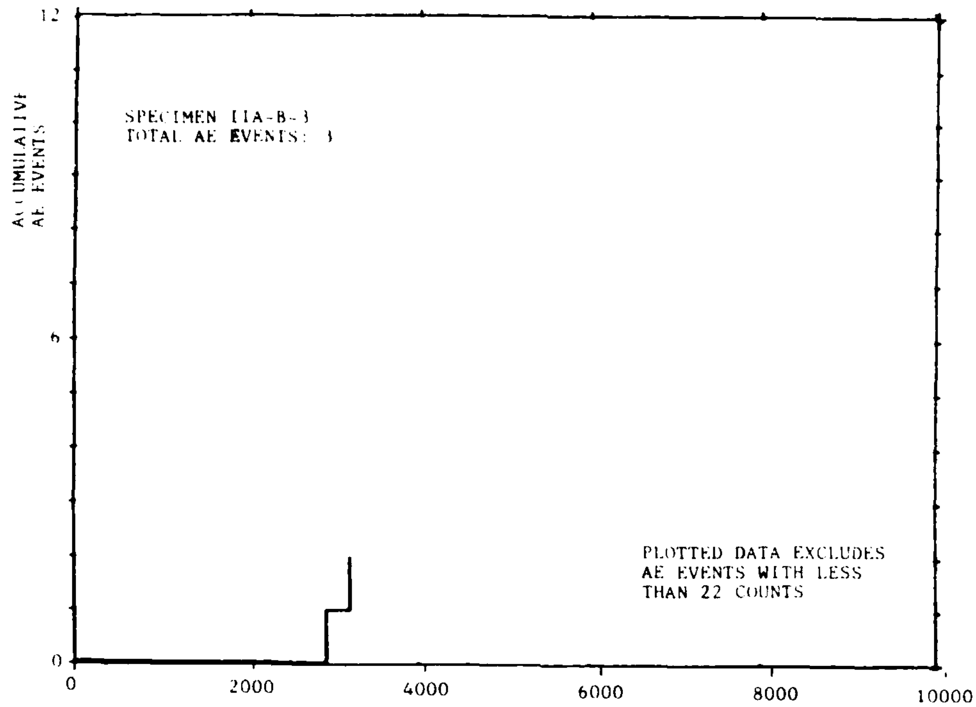


Figure E-60. Lamina Damage Characterization Chart for Specimen IIA-B-2 Strap A Load Level B



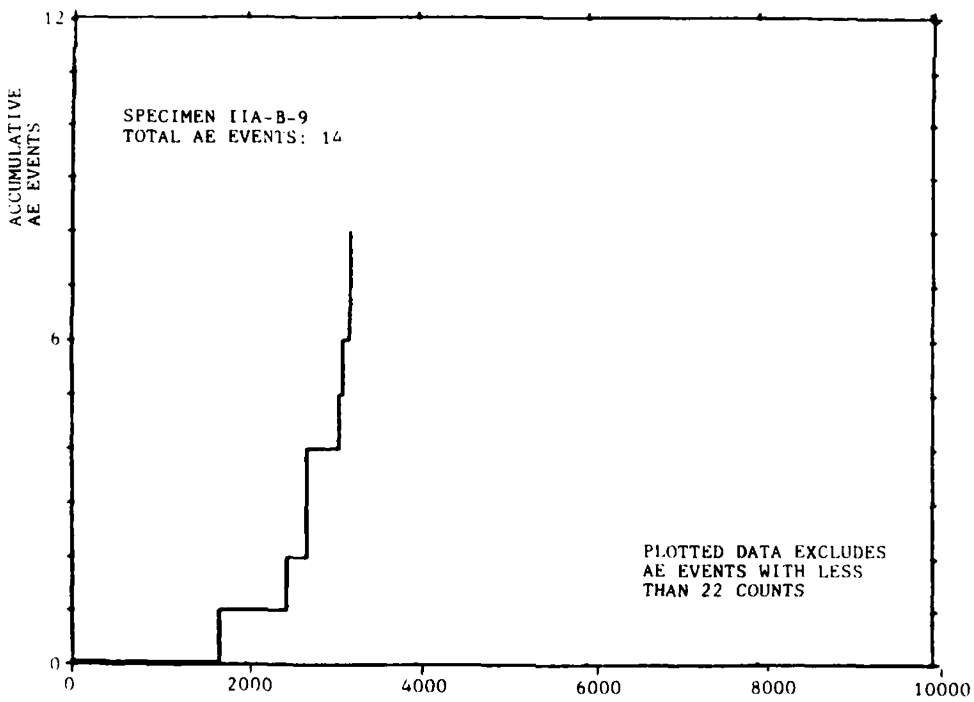
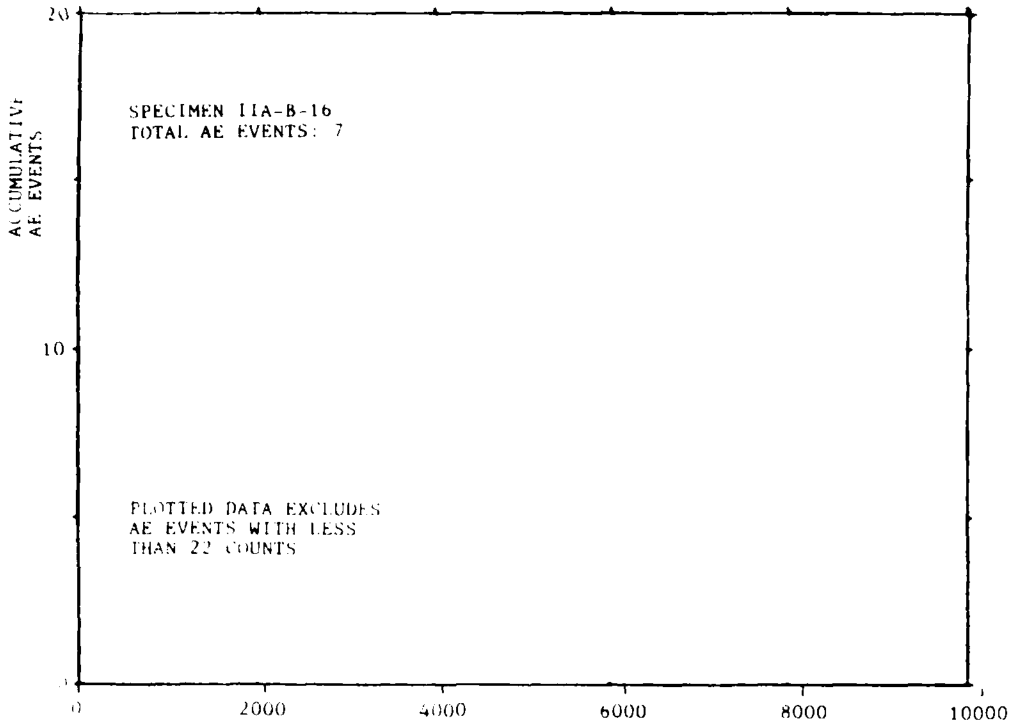


Figure E-61. Plots of Accumulative AE Events vs Applied Load for Type IIA-B Specimens with Minimum and Maximum Response for Load Level A.



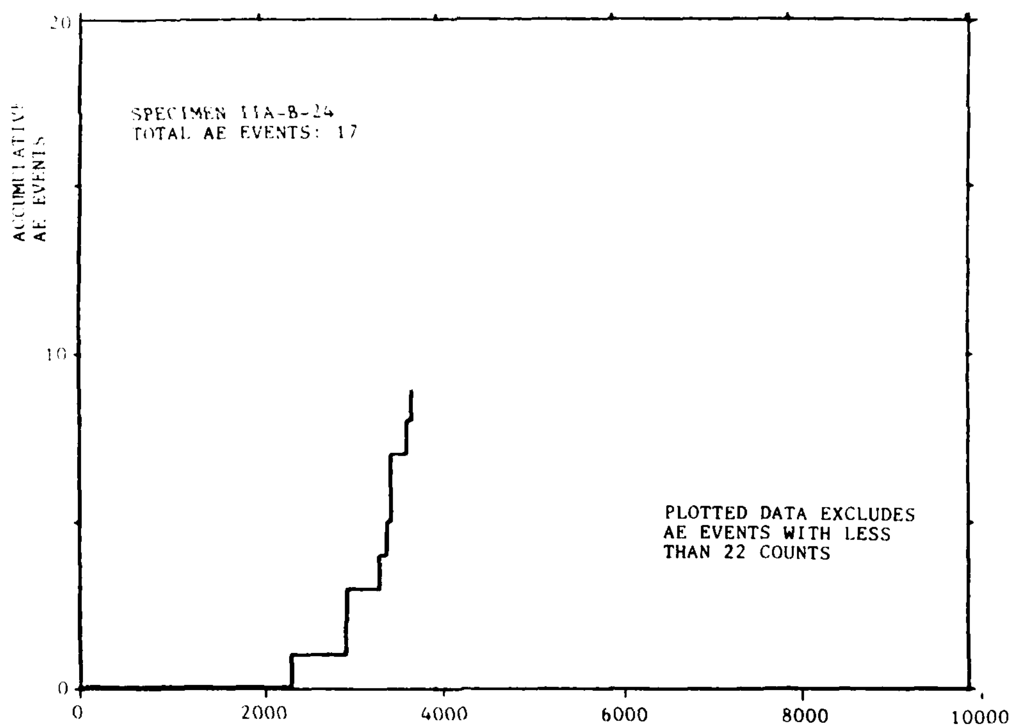
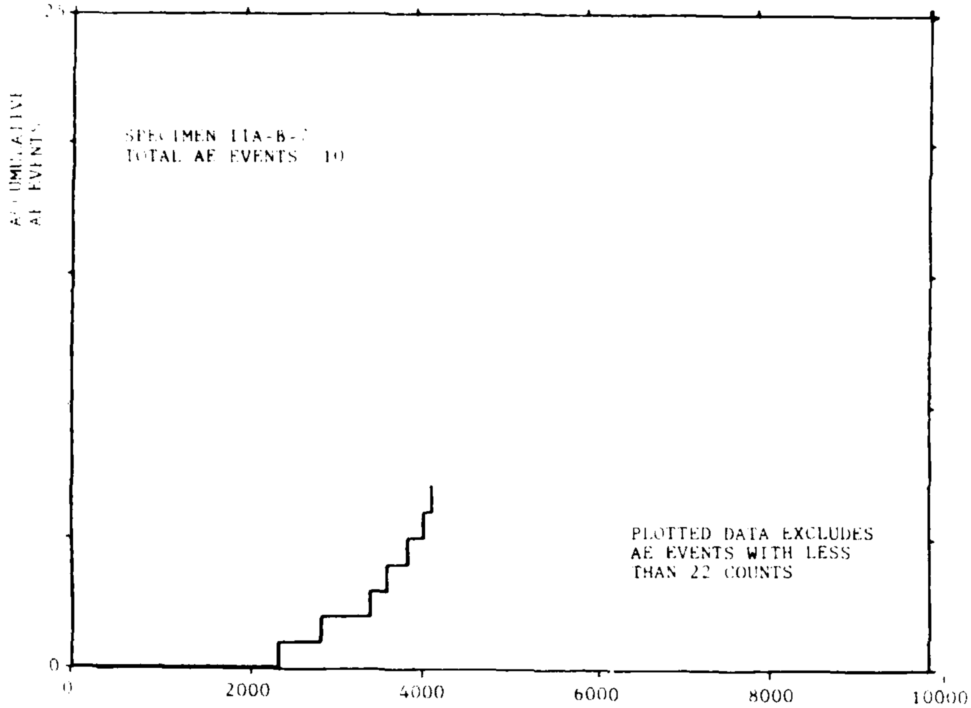


Figure E-62. Plots of Accumulative AE Events vs Applied Load for Type IIA-B Specimens with Minimum and Maximum Response for Load Level C.



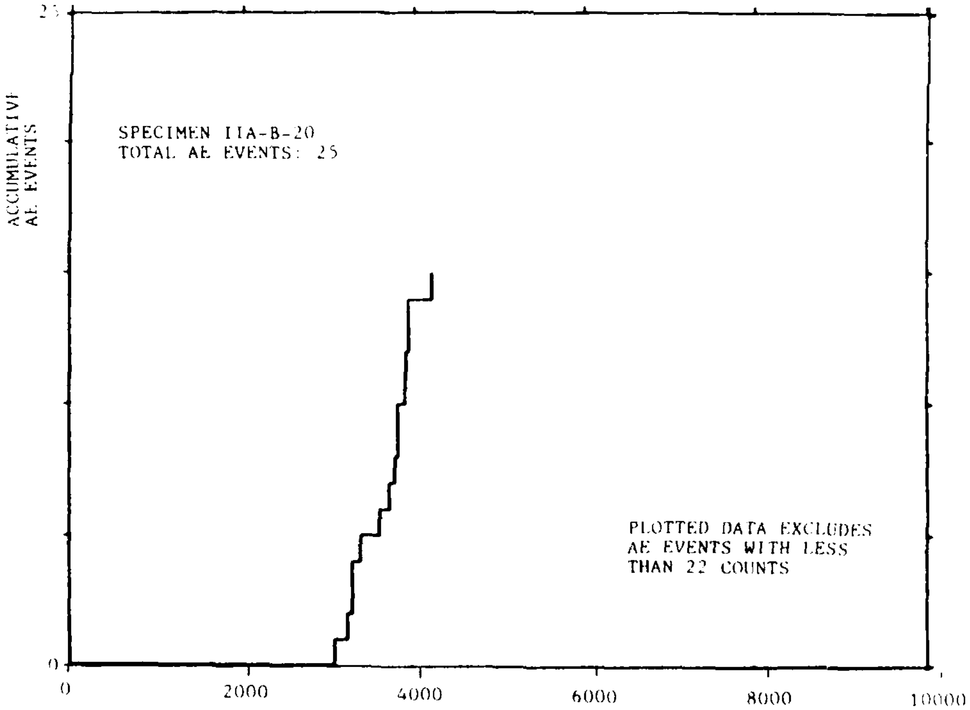
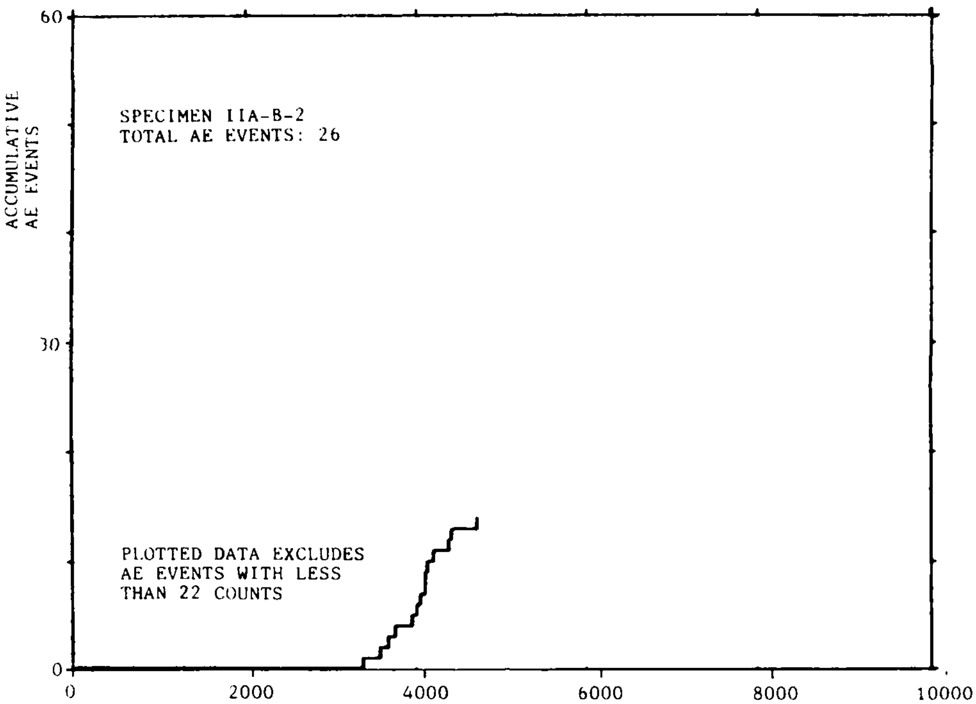


Figure E-63. Plots of Accumulative AE Events vs Applied Load for Type IIA-B Specimens with Minimum and Maximum Response for Load Level D.



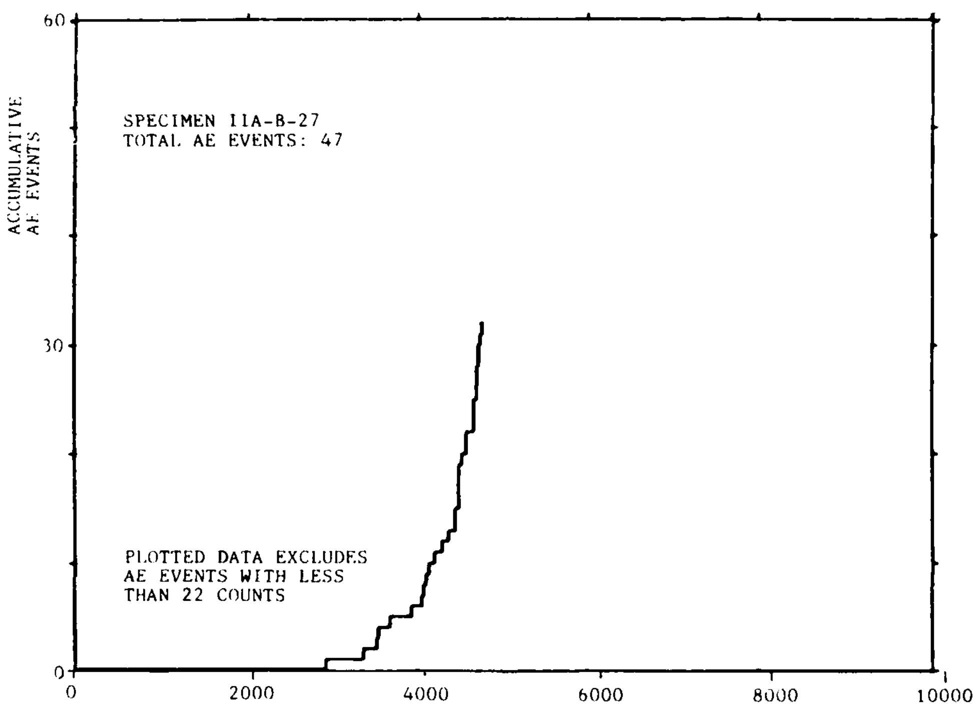


Figure E-64. Plots of Accumulative AE Events vs Applied Load for Type IIA-B Specimens with Minimum and Maximum Response for Load Level B.

APPENDIX F

DETAIL DAMAGE INFORMATION FOR TYPE IIA-C SPECIMENS

The detail information for the Type IIA specimens of Laminate C is presented in this appendix. It is presented in the order of increasing load levels. All specimens of the same load level are grouped together. Three figures are presented for each specimen. The first figure gives specimen type, laminate information and load conditions. The second figure consists of positive prints of enhanced x-ray radiographs made before and after loading. In addition, prints of a stereo x-ray pair are included for one specimen of each load level. The third figure consists of a Lamina Damage Characterization Chart. This chart contains a pictorial sketch for each lamina with fiber orientations indicated on one side or edge of each sketch. Also an outline of the fastener head is shown on these sketches to provide a visual reference as to the magnitude of the damage. The damage observed on each lamina is recorded on the appropriate sketch in a manner to indicate size and location relative to the fastener hole. As shown in these charts lamina No. 1 was adjacent to the joint interface and lamina No. 23 was adjacent to the fastener head.

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - $C(\pm 45^\circ, 0^\circ, 90^\circ, \mp 45^\circ, 0^\circ, 90^\circ, \pm 45^\circ, 0^\circ, 90^\circ)_s$

LOAD LEVEL - A

POUNDS LOAD - 6000 PERCENT OF ULTIMATE - 62

FIGURE F-1. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-3.

BEFORE LOADING AFTER LOADING

FIGURE F-2. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-3.

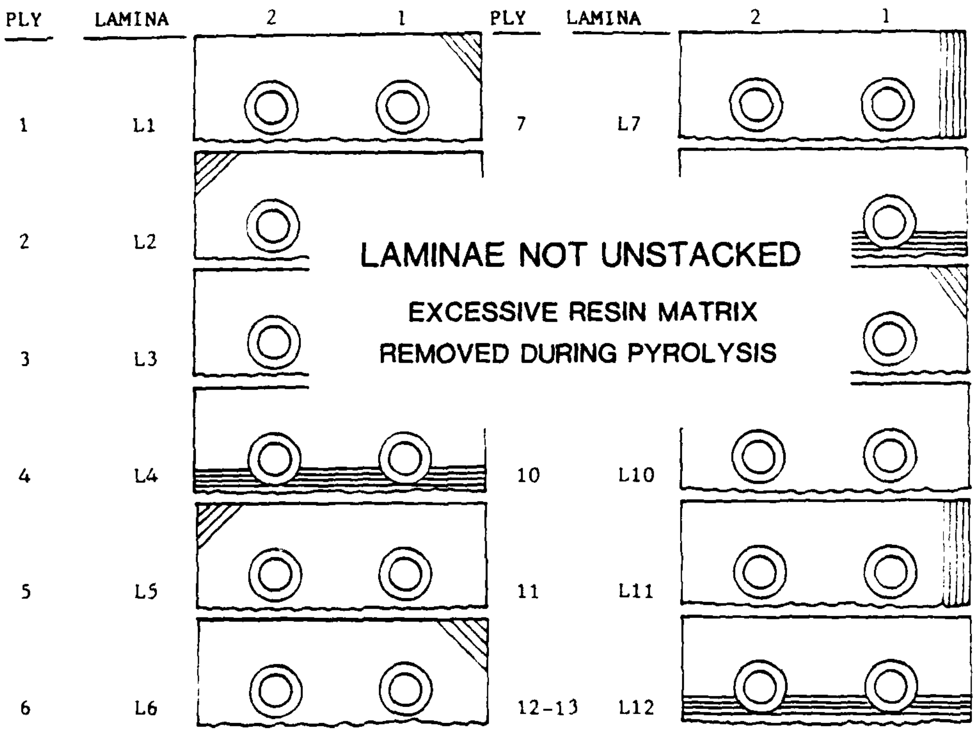


Figure F-3. Lamina Damage Characterization Chart for Specimen
IIA-C-3 Strap A Load Level A

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm 45^\circ$, 0°, 90°, $\mp 45^\circ$, 0°, 90°, $\pm 45^\circ$, 0°, 90°)s

LOAD LEVEL - A

POUNDS LOAD - 6000 PERCENT OF ULTIMATE - 62

FIGURE F-4. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-18.

BEFORE LOADING AFTER LOADING

FIGURE F-5. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-18.

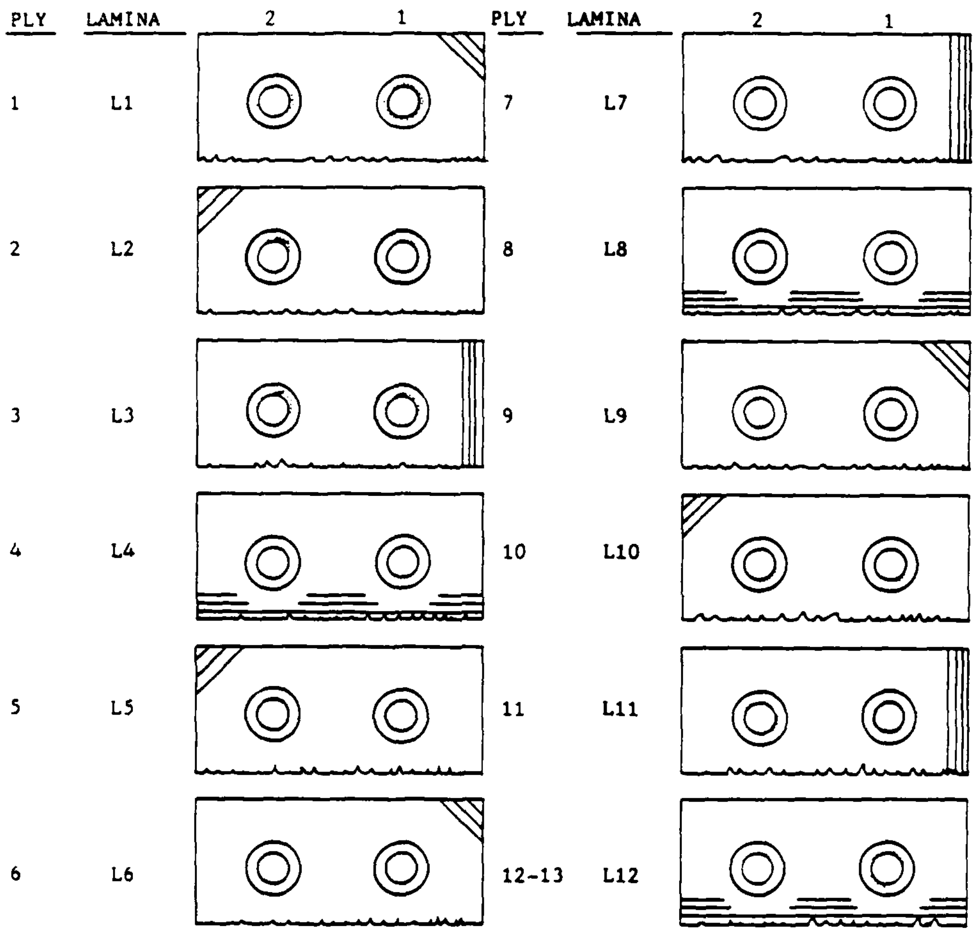


Figure F-6. Lamina Damage Characterization Chart for Specimen

IIA-C-18 Strap B Load Level A (Continued)

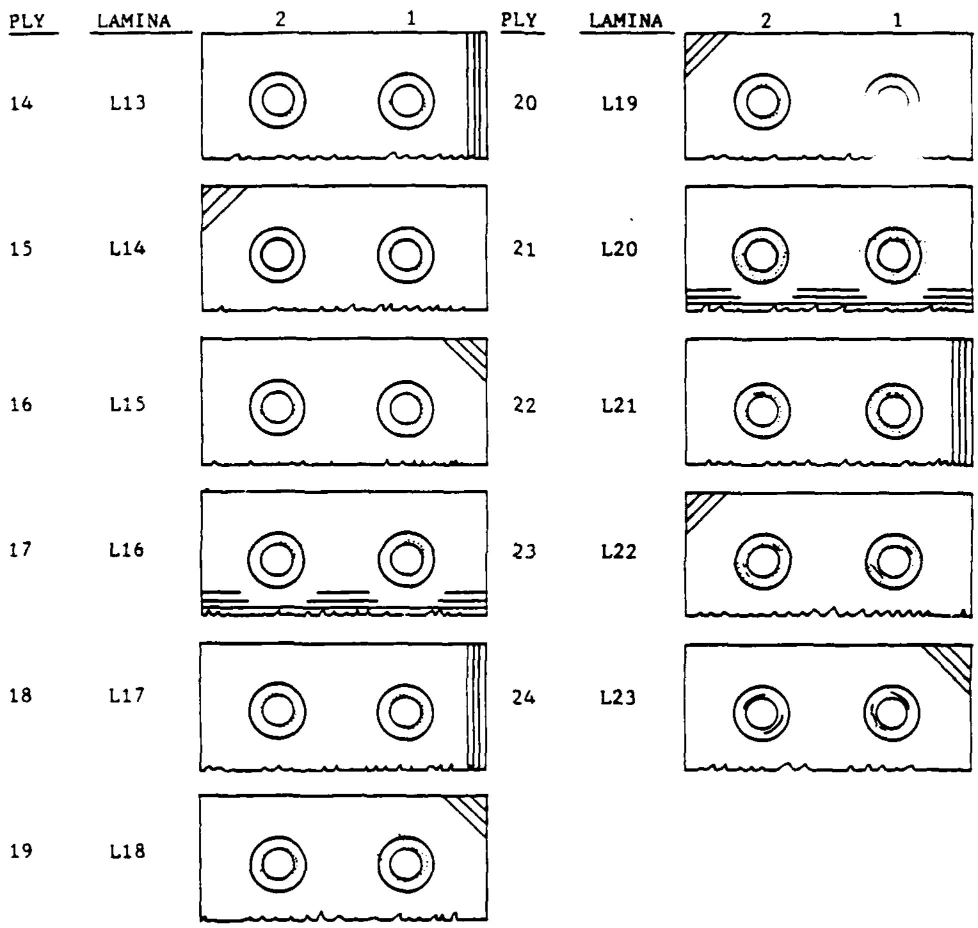


Figure F-6. Lamina Damage Characterization Chart for Specimen

IIA-C-18 Strap B Load Level A

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm 45^\circ$, 0°, 90°, $\mp 45^\circ$, 0°, 90°, $\pm 45^\circ$, 0°, 90°)s

LOAD LEVEL - A

POUNDS LOAD - 6000 PERCENT OF ULTIMATE - 62

FIGURE F-7. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-12.

BEFORE LOADING AFTER LOADING

FIGURE F-8. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-12.

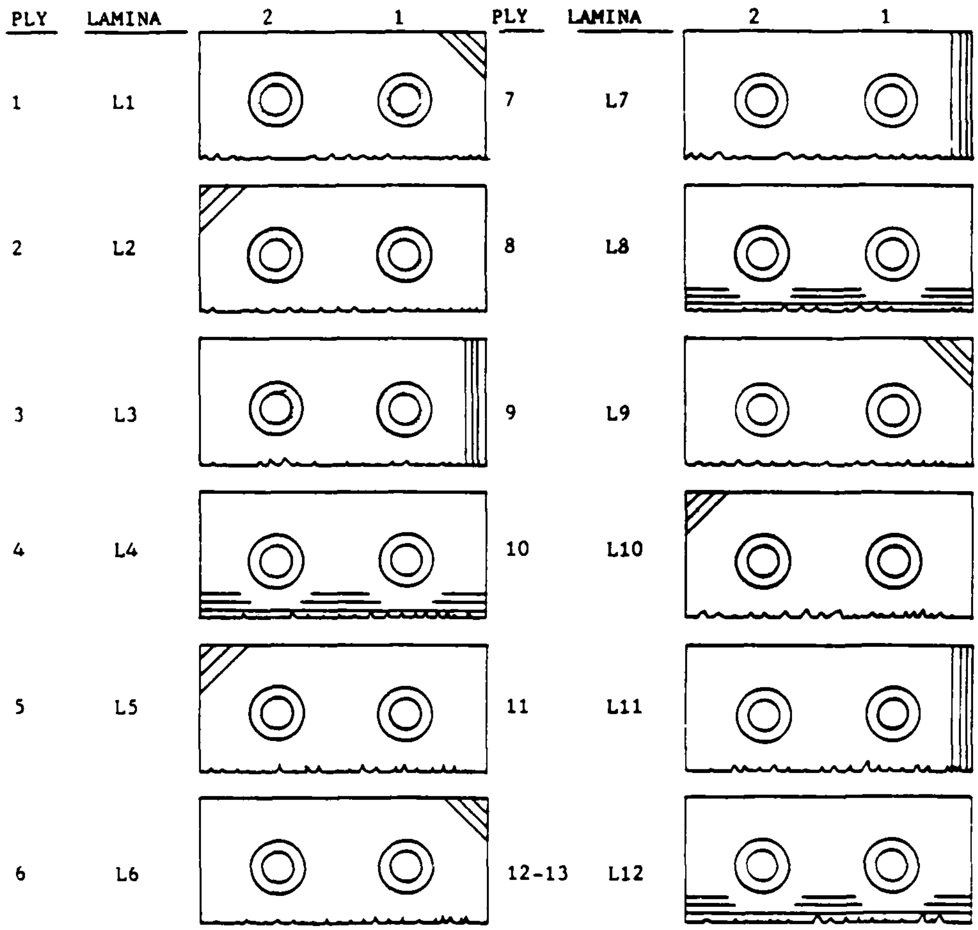


Figure F-9. Lamina Damage Characterization Chart for Specimen

IIA-C-12 Strap B Load Level A (Continued)

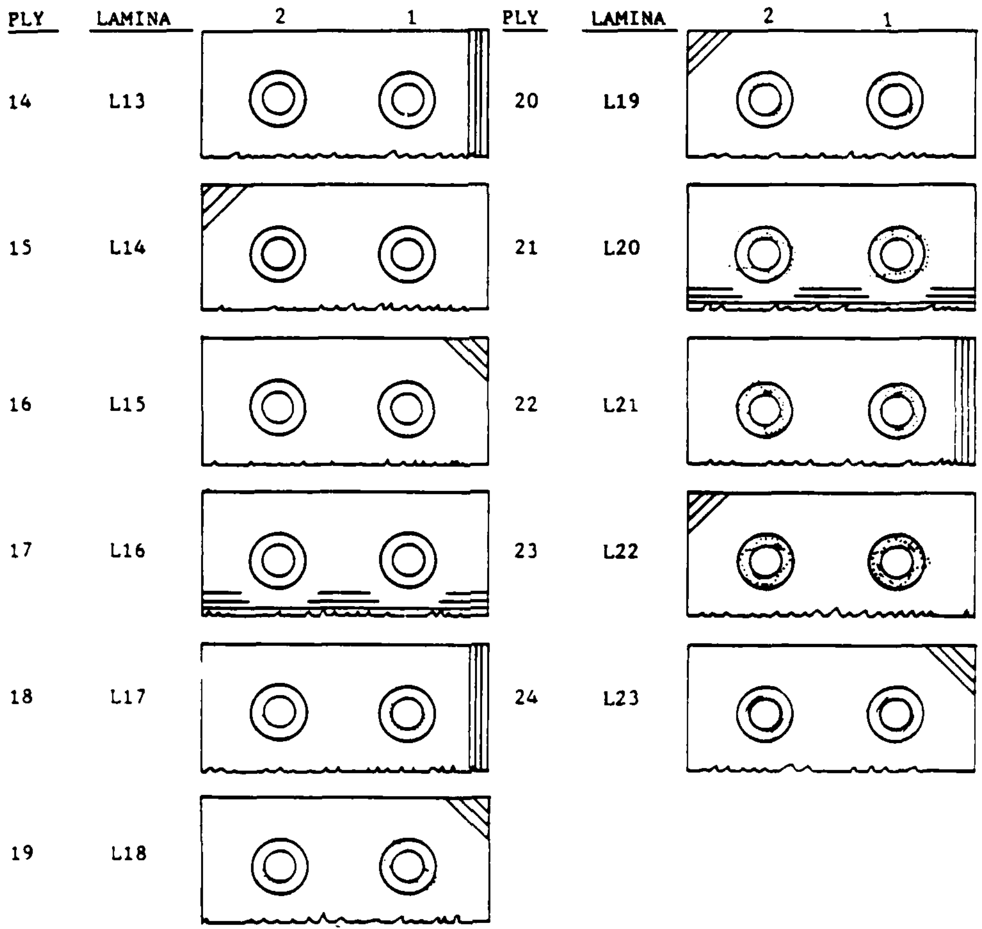


Figure F-9. Lamina Damage Characterization Chart for Specimen

IIA-C-12 Strap B Load Level A

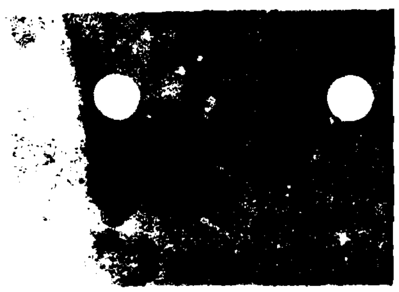
SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm 45^\circ$, 0°, 90°, $\mp 45^\circ$, 0°, 90°, $\pm 45^\circ$, 0°, 90°)s

LOAD LEVEL - A

POUNDS LOAD - 6000 PERCENT OF ULTIMATE - 62

FIGURE F-10. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-8.



BEFORE LOADING

AFTER LOADING

FIGURE F-11. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-8.

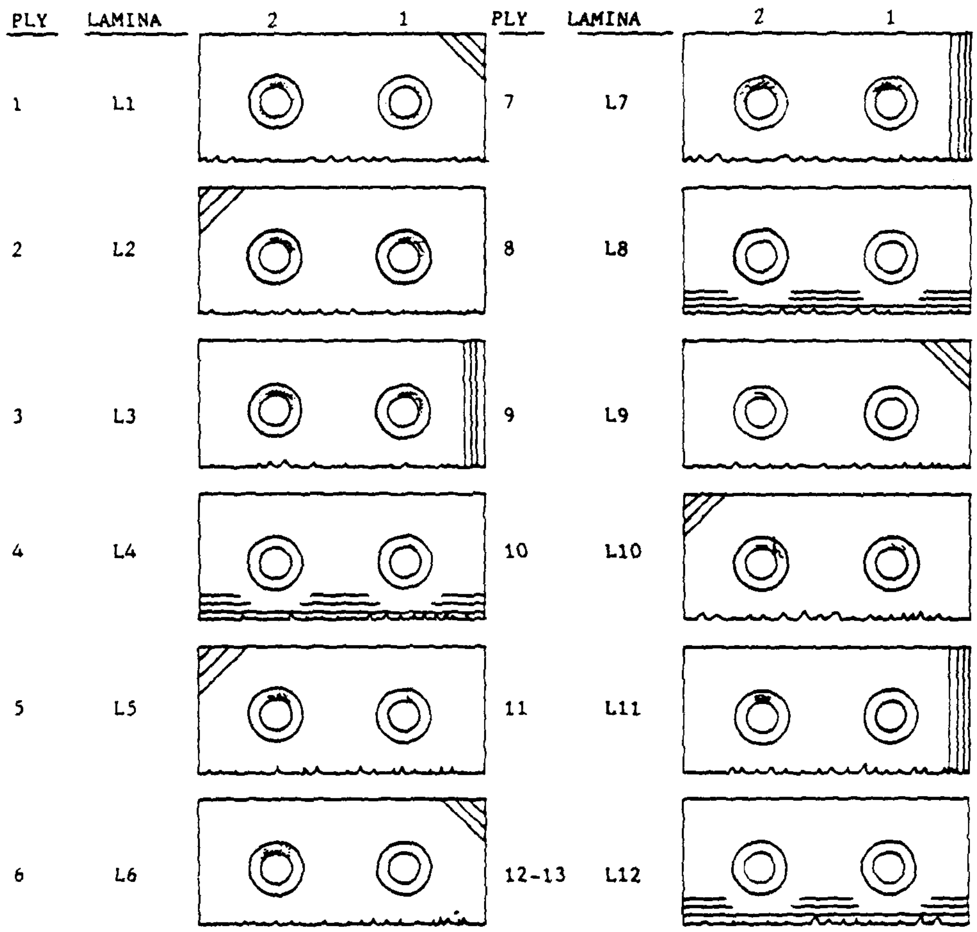


Figure F-12. Lamina Damage Characterization Chart for Specimen

IIA-C-8 Strap A Load Level A (Continued)

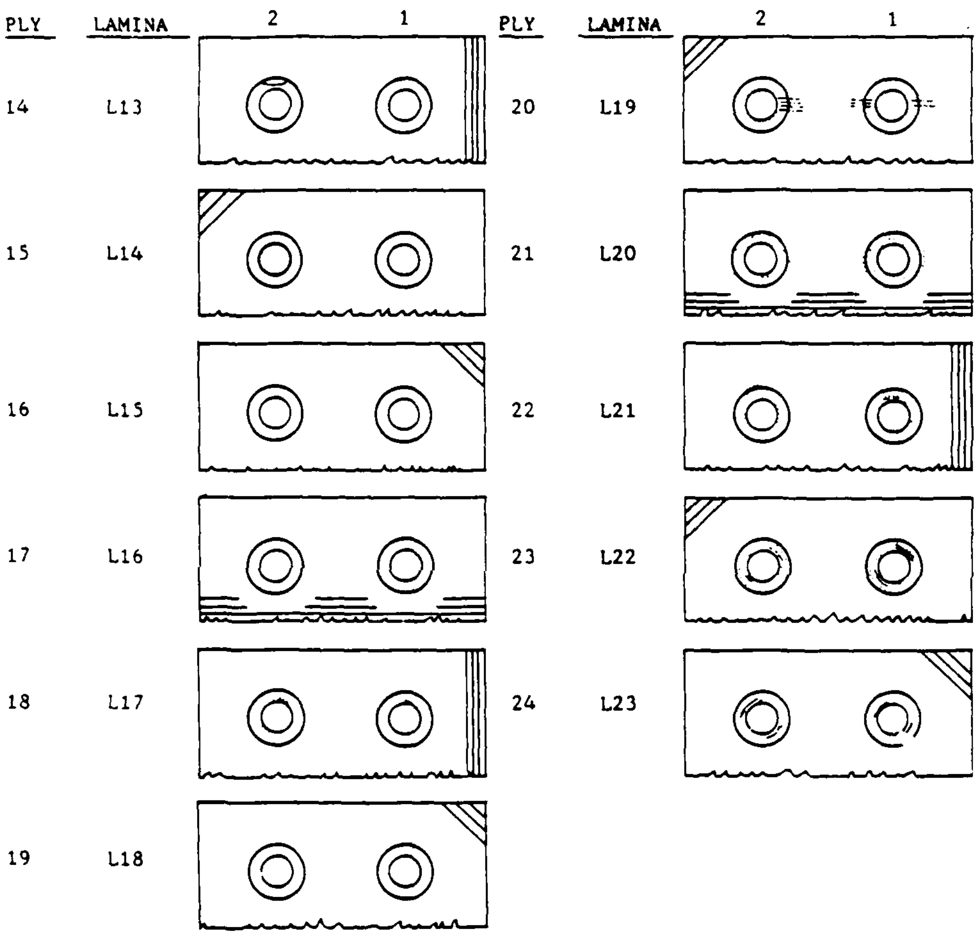


Figure F-12. Lamina Damage Characterization Chart for Specimen

IIA-C-8 Strap A Load Level A

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm 45^{\circ}$, 0°, 90°, $\mp 45^{\circ}$, 0°, 90°, $\pm 45^{\circ}$, 0°, 90°)s

LOAD LEVEL - A

POUNDS LOAD - 6000 PERCENT OF ULTIMATE - 62

FIGURE F-13. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-9.

BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE F-14. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-9.

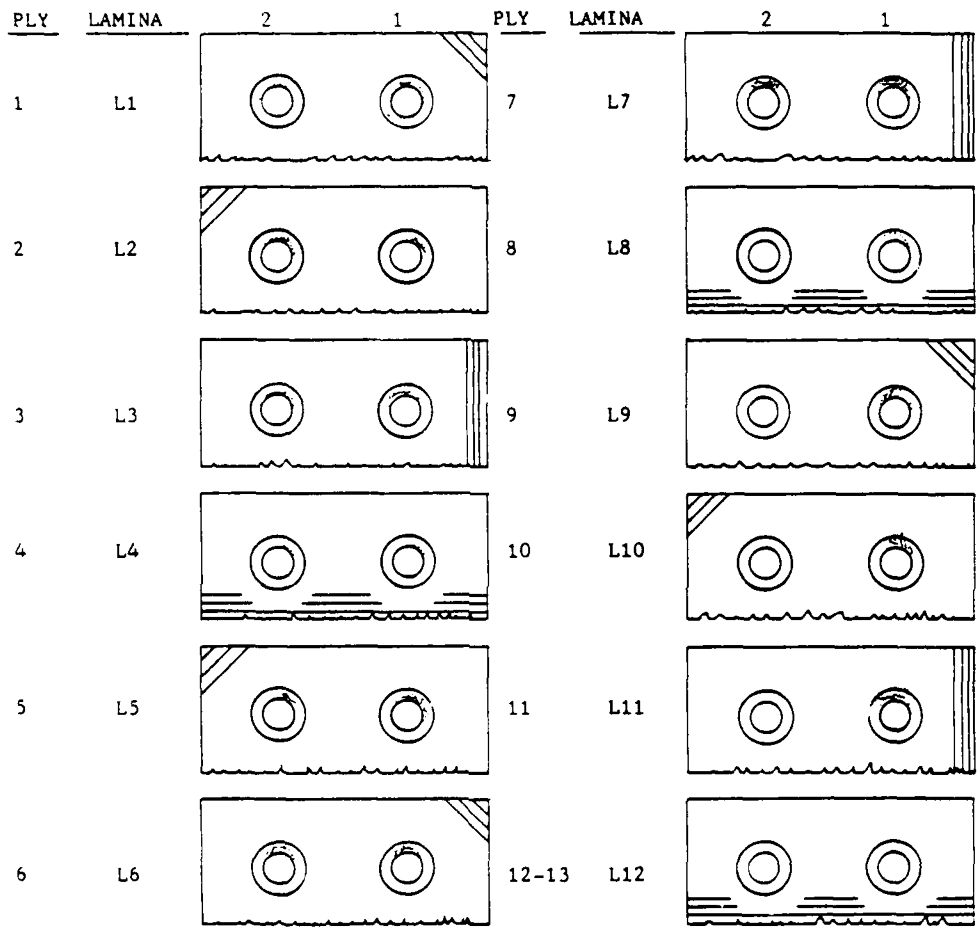


Figure F-15. Lamina Damage Characterization Chart for Specimen

IIA-C-9 Strap A Load Level A (Continued)

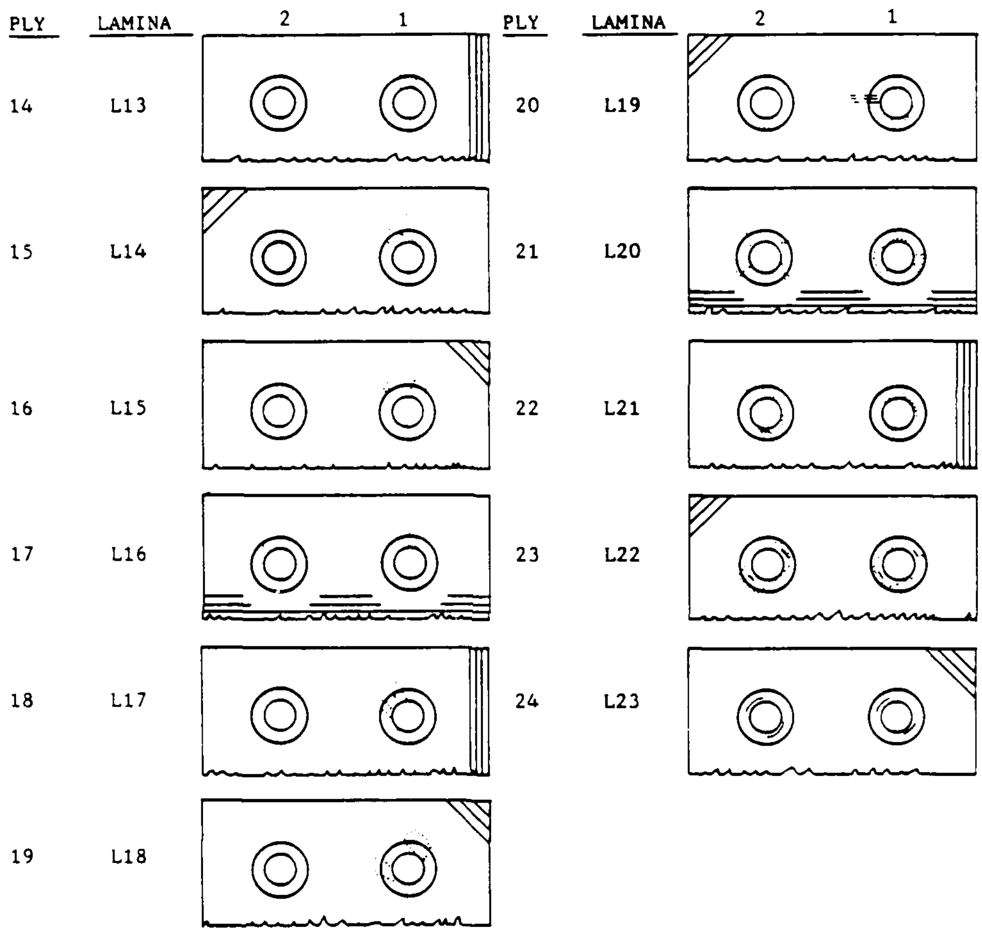


Figure F-15. Lamina Damage Characterization Chart for Specimen

IIA-C -9 Strap A Load Level A

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - $C(\pm 45^{\circ}, 0^{\circ}, 90^{\circ}, \mp 45^{\circ}, 0^{\circ}, 90^{\circ}, \pm 45^{\circ}, 0^{\circ}, 90^{\circ})_s$

LOAD LEVEL - C

POUNDS LOAD - 6819 PERCENT OF ULTIMATE - 71

FIGURE F-16. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-24.

BEFORE LOADING AFTER LOADING

FIGURE F-17. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-24.

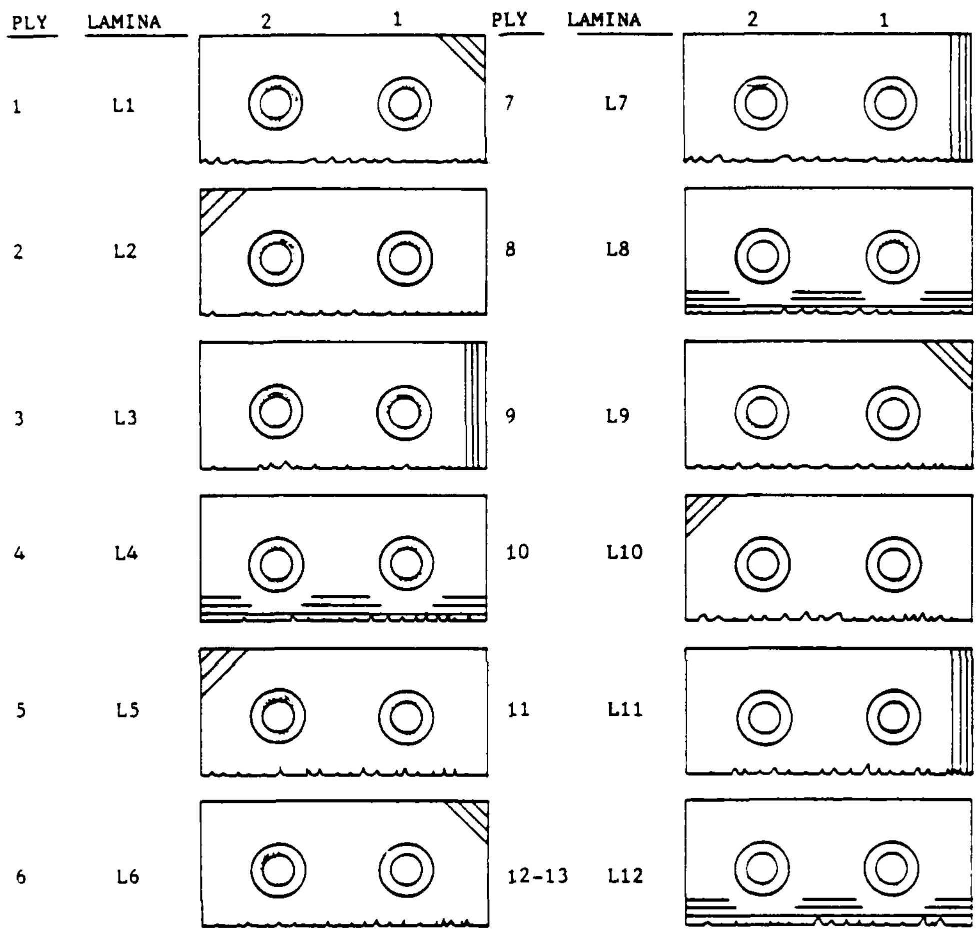


Figure F-18. Lamina Damage Characterization Chart for Specimen

IIA-C-24 Strap A Load Level C (Continued)

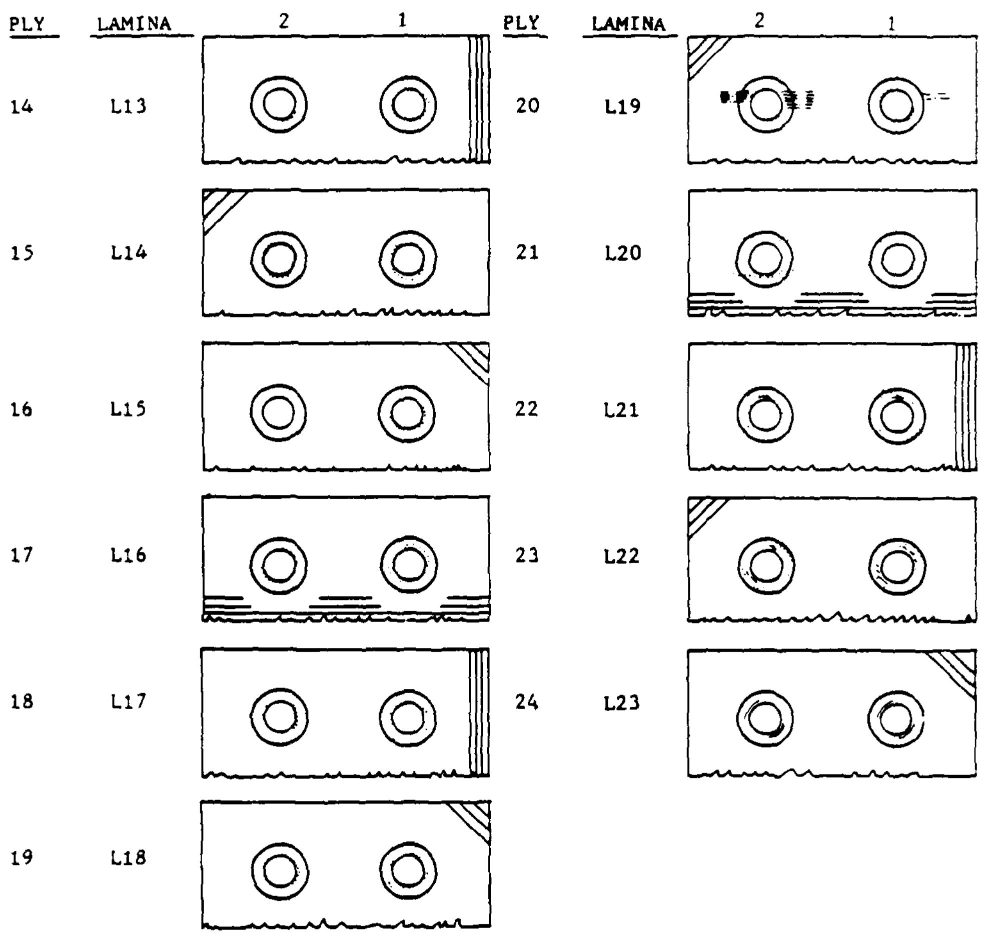


Figure F-18. Lamina Damage Characterization Chart for Specimen

IIA-C-24 Strap A Load Level C

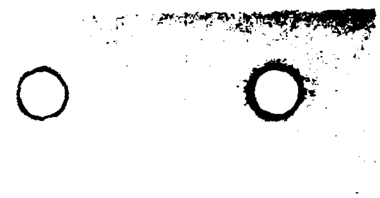
SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm45^\circ$, 0°, 90°, $\mp45^\circ$, 0°, 90°, $\pm45^\circ$, 0°, 90°)s

LOAD LEVEL - C

POUNDS LOAD - 6819 PERCENT OF ULTIMATE - 71

FIGURE F-19. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-14.



BEFORE LOADING AFTER LOADING

FIGURE F-20. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-14.

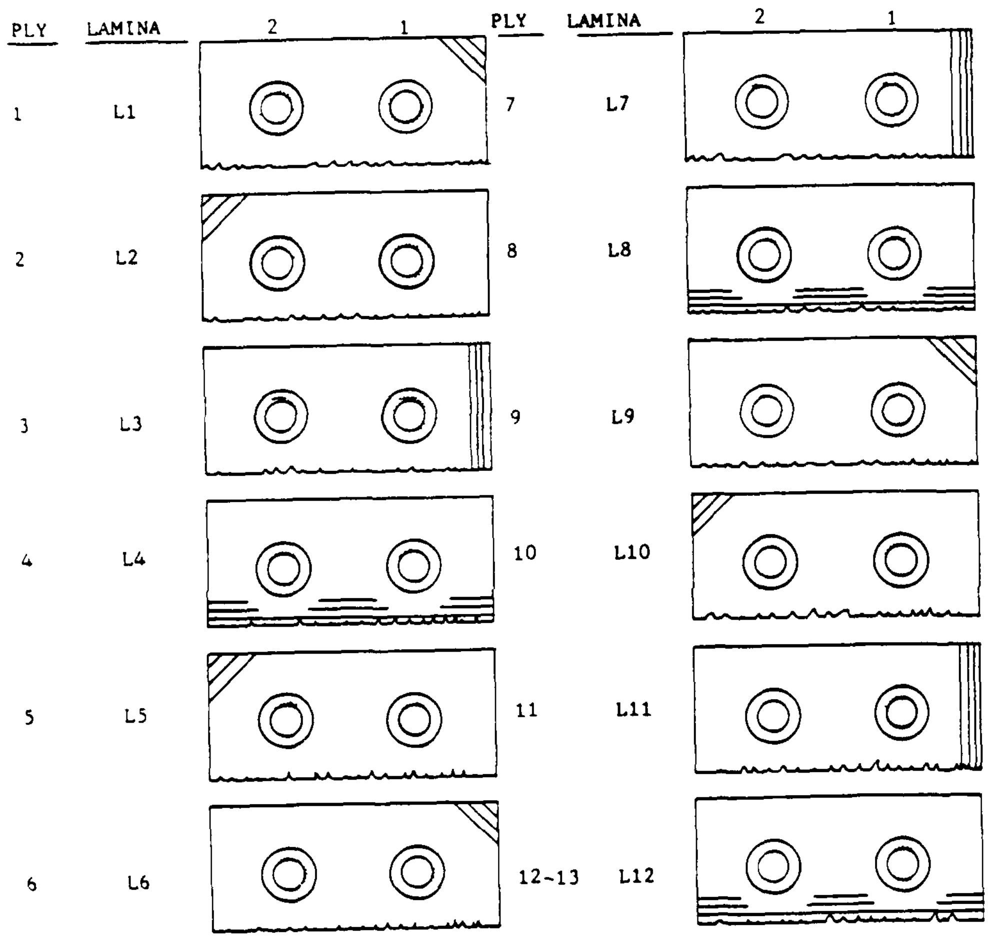


Figure F-21. Lamina Damage Characterization Chart for Specimen

IIA-C-14 Strap B Load Level C (Continued)

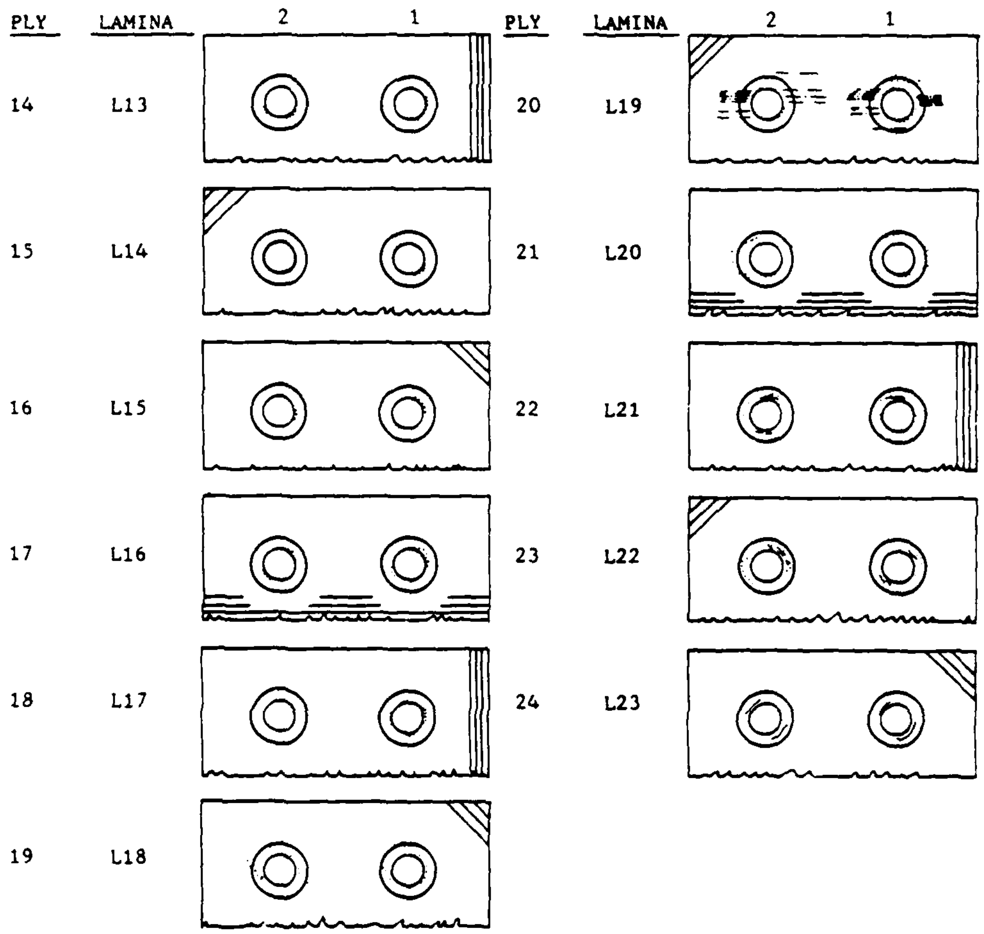


Figure F-21. Lamina Damage Characterization Chart for Specimen

IIA-C-14 Strap B Load Level C

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm 45^{\circ}$, 0°, 90°, $\mp 45^{\circ}$, 0°, 90°, $\pm 45^{\circ}$, 0°, 90°)s

LOAD LEVEL - C

POUNDS LOAD - 6819 PERCENT OF ULTIMATE - 71

FIGURE F-22. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-16.

BEFORE LOADING AFTER LOADING

FIGURE F-23. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-16.

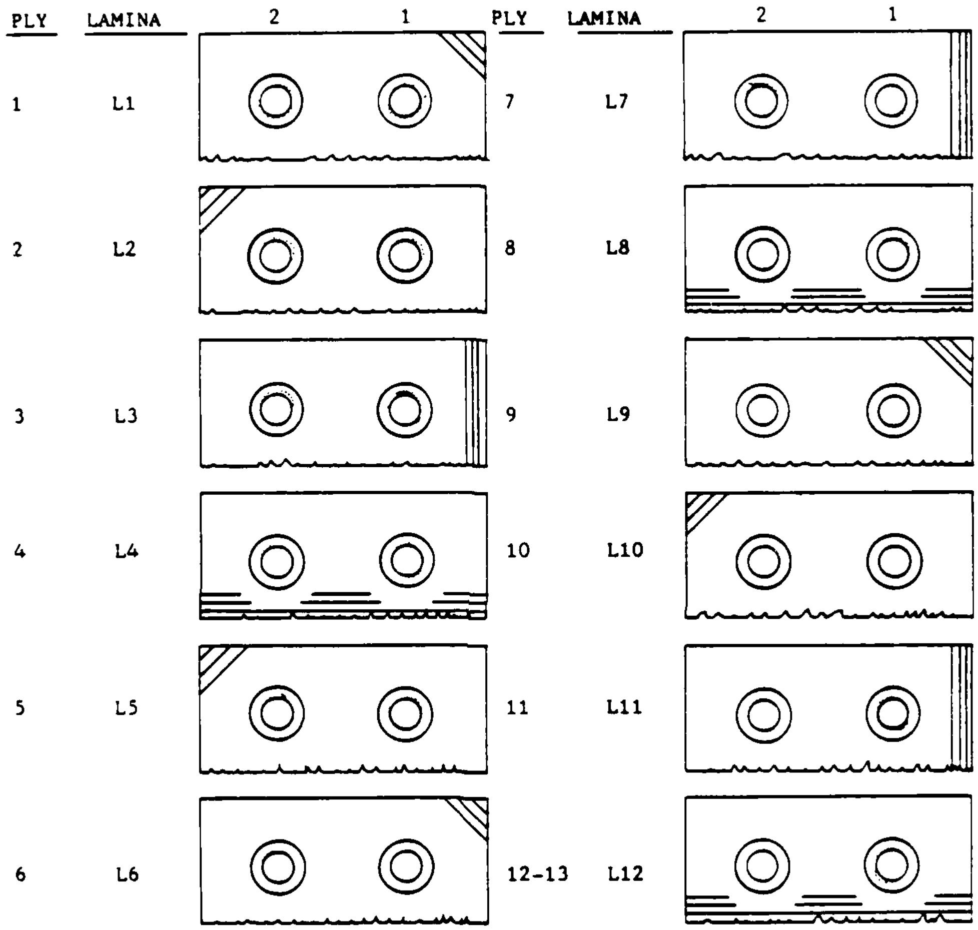


Figure F-24. Lamina Damage Characterization Chart for Specimen

IIA-C-16 Strap A Load Level C (Continued)

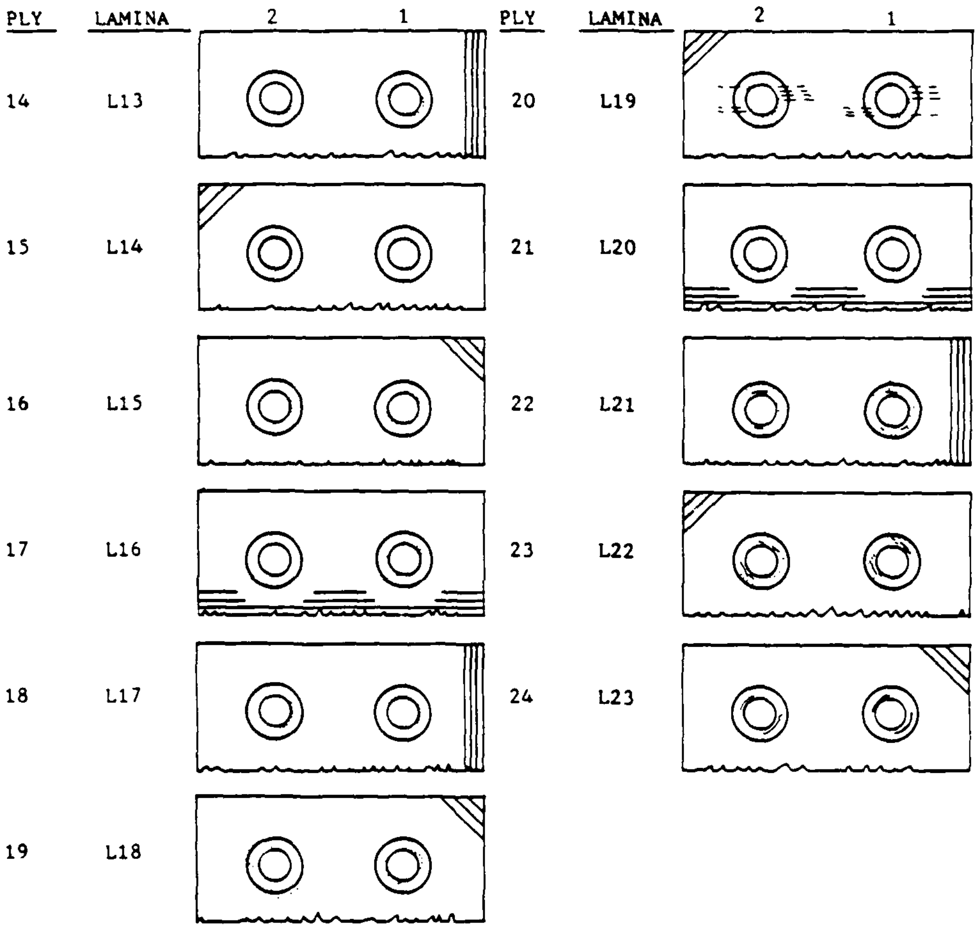


Figure F-24. Lamina Damage Characterization Chart for Specimen

IIA-C-16 Strap A Load Level C

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm45^\circ$, 0°, 90°, $\mp45^\circ$, 0°, 90°, $\pm45^\circ$, 0°, 90°)s

LOAD LEVEL - C

POUNDS LOAD - 6819 PERCENT OF ULTIMATE - 71

FIGURE F-25. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-22.

BEFORE LOADING AFTER LOADING

FIGURE F-26. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-22.

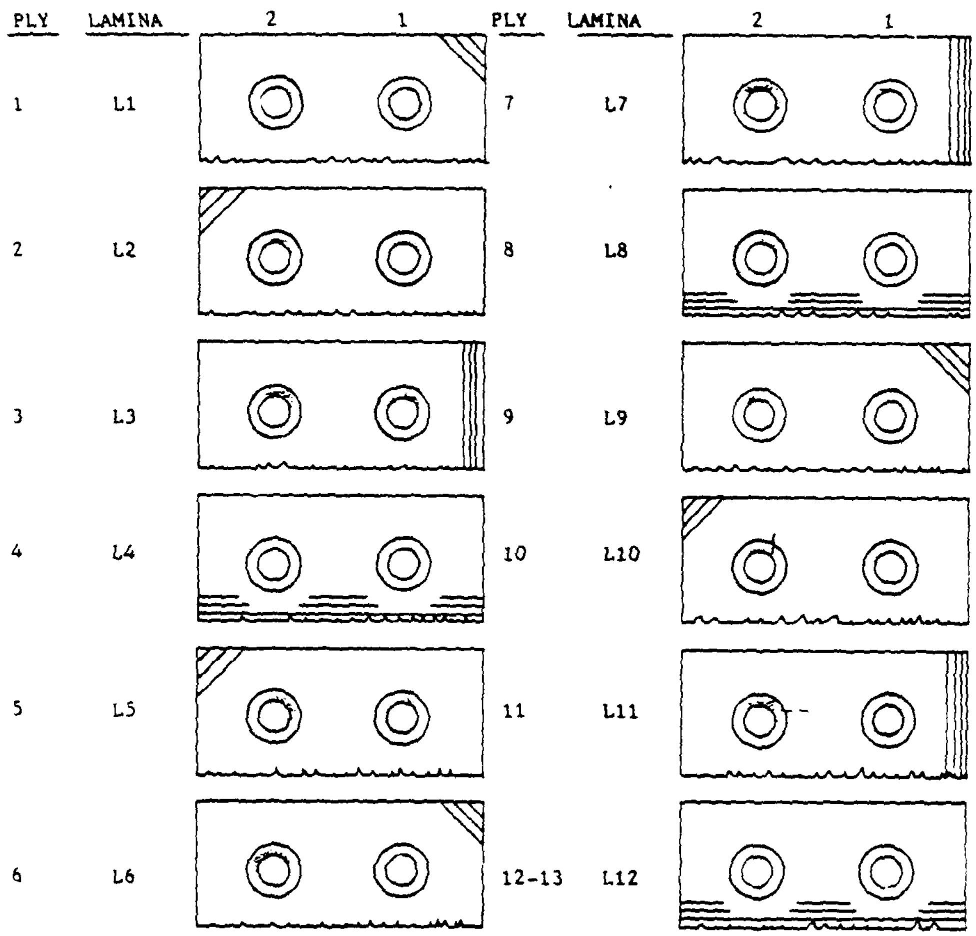


Figure F-27. Lamina Damage Characterization Chart for Specimen

IIA-C-22 Strap A Load Level C (Continued)

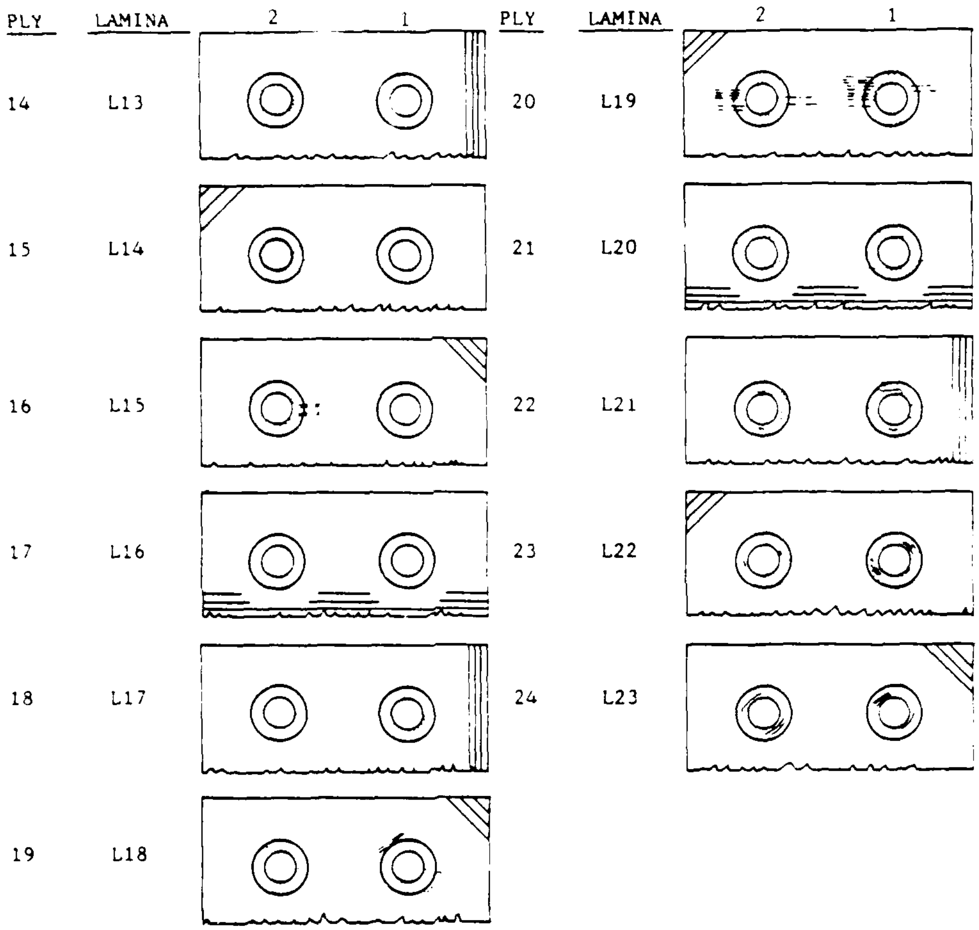


Figure F-27. Lamina Damage Characterization Chart for Specimen

IIA-C-22 Strap A Load Level C

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm 45^{\circ}$, 0°, 90°, $\mp 45^{\circ}$, 0°, 90°, $\pm 45^{\circ}$, 0°, 90°)s

LOAD LEVEL - C

POUNDS LOAD - 6819 PERCENT OF ULTIMATE - 71

FIGURE F-28. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-21.

BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE F-29. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-21.

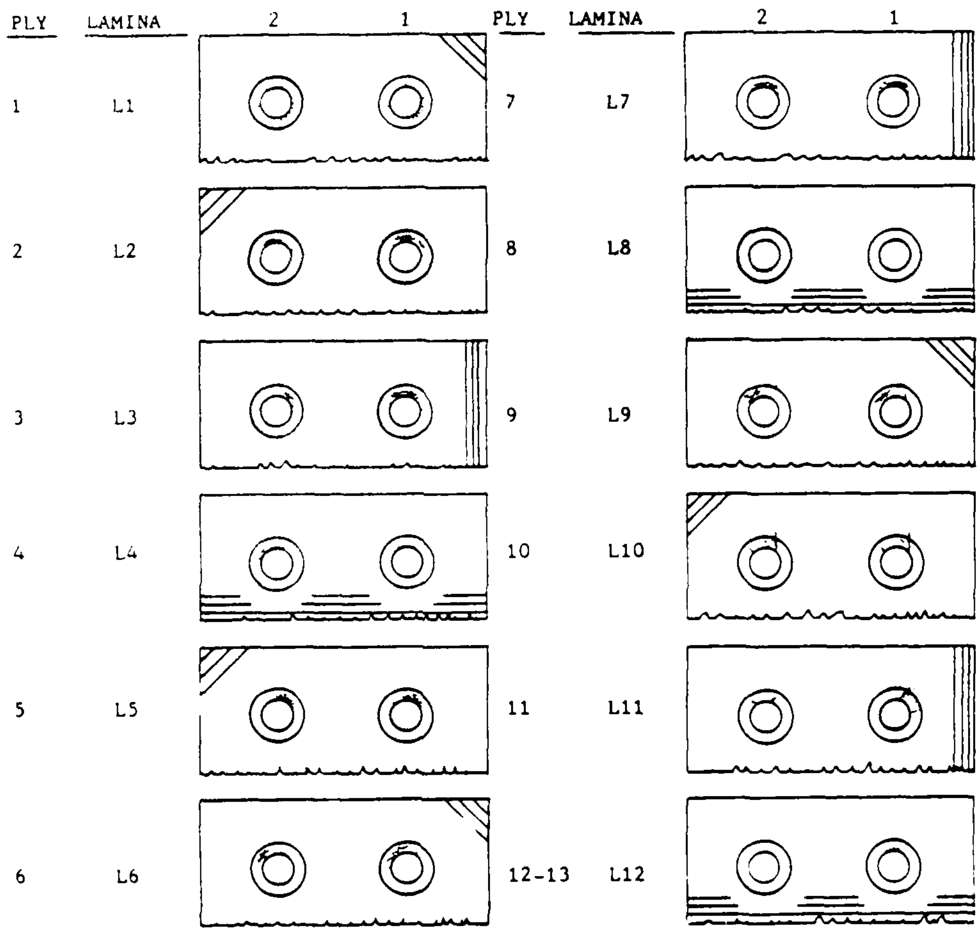


Figure F-30. Lamina Damage Characterization Chart for Specimen

IIA-C-21 Strap A Load Level C (Continued)

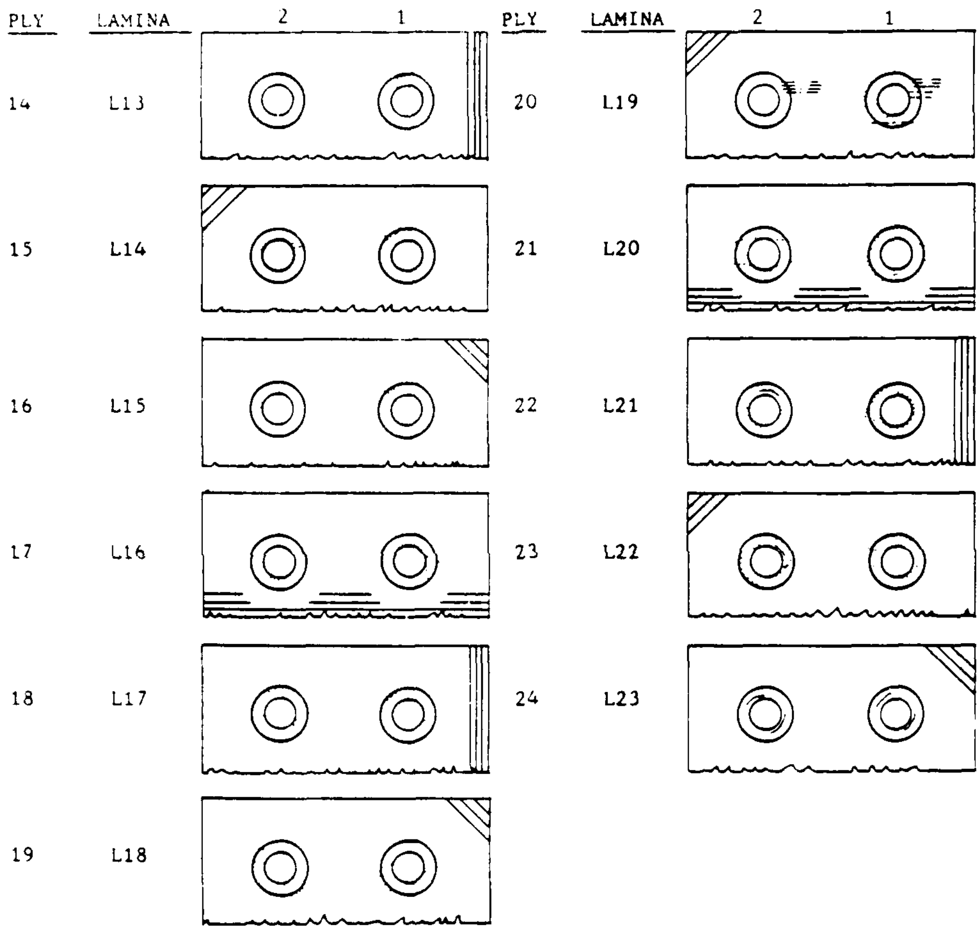


Figure F-30. Lamina Damage Characterization Chart for Specimen

IIA-C-21 Strap A Load Level C

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm 45^{\circ}$, 0°, 90°, $\mp 45^{\circ}$, 0°, 90°, $\pm 45^{\circ}$, 0°, 90°)s

LOAD LEVEL - D

POUNDS LOAD - 7658 PERCENT OF ULTIMATE - 79

FIGURE F-31. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-15.

BEFORE LOADING AFTER LOADING

FIGURE F-32. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-15.

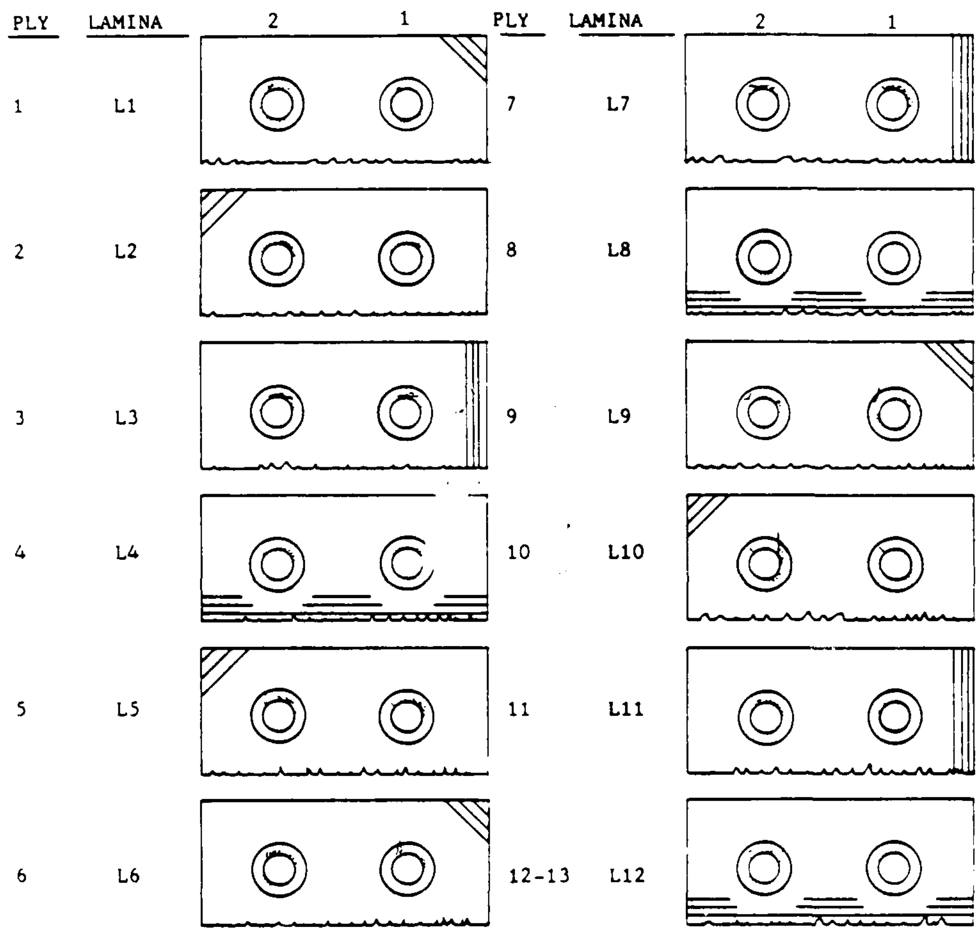


Figure F-33. Lamina Damage Characterization Chart for Specimen

IIA-C-15 Strap B Load Level D (Continued)

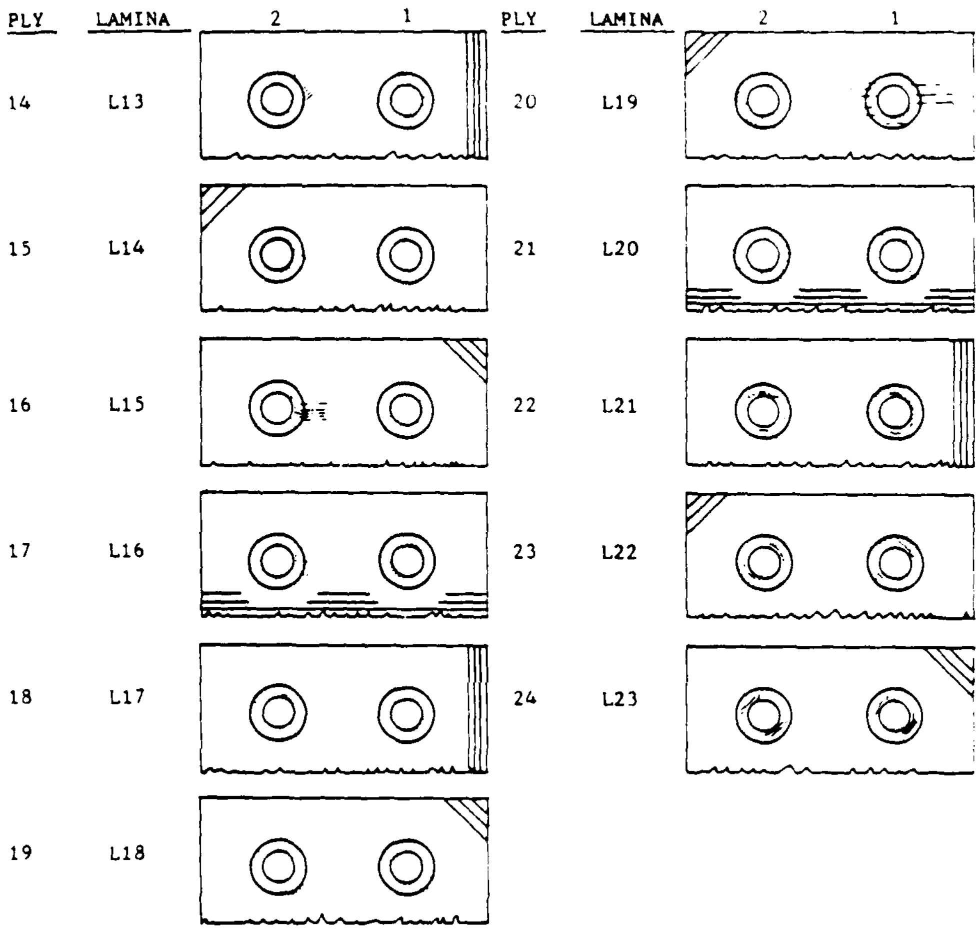


Figure F-33. Lamina Damage Characterization Chart for Specimen

IIA-C-15 Strap B Load Level D

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm 45^\circ$, 0°, 90°, $\mp 45^\circ$, 0°, 90°, $\pm 45^\circ$, 0°, 90°)s

LOAD LEVEL - D

POUNDS LOAD - 7658 PERCENT OF ULTIMATE - 79

FIGURE F-34. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-20.

BEFORE LOADING AFTER LOADING

FIGURE F-35. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-20.

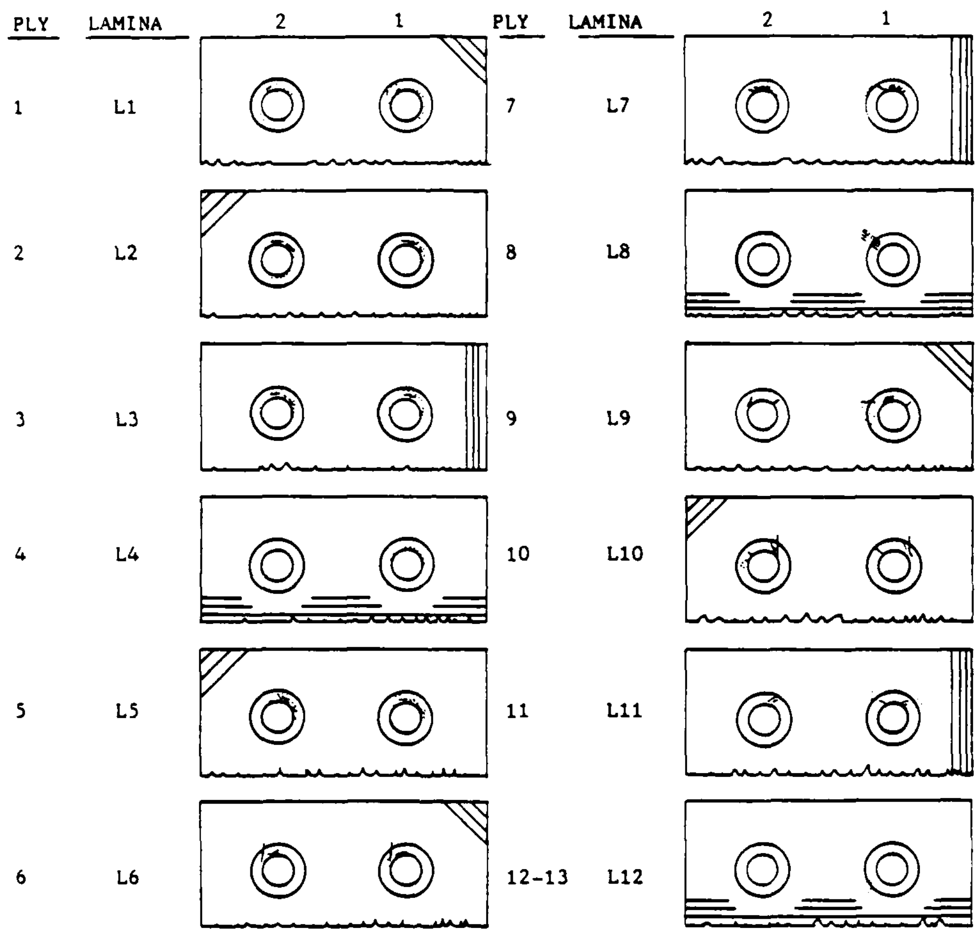


Figure F-36. Lamina Damage Characterization Chart for Specimen

IIA-C-20 Strap A Load Level D (Continued)

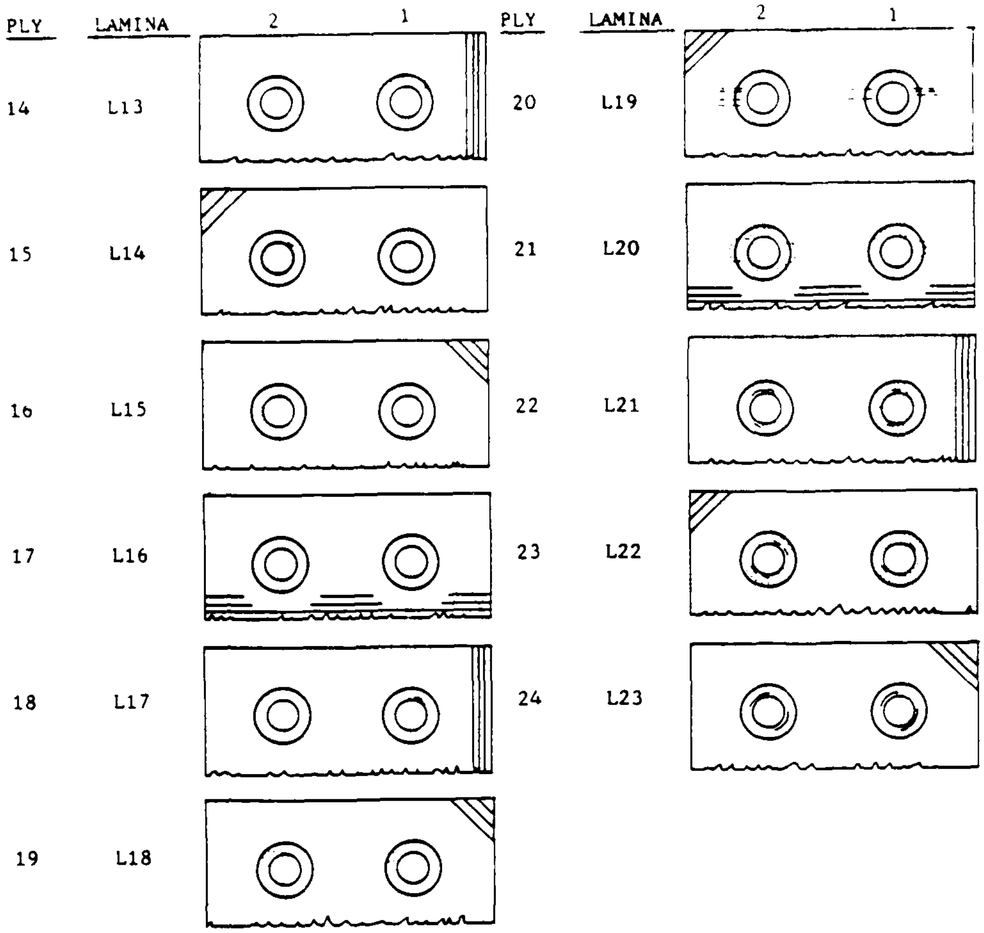


Figure F-36. Lamina Damage Characterization Chart for Specimen

IIA-C-20 Strap A Load Level D

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm$45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)s

LOAD LEVEL - D

POUNDS LOAD - 7658 PERCENT OF ULTIMATE - 79

FIGURE F-37. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-13.

BEFORE LOADING AFTER LOADING

FIGURE F-38. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-13.

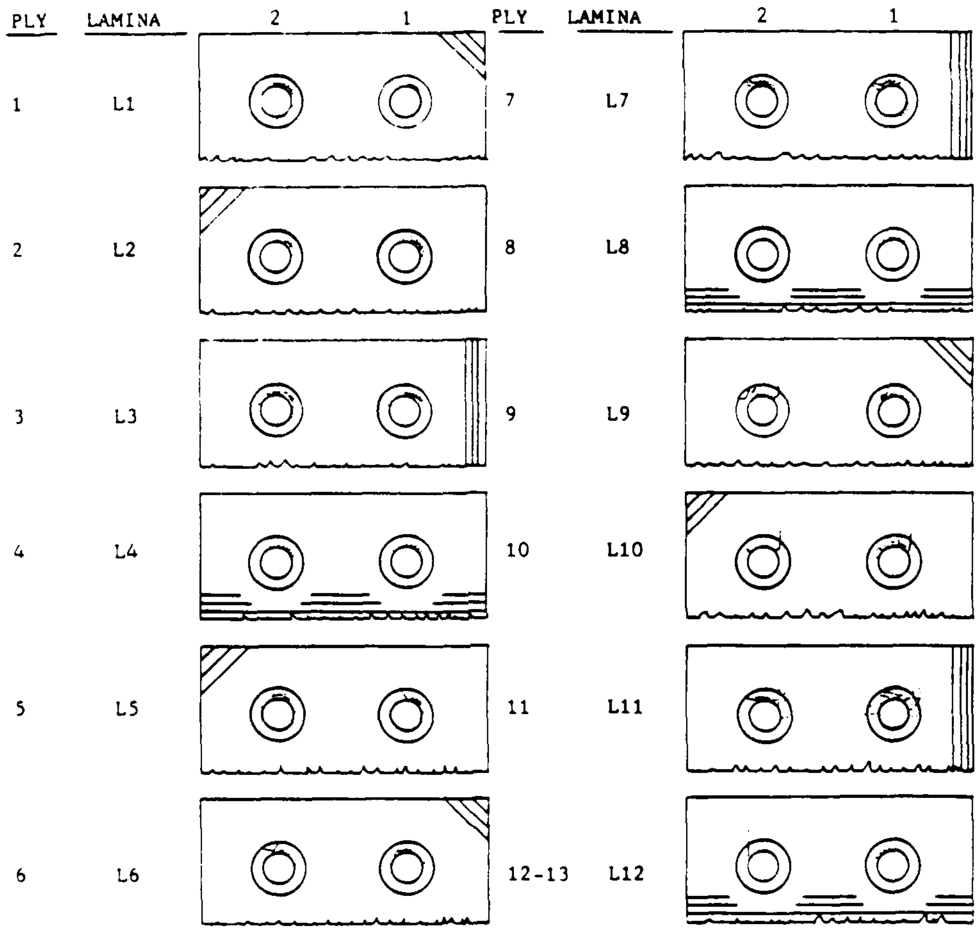


Figure F-39. Lamina Damage Characterization Chart for Specimen

IIA-C-13 Strap A Load Level D (Continued)

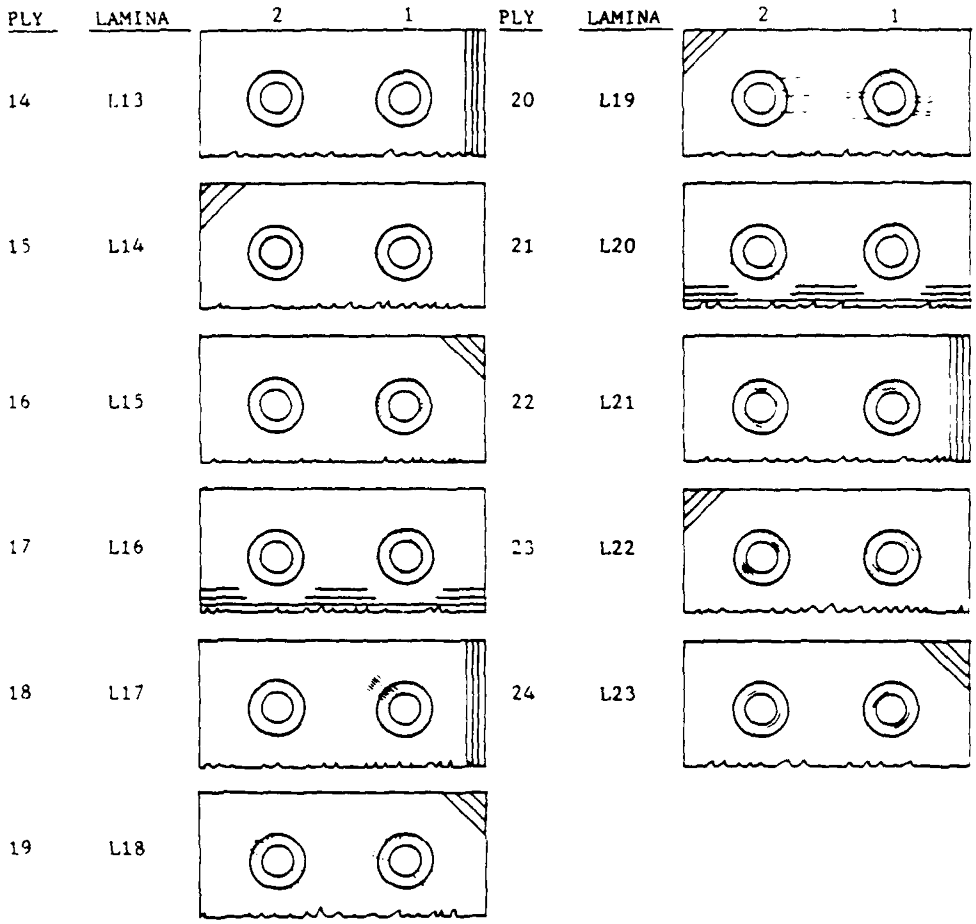


Figure F-39. Lamina Damage Characterization Chart for Specimen

IIA-C-13 Strap A Load Level D

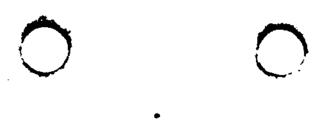
SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm 45^\circ$, 0°, 90°, $\mp 45^\circ$, 0°, 90°, $\pm 45^\circ$, 0°, 90°)$_s$

LOAD LEVEL - D

POUNDS LOAD - 7658 PERCENT OF ULTIMATE - 79

FIGURE F-40. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-1.



BEFORE LOADING AFTER LOADING

FIGURE F-41. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-1.

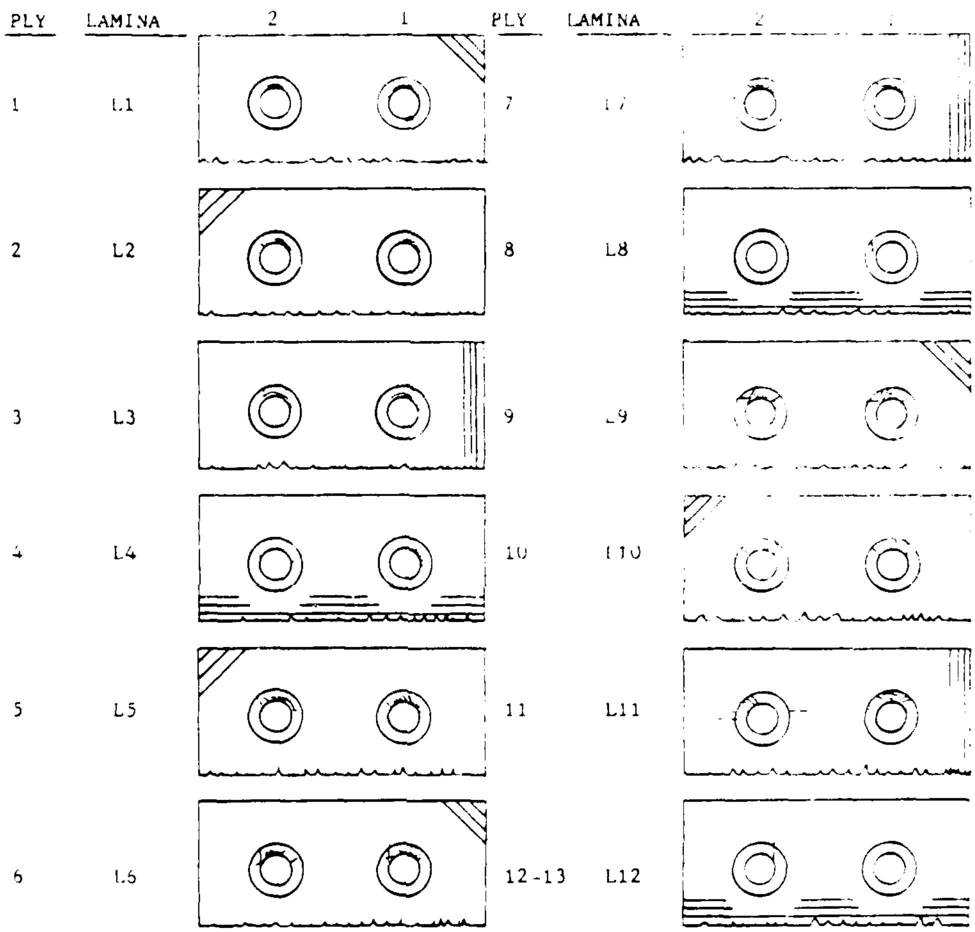


Figure F-42. Lamina Damage Characterization Chart for Specimen

IIA-C-1 Strap A Load Level D (Continued)

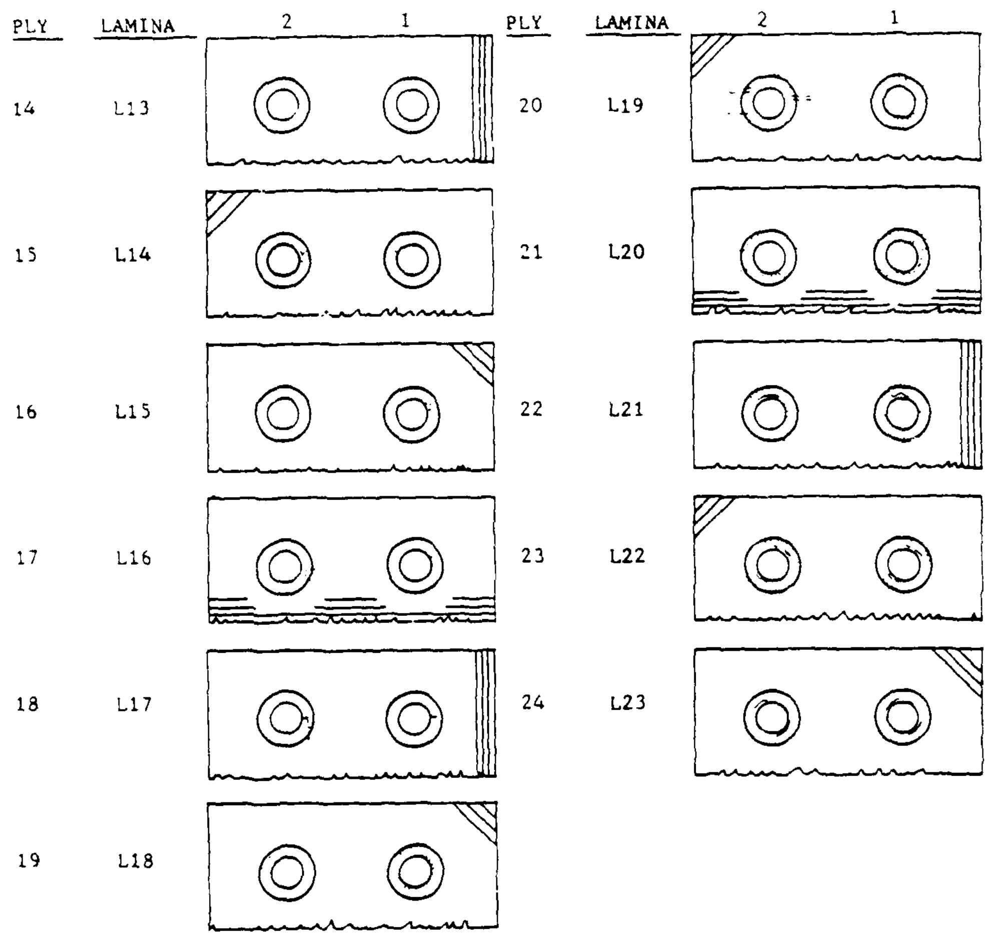


Figure F-42. Lamina Damage Characterization Chart for Specimen

IIA-C-1 Strap A Load Level D

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm 45^{\circ}$, 0°, 90°, $\mp 45^{\circ}$, 0°, 90°, $\pm 45^{\circ}$, 0°, 90°)s

LOAD LEVEL - D

POUNDS LOAD - 7658 PERCENT OF ULTIMATE - 79

FIGURE F-43. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-7.

BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE F-44. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-7.

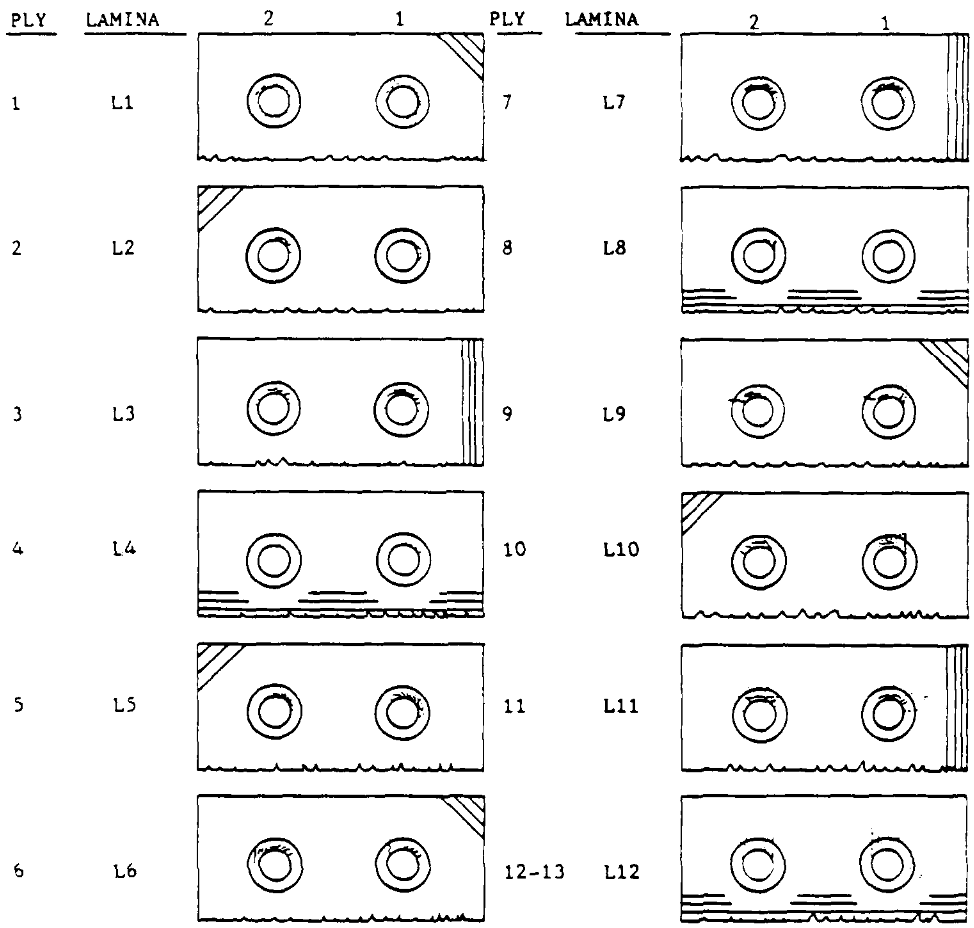


Figure F-45. Lamina Damage Characterization Chart for Specimen

IIA-C-7 Strap A Load Level D (Continued)

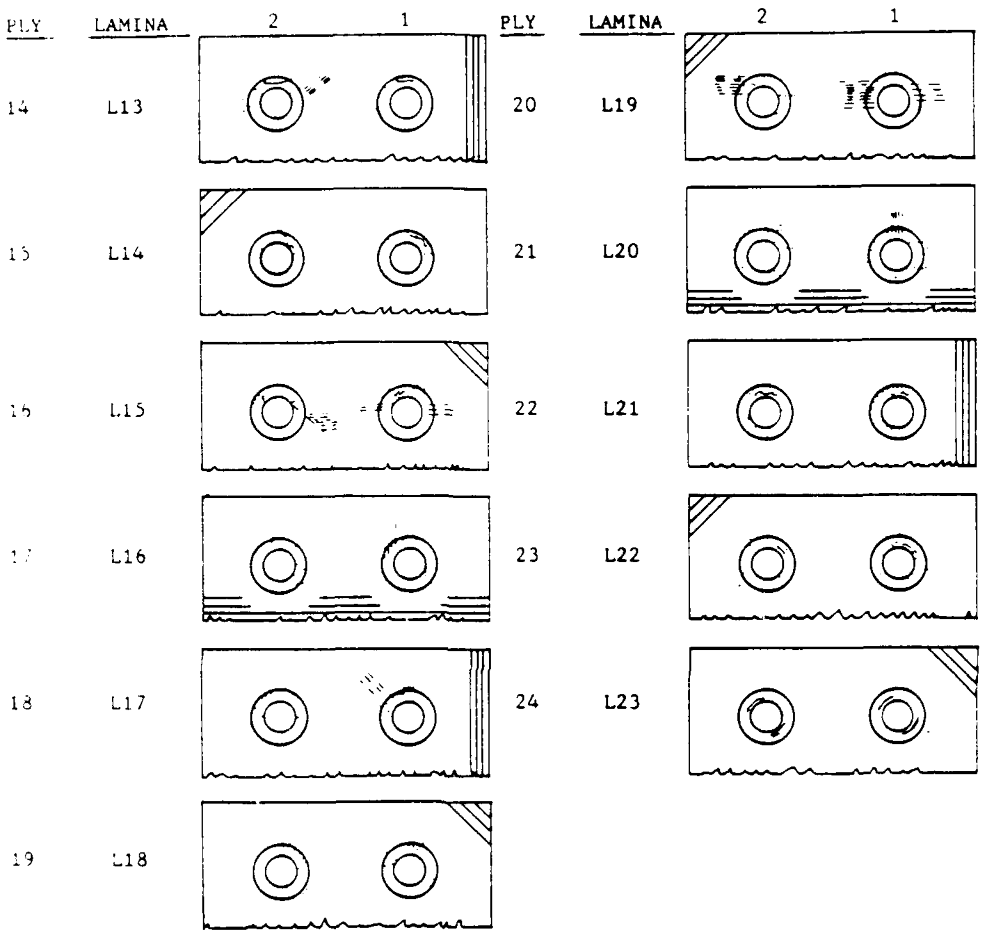


Figure F-45. Lamina Damage Characterization Chart for Specimen

IIA-C -7 Strap A Load Level D

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm 45^\circ$, 0°, 90°, $\mp 45^\circ$, 0°, 90°, $\pm 45^\circ$, 0°, 90°)s

LOAD LEVEL - B

POUNDS LOAD - 8459 PERCENT OF ULTIMATE - 88

FIGURE F-46. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-27.

BEFORE LOADING AFTER LOADING

FIGURE F-47. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-27.

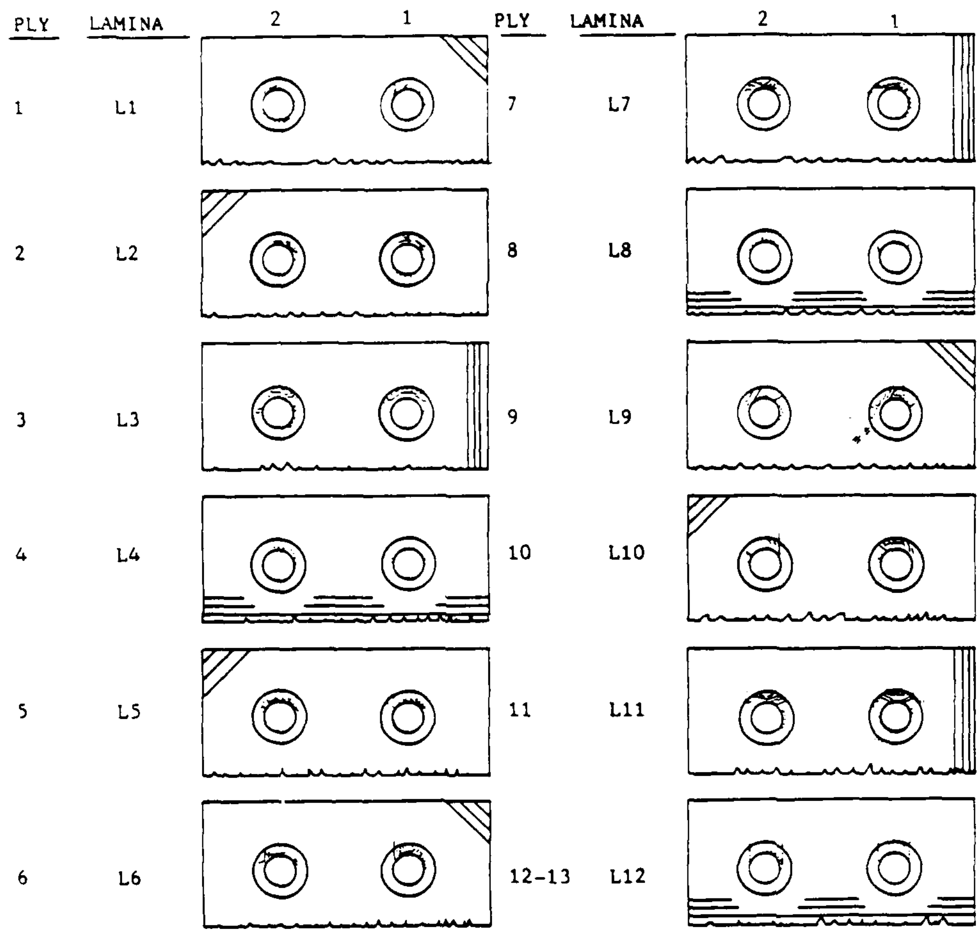


Figure F-48. Lamina Damage Characterization Chart for Specimen

IIA-C-27 Strap A Load Level B (Continued)

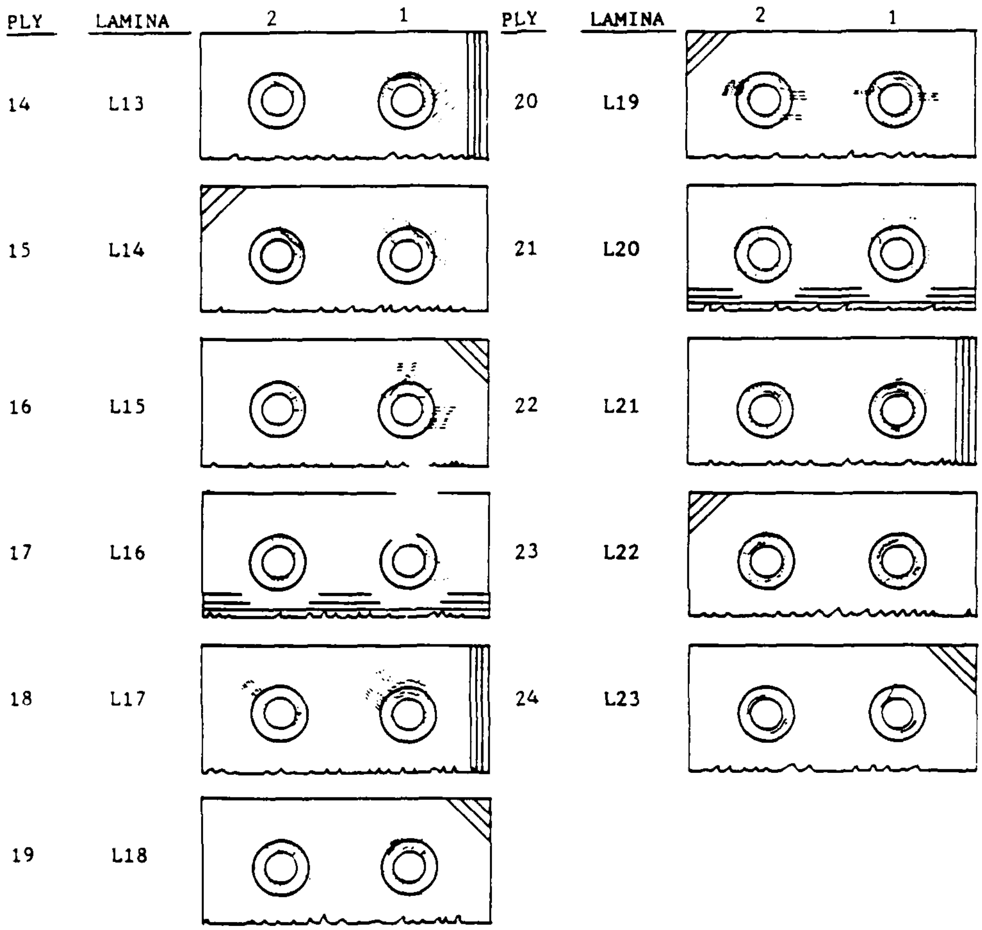


Figure F-48. Lamina Damage Characterization Chart for Specimen

IIA-C-27 Strap A Load Level B

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - $C(\pm45^{\circ}, 0^{\circ}, 90^{\circ}, \mp45^{\circ}, 0^{\circ}, 90^{\circ}, \pm45^{\circ}, 0^{\circ}, 90^{\circ})_s$

LOAD LEVEL - B

POUNDS LOAD - 8459 PERCENT OF ULTIMATE - 88

FIGURE F-49. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-6.

BEFORE LOADING AFTER LOADING

FIGURE F-50. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-6.

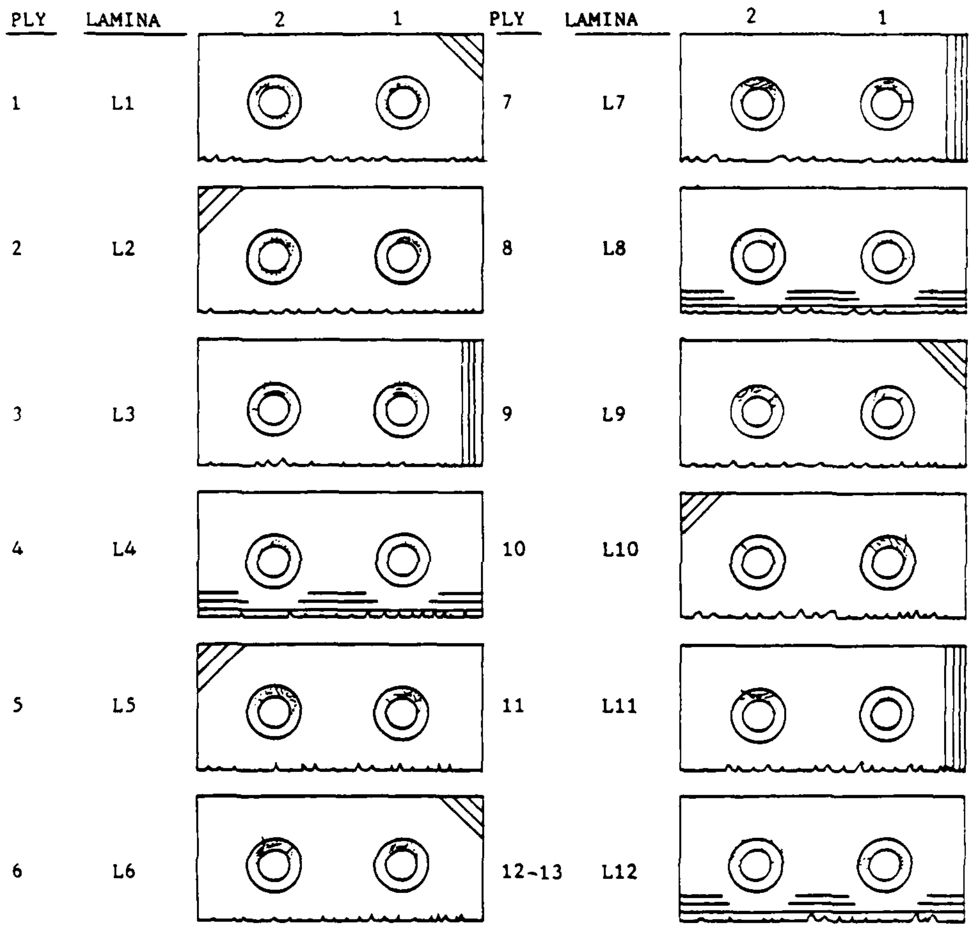


Figure F-51. Lamina Damage Characterization Chart for Specimen

IIA-C-6 Strap A Load Level B (Continued)

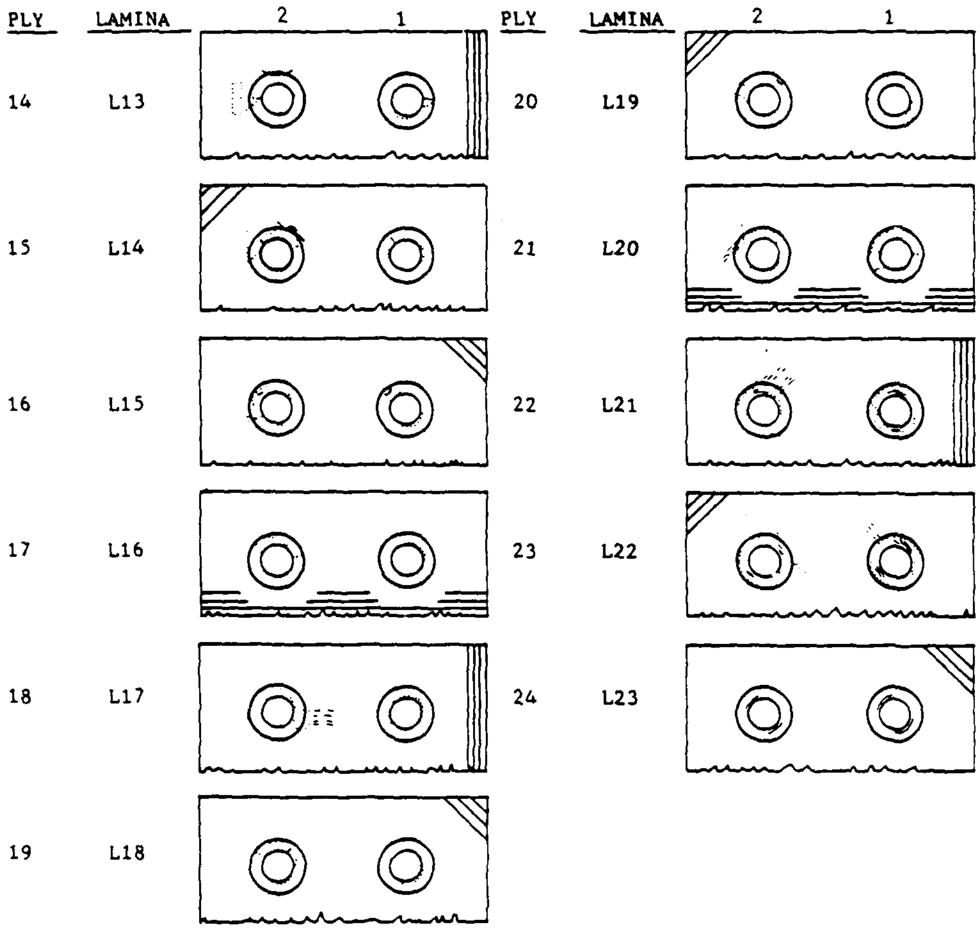


Figure F-51. Lamina Damage Characterization Chart for Specimen

IIA-C-6 Strap A Load Level B

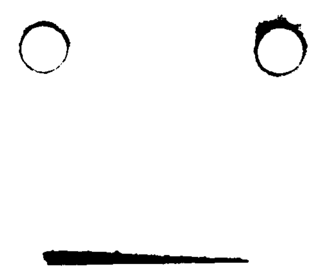
SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm45^\circ$, 0°, 90°, $\mp45^\circ$, 0°, 90°, $\pm45^\circ$, 0°, 90°)s

LOAD LEVEL - B

POUNDS LOAD - 8459 PERCENT OF ULTIMATE - 88

FIGURE F-52. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-11.



BEFORE LOADING AFTER LOADING

FIGURE F-53. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-11.

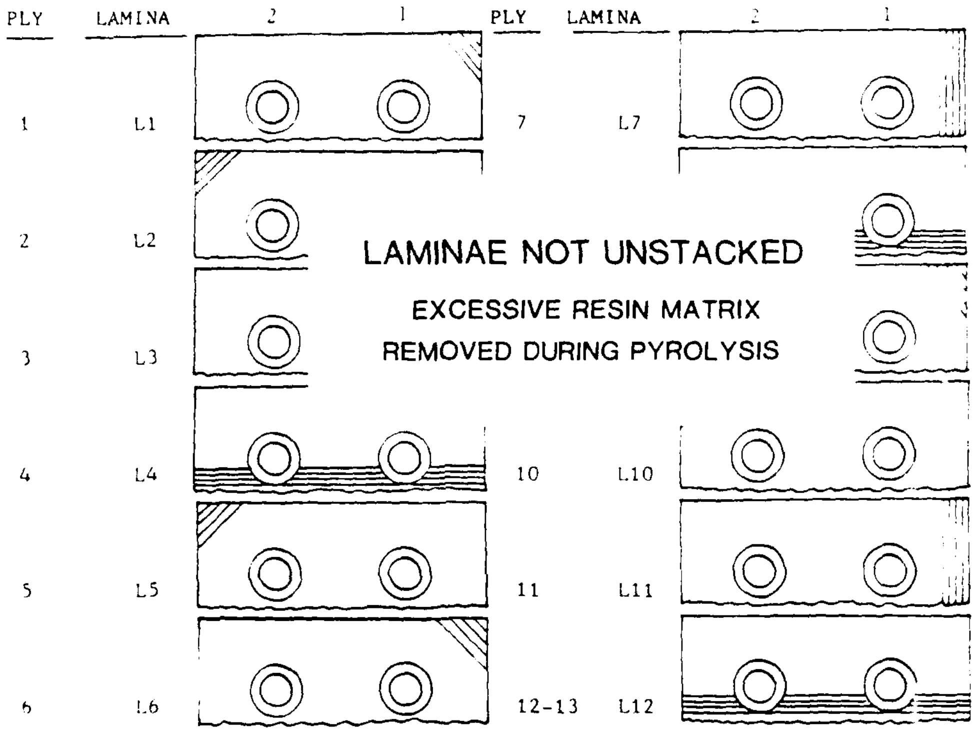


Figure F.[illegible]. Lamina Damage Characterization Chart for Specimen IIA-C-11 Strap A Load Level B

SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm 45^{o}$, 0^{o}, 90^{o}, $\mp 45^{o}$, 0^{o}, 90^{o}, $\pm 45^{o}$, 0^{o}, 90^{o})s

LOAD LEVEL - B

POUNDS LOAD - 8459 PERCENT OF ULTIMATE - 88

FIGURE F-55. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-10.

BEFORE LOADING AFTER LOADINC

FIGURE F-56. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-10.

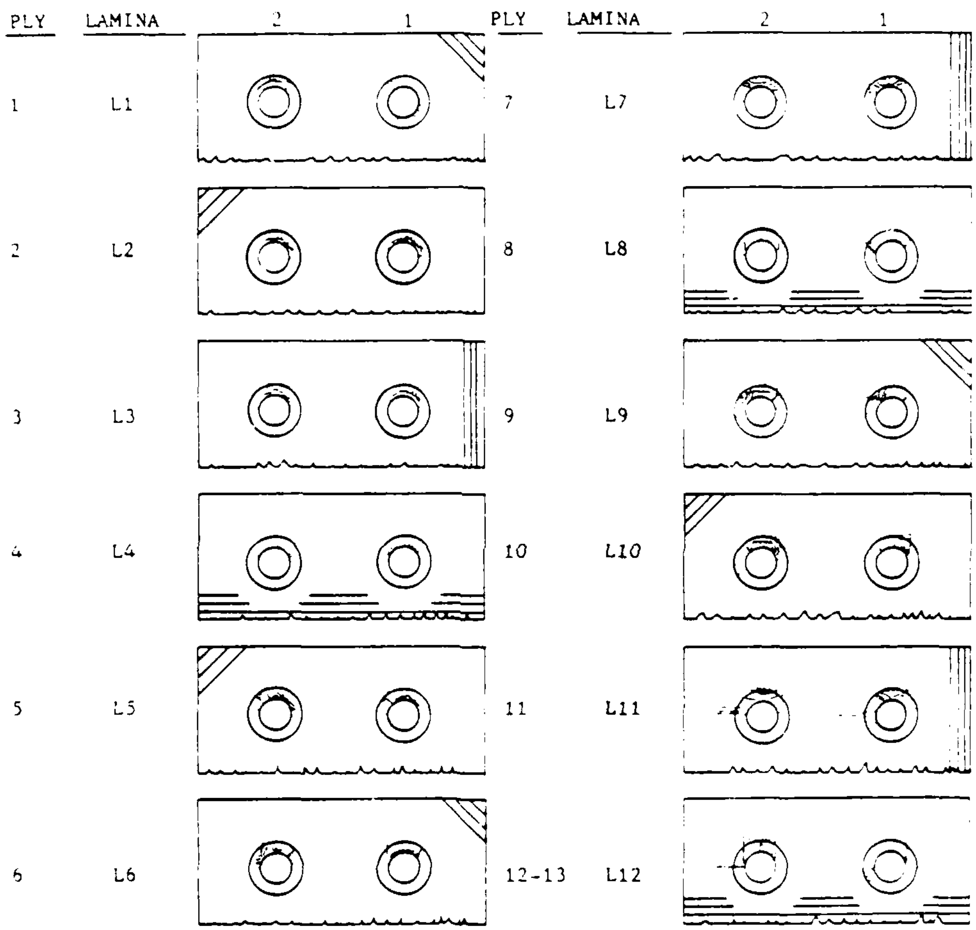


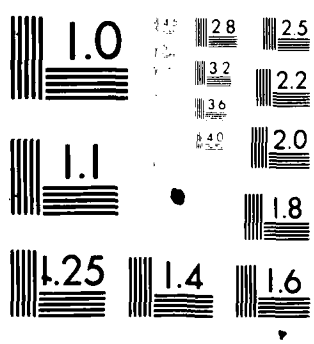
Figure F-57. Lamina Damage Characterization Chart for Specimen

IIA-C-10 Strap A Load Level B (Continued)

AD-A116 120 LOCKHEED-GEORGIA CO MARIETTA F/G 11/4
DAMAGE PROGRESSION IN GRAPHITE-EPOXY BY A DEPLYING TECHNIQUE.(U)
DEC 81 S M FREEMAN F33615-80-C-3224
UNCLASSIFIED LG-81ER0245 AFWAL-TR-81-3157 NL

5 of 6
AD
A116120

116120



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

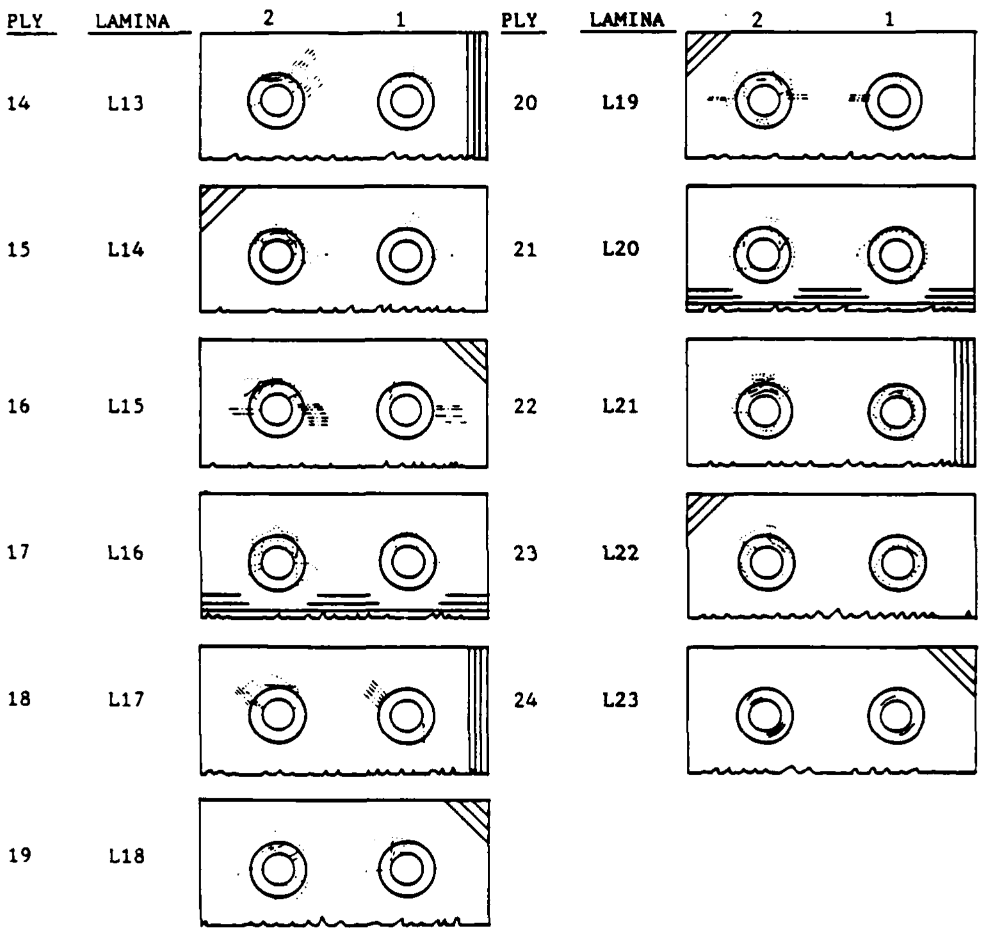


Figure F-57. Lamina Damage Characterization Chart for Specimen

IIA-C-10 Strap A Load Level B

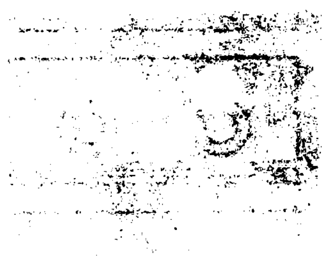
SPECIMEN TYPE - IIA (BOLTED JOINT)

LAMINATE - C($\pm 45^\circ$, 0°, 90°, $\mp 45^\circ$, 0°, 90°, $\pm 45^\circ$, 0°, 90°)s

LOAD LEVEL - B

POUNDS LOAD - 8459 PERCENT OF ULTIMATE - 88

FIGURE F-58. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIA-C-2.



BEFORE LOADING

AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE F-59. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIA-C-2.

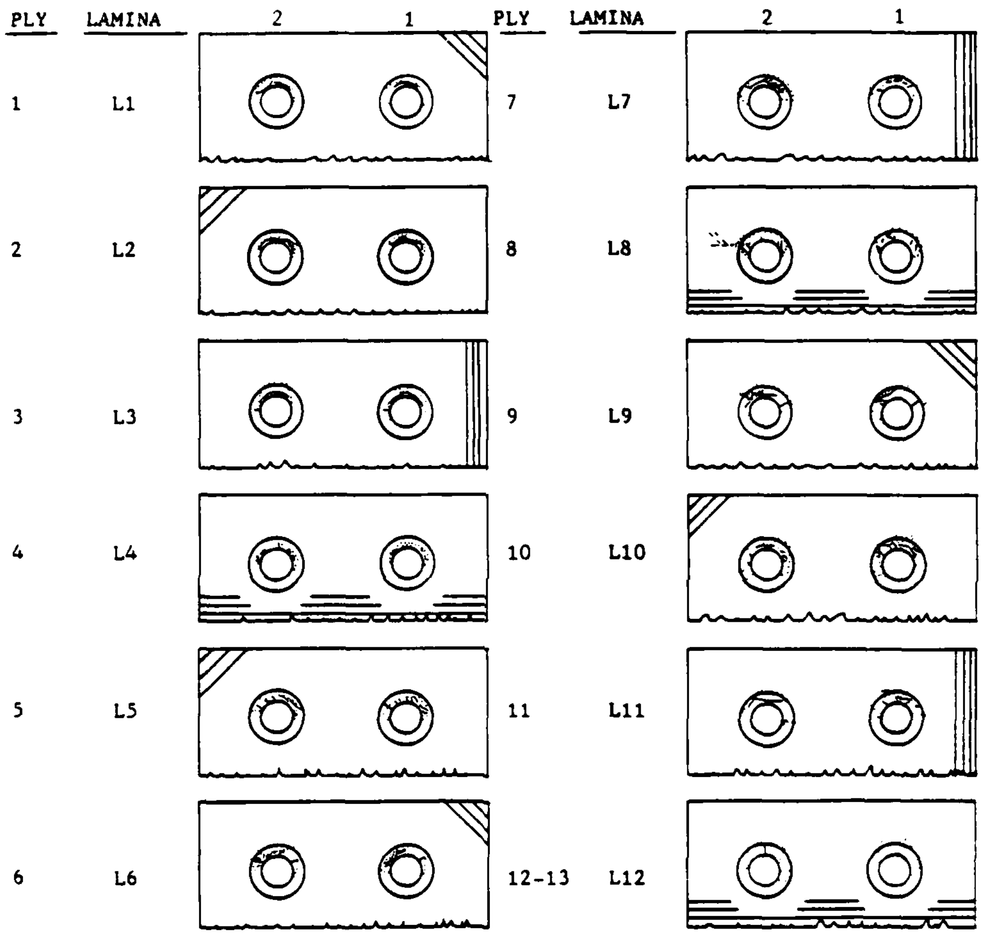


Figure F-60. Lamina Damage Characterization Chart for Specimen

IIA-C-2 Strap A Load Level B (Continued)

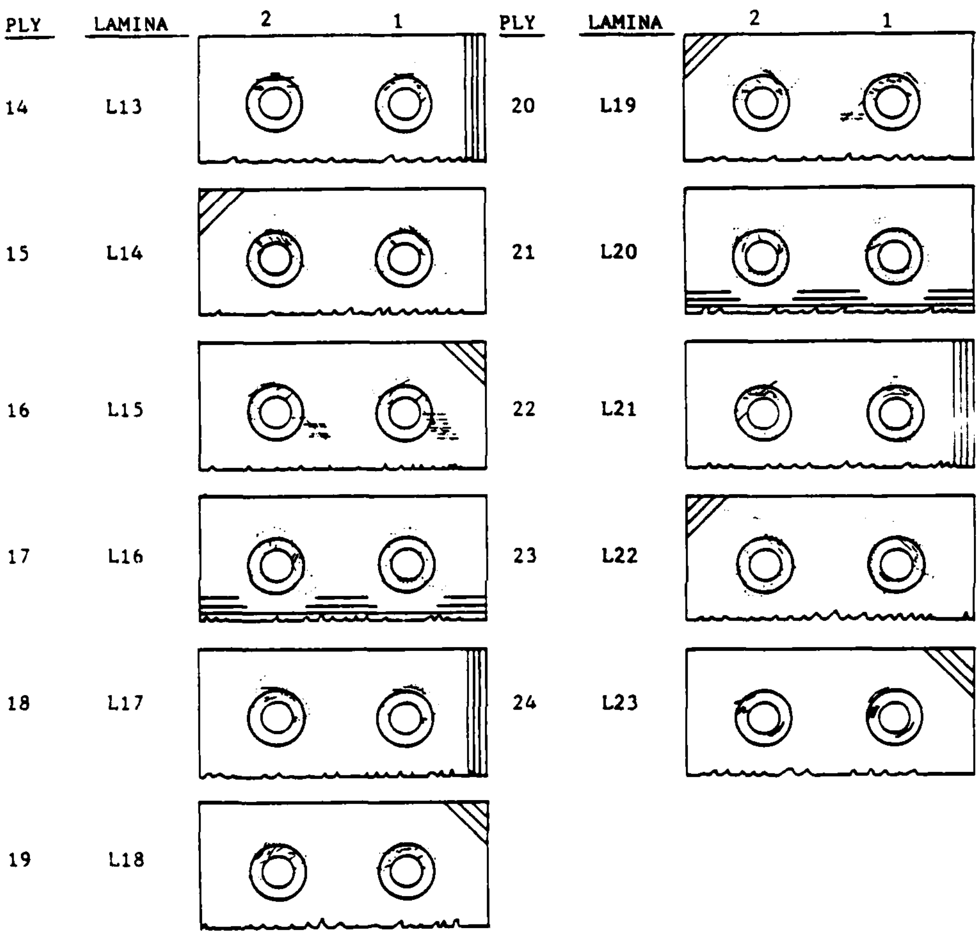


Figure F-60. Lamina Damage Characterization Chart for Specimen

IIA-C-2 Strap A Load Level B

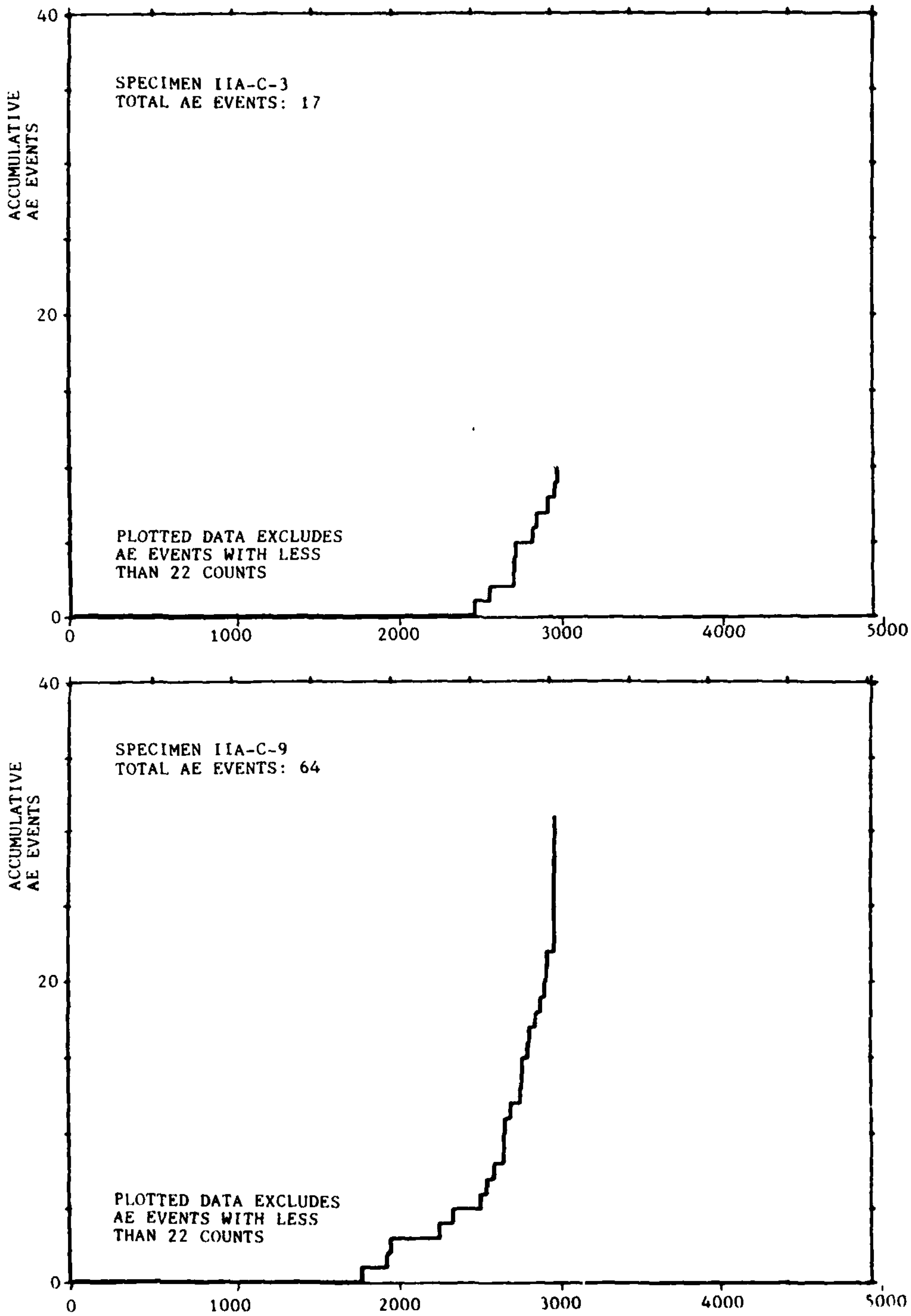


Figure F-61. Plots of Accumulative AE Events vs Applied Load for Type IIA-C Specimens with Minimum and Maximum Response for Load Level A.

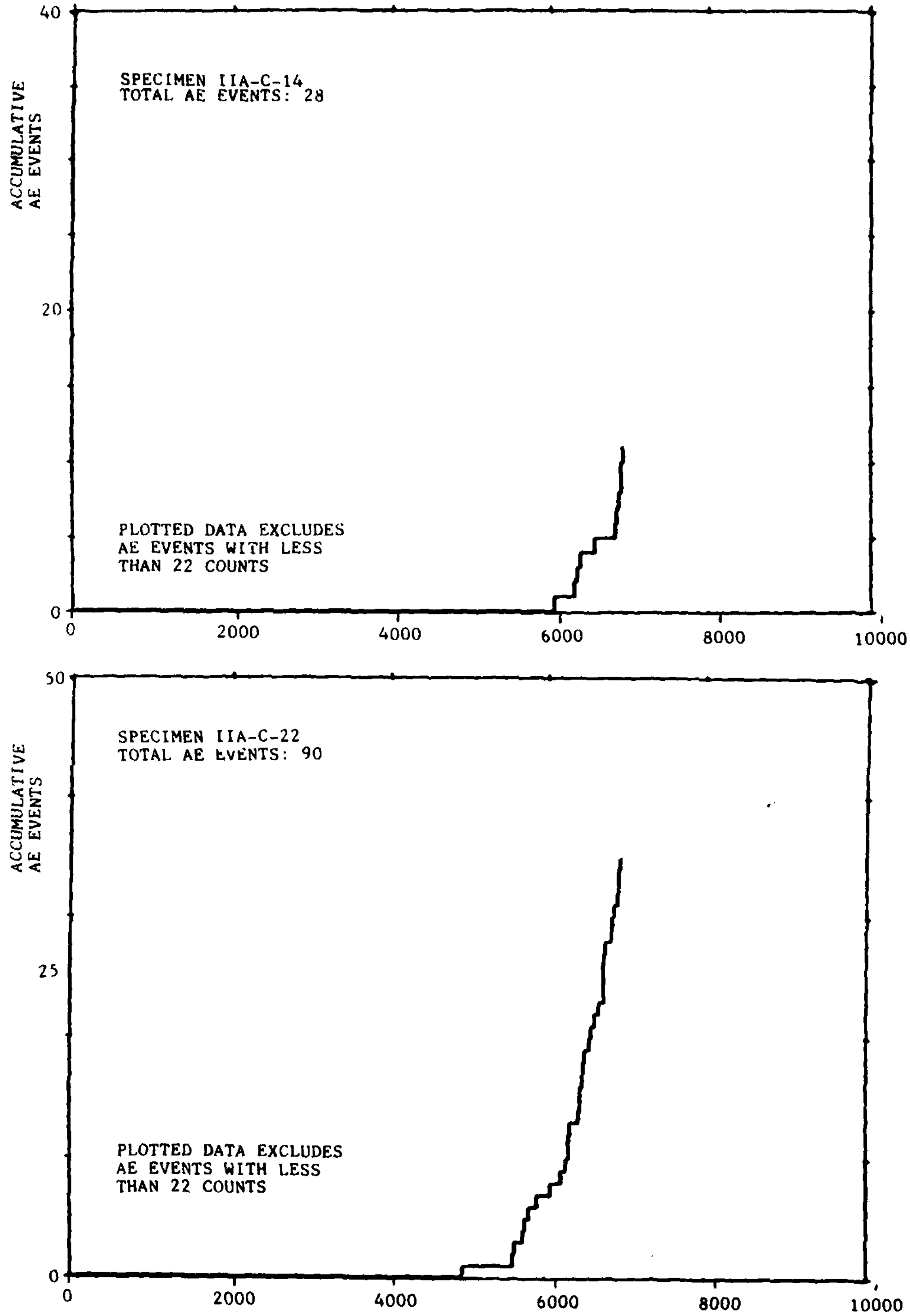


Figure F-62. Plots of Accumulative AE Events vs Applied Load for Type IIA-C Specimens with Minimum and Maximum Response for Load Level C.

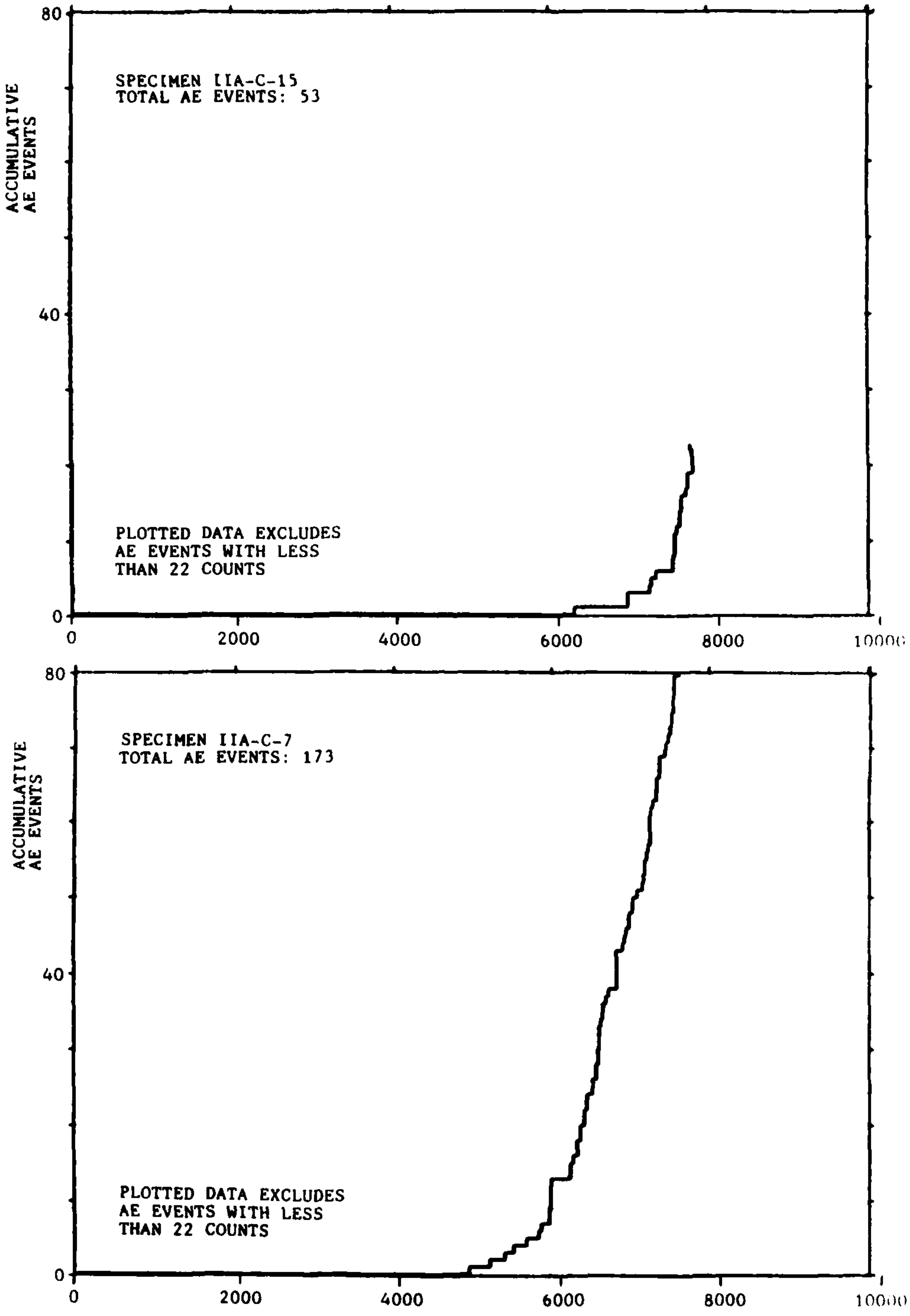
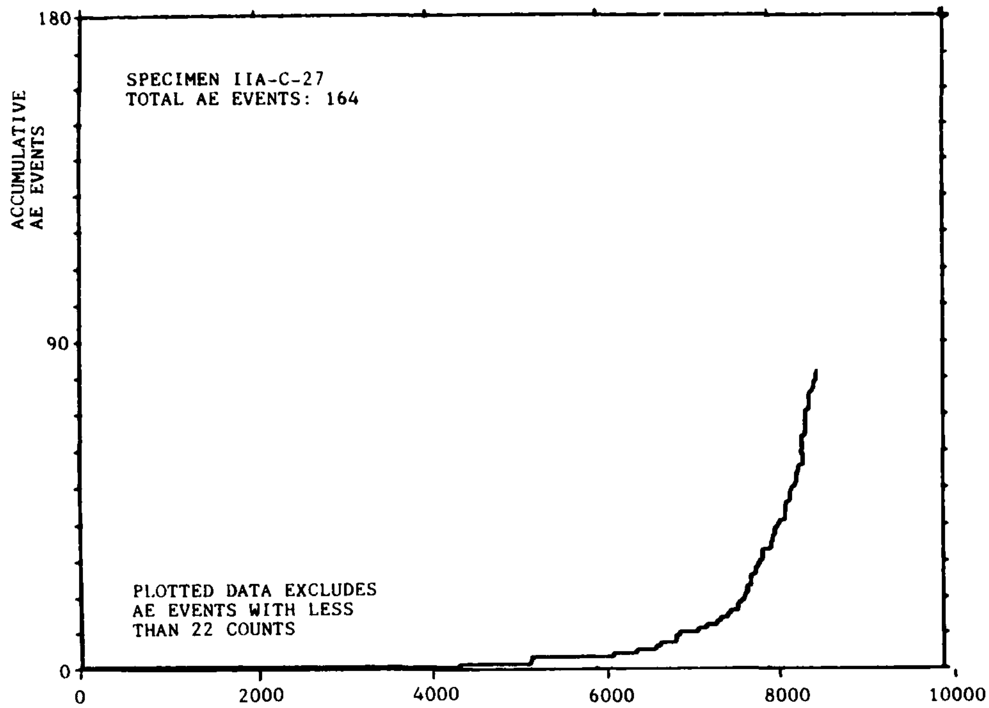


Figure F-63. Plots of Accumulative AE Events vs Applied Load for Type IIA-C Specimens with Minimum and Maximum Response for Load Level D.



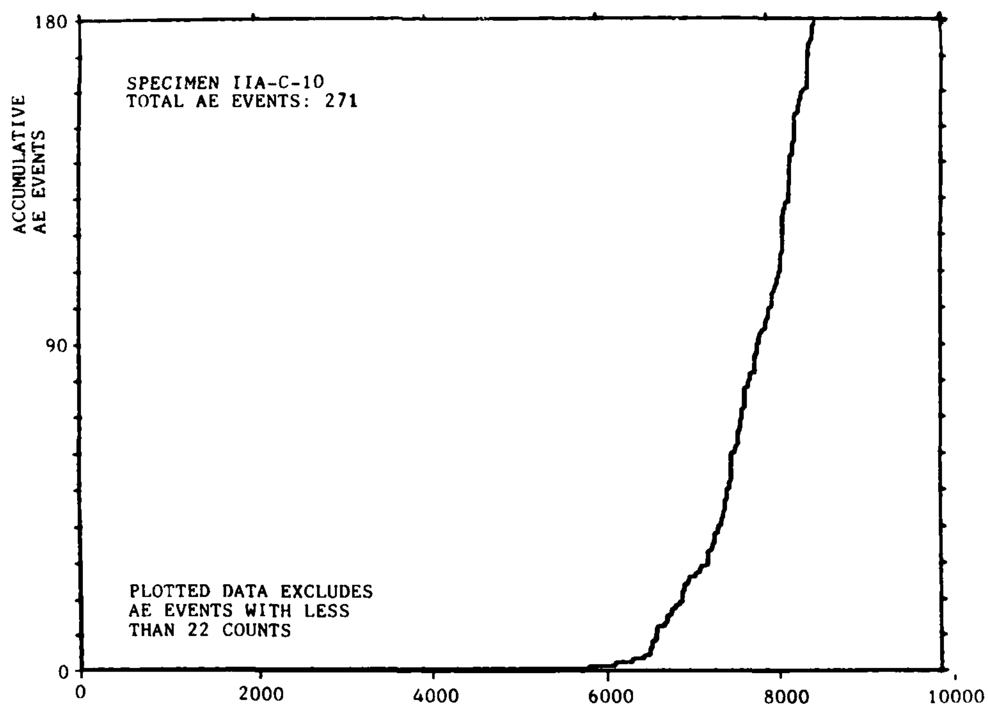


Figure F-64. Plots of Accumulative AE Events vs Applied Load for Type IIA-C Specimens with Minimum and Maximum Response for Load Level B.

APPENDIX G

DETAIL DAMAGE INFORMATION FOR TYPE IIB-A SPECIMENS

The detail information for the Type IIB specimens of Laminate A is presented in this appendix. It is presented in the order of increasing load levels. All specimens of the same load level are grouped together. Three figures are presented for each specimen. The first figure gives specimen type, laminate information and load conditions. The second figure consists of positive prints of enhanced x-ray radiographs made before and after loading. In addition, prints of a stereo x-ray pair are included for one specimen of each load level. The third figure consists of a Lamina Damage Characterization Chart. This chart contains a pictorial sketch for each lamina with fiber orientations indicated on one side or edge of each sketch. Also an outline of the fastener head is shown on these sketches to provide a visual reference as to the magnitude of the damage. The damage observed on each lamina is recorded on the appropriate sketch in a manner to indicate size and location relative to the fastener hole As shown in these charts lamina No. 1 was adjacent to the joint inter :e and lamina No. 17 was adjacent to the fastener head.

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - A

POUNDS LOAD - 5000 PERCENT OF ULTIMATE - 64

FIGURE G-1. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-9.

BEFORE LOADING AFTER LOADING

FIGURE G-2. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-9.

PRECEDING PAGE BLANK-NOT FILMED

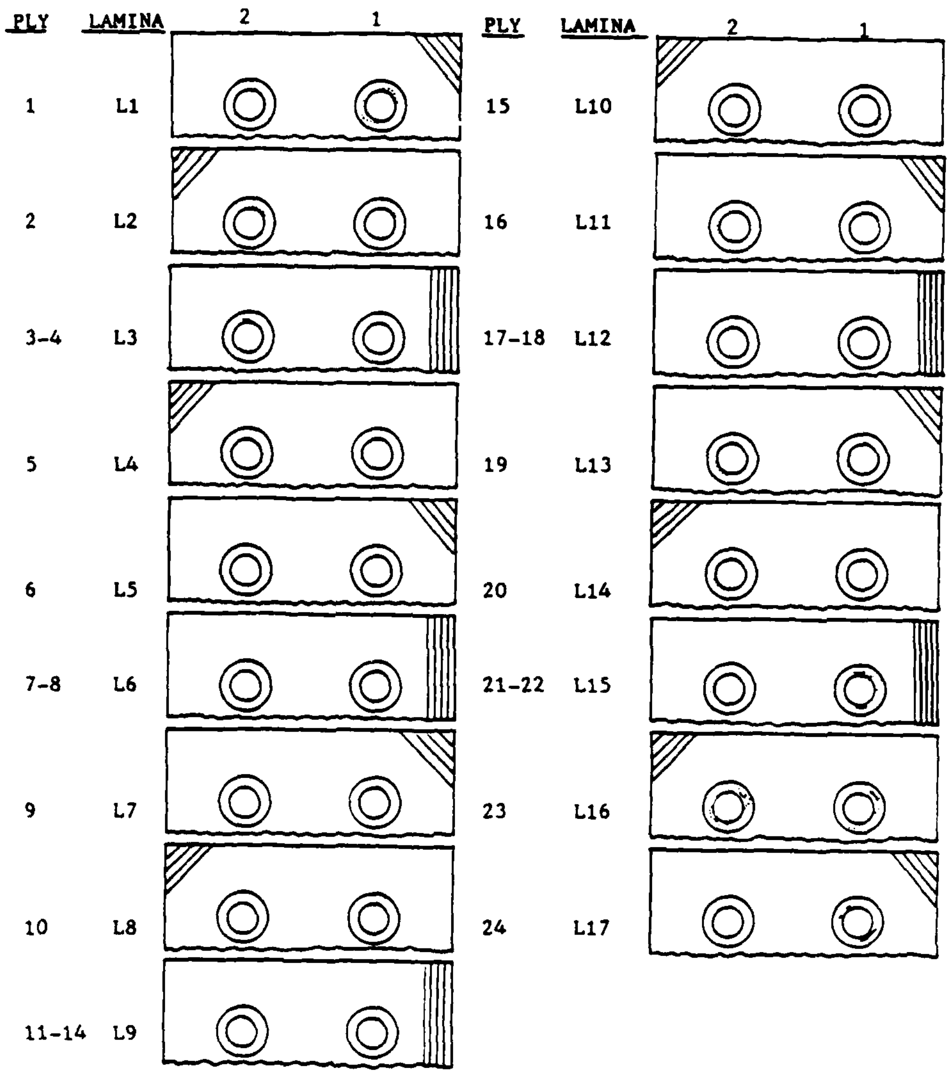


Figure G-3. Lamina Damage Characterization Chart for Specimen IIB-A-9 Strap A Load Level A

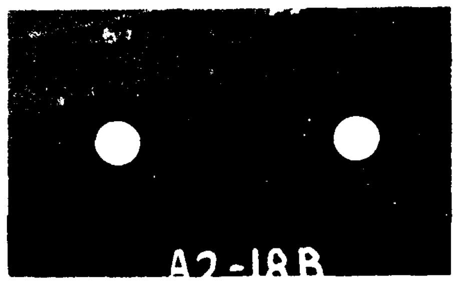
SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm45^\circ$, 0_2°, $\mp45^\circ$, 0_2°, $\pm45^\circ$, 0_2°)s

LOAD LEVEL - A

POUNDS LOAD - 5000 PERCENT OF ULTIMATE - 64

FIGURE G-4. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-18.



BEFORE LOADING AFTER LOADING

FIGURE G-5. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-18.

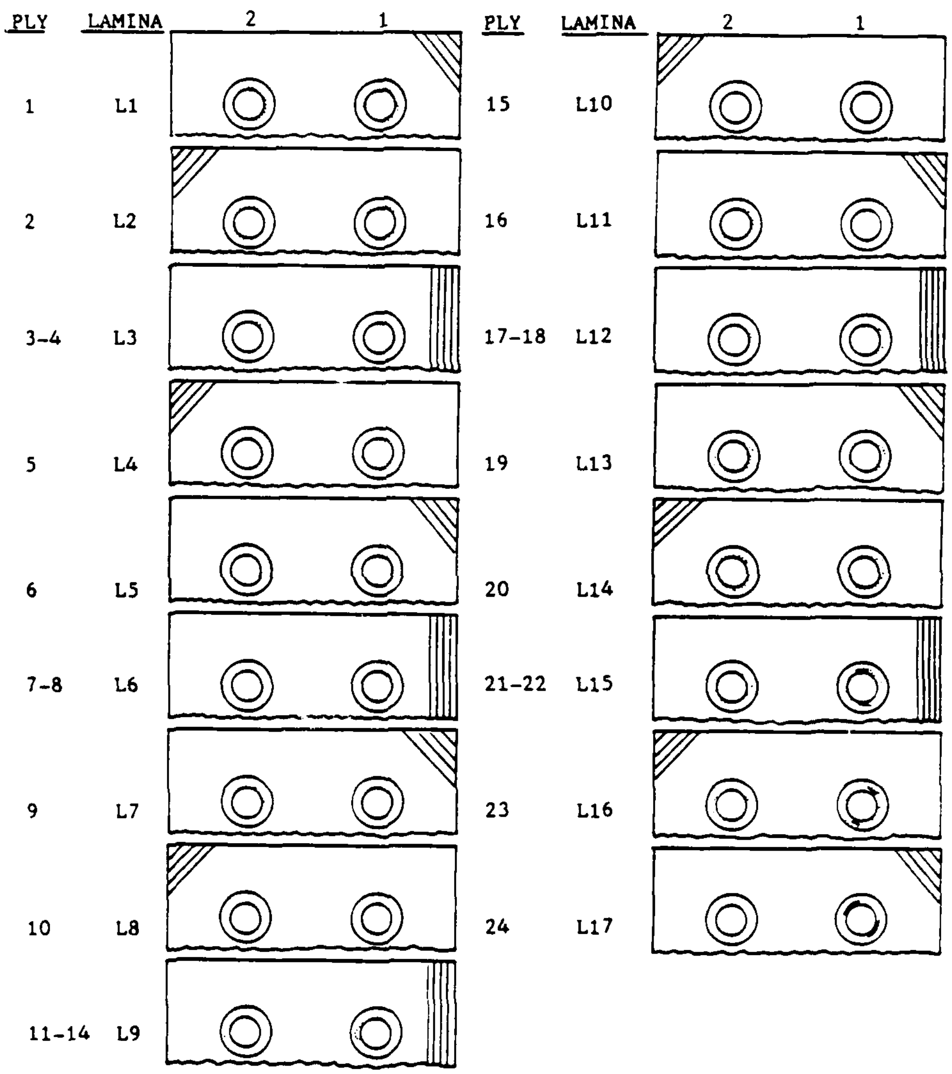


Figure G-6. Lamina Damage Characterization Chart for Specimen IIB-A-18 Strap B Load Level A

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm 45^\circ$, $0_2{}^\circ$, $\mp 45^\circ$, $0_2{}^\circ$, $\pm 45^\circ$, $0_2{}^\circ$)s

LOAD LEVEL - A

POUNDS LOAD - 5000 PERCENT OF ULTIMATE - 64

FIGURE G-7. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-12.

BEFORE LOADING AFTER LOADING

FIGURE G-8. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-12.

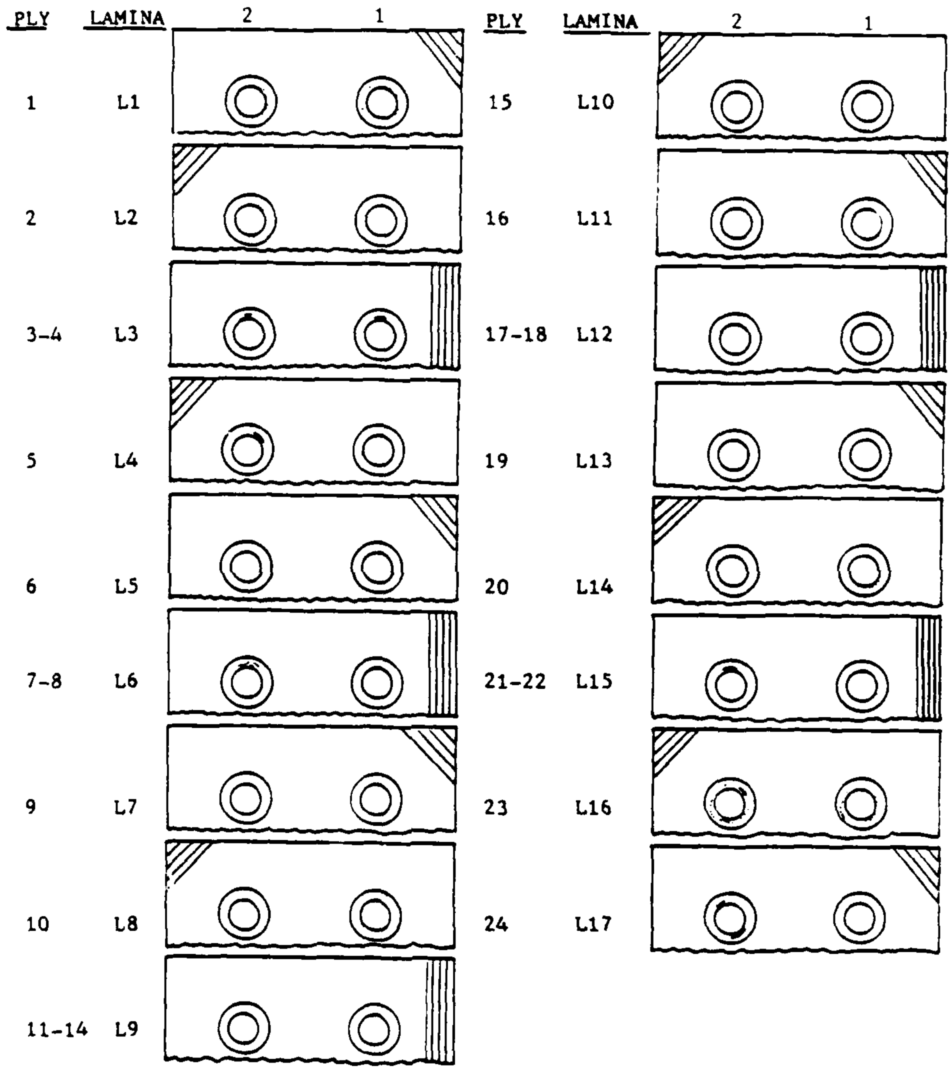


Figure G-9. Lamina Damage Characterization Chart for Specimen
IIB-A-12 Strap A Load Level A

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - A

POUNDS LOAD - 5000 PERCENT OF ULTIMATE - 64

FIGURE G-10 SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-8.

BEFORE LOADING AFTER LOADING

FIGURE G-11. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-8.

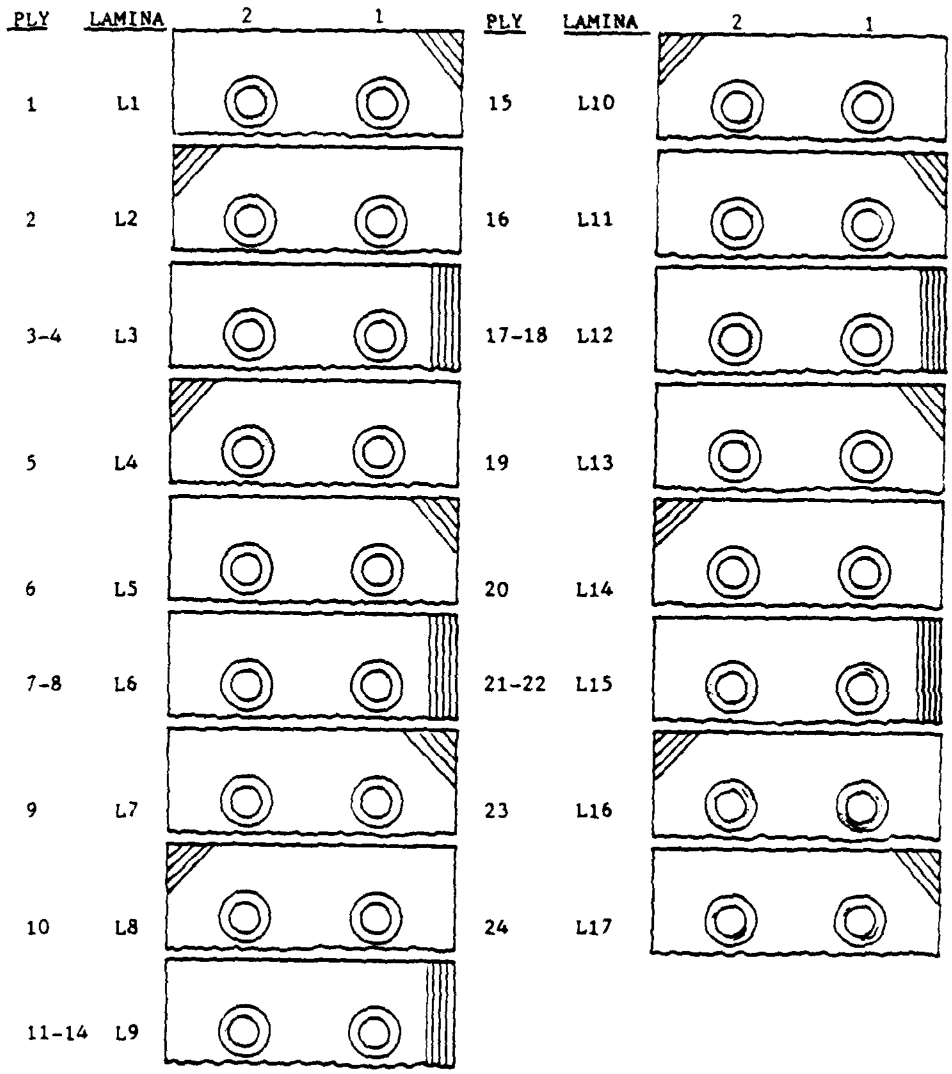


Figure G-12. Lamina Damage Characterization Chart for Specimen
IIB-A-8 Strap A Load Level A

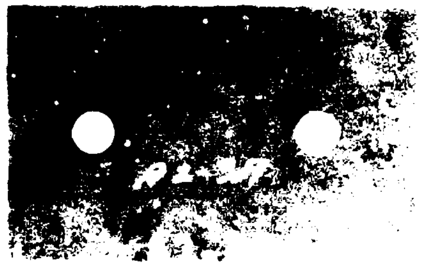
SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm 45^{o}$, 0_2^{o}, $\mp 45^{o}$, 0_2^{o}, $\pm 45^{o}$, 0_2^{o})s

LOAD LEVEL - A

POUNDS LOAD - 5000 PERCENT OF ULTIMATE - 64

FIGURE G-13. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-3.



BEFORE LOADING

AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE G-14. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-3.

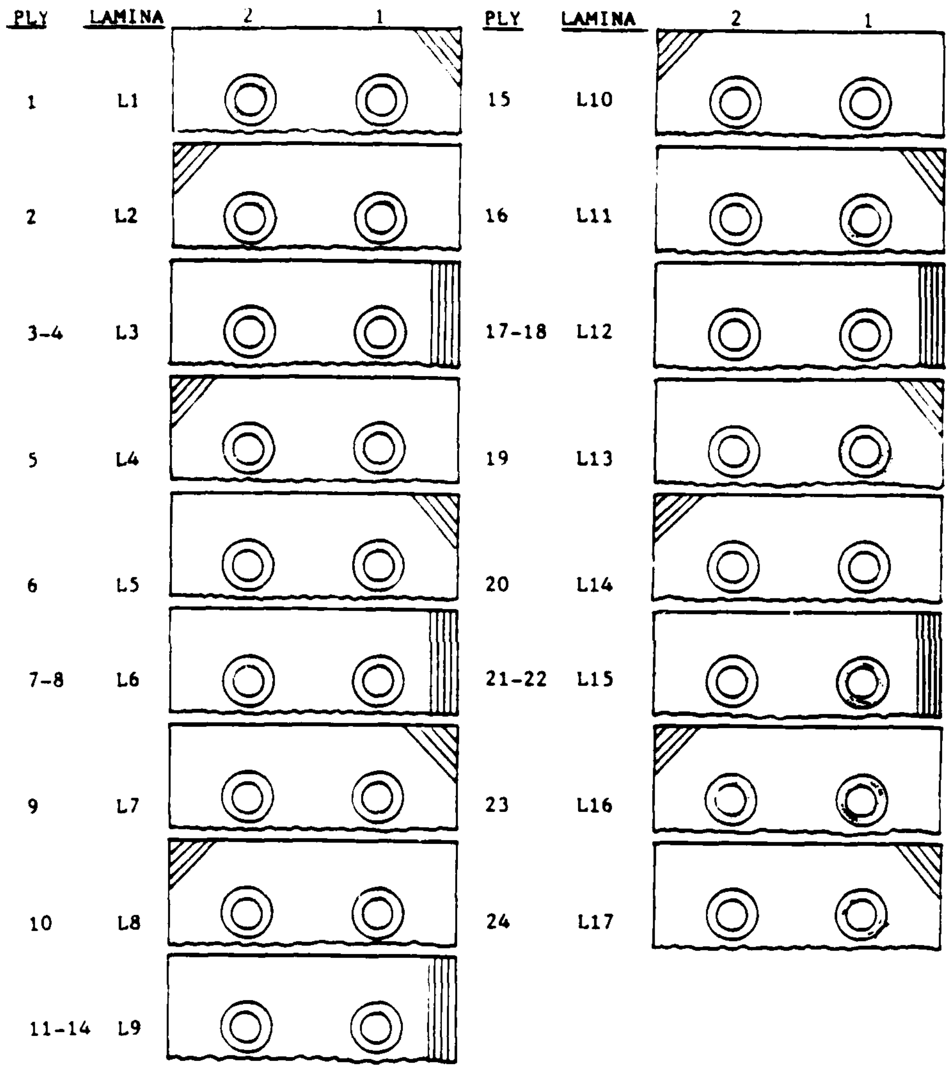


Figure G-15. Lamina Damage Characterization Chart for Specimen
IIB-A-3 Strap A Load Level A

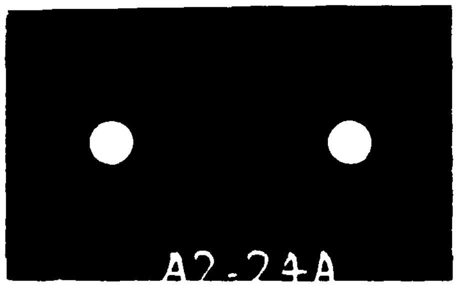
SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm 45^\circ$, 0_2°, $\mp 45^\circ$, 0_2°, $\pm 45^\circ$, 0_2°)s

LOAD LEVEL - C

POUNDS LOAD - 5614 PERCENT OF ULTIMATE - 72

FIGURE G-16. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-24.



BEFORE LOADING AFTER LOADING

FIGURE G-17. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-24.

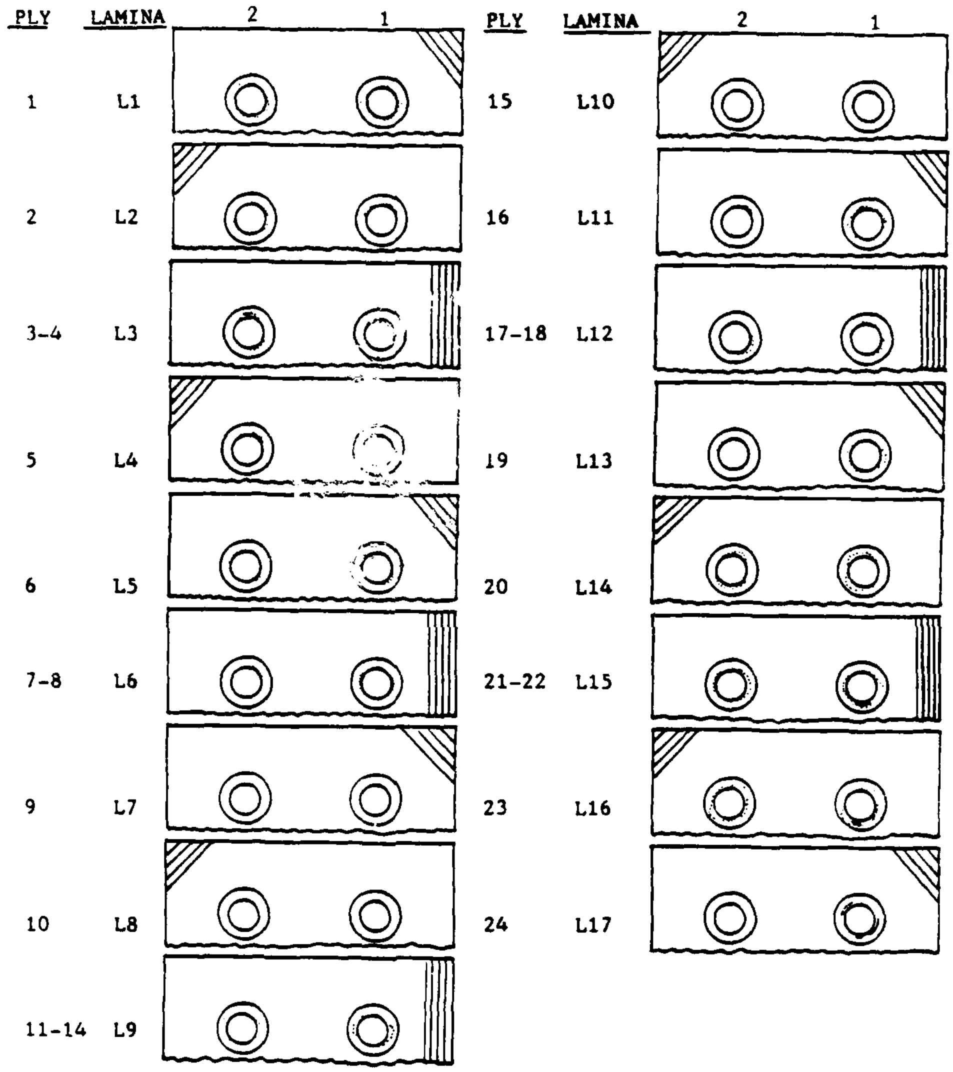


Figure G-18. Lamina Damage Characterization Chart for Specimen IIB-A-24 Strap A Load Level C

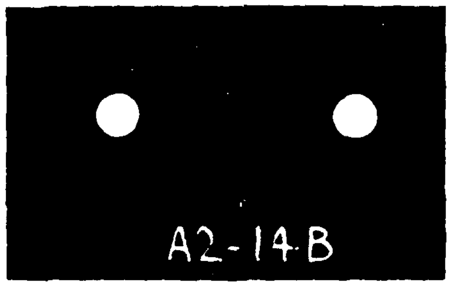
SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - C

POUNDS LOAD - 5614 PERCENT OF ULTIMATE - 72

FIGURE G-19. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-14.



BEFORE LOADING AFTER LOADING

FIGURE G-20. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-14.

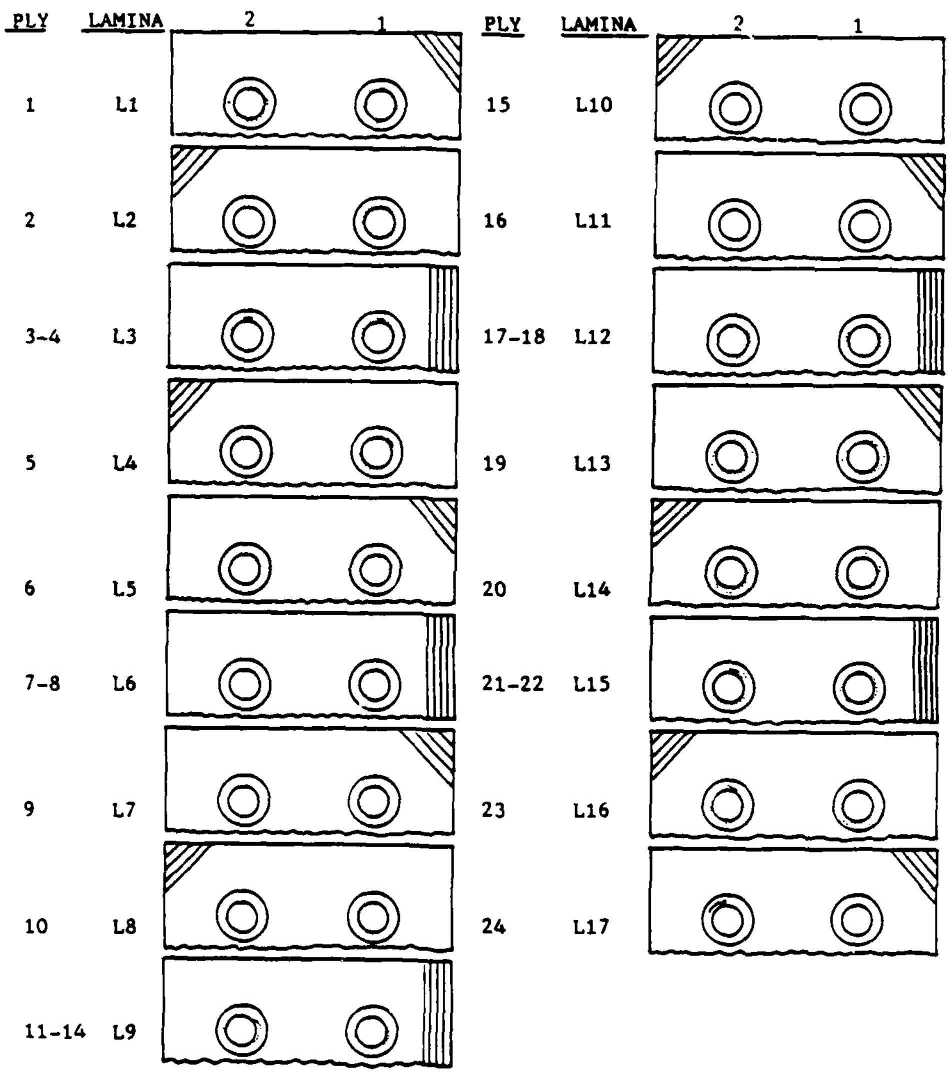


Figure G-21. Lamina Damage Characterization Chart for Specimen
IIB-A-14 Strap B Load Level C

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm 45^\circ$, $0_2{}^\circ$, $\mp 45^\circ$, $0_2{}^\circ$, $\pm 45^\circ$, $0_2{}^\circ$)s

LOAD LEVEL - C

POUNDS LOAD - 5614 PERCENT OF ULTIMATE - 72

FIGURE G-22. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-21.

BEFORE LOADING AFTER LOADING

FIGURE G-23. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-21.

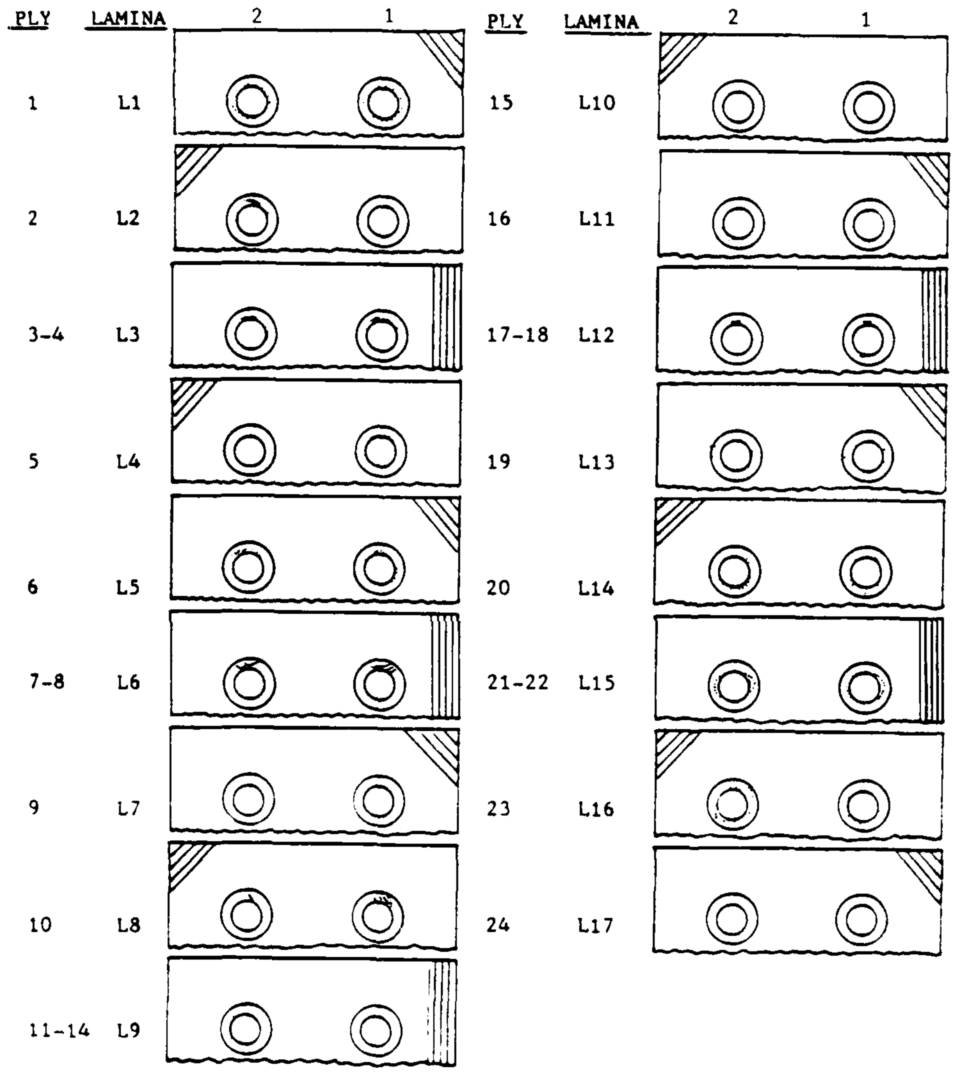


Figure G-24. Lamina Damage Characterization Chart for Specimen
IIB-A-21 Strap B Load Level C

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - C

POUNDS LOAD - 5614 PERCENT OF ULTIMATE - 72

FIGURE G-25. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-16.

BEFORE LOADING AFTER LOADING

FIGURE G-26. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-16.

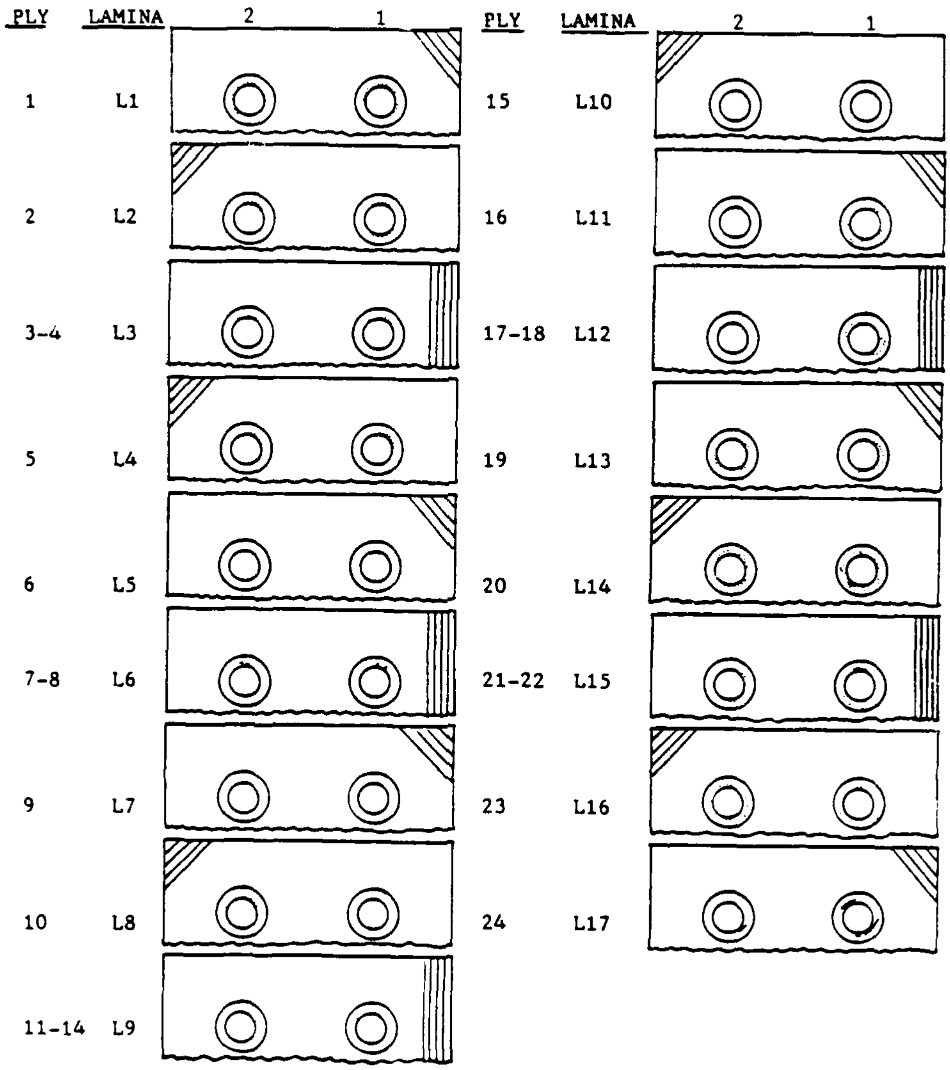


Figure G-27. Lamina Damage Characterization Chart for Specimen IIB-A-16 Strap A Load Level C

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm45^\circ$, 0_2°, $\mp45^\circ$, 0_2°, $\pm45^\circ$, 0_2°)s

LOAD LEVEL - C

POUNDS LOAD - 5614 PERCENT OF ULTIMATE - 72

FIGURE G-28. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-22.

BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE G-29. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-22.

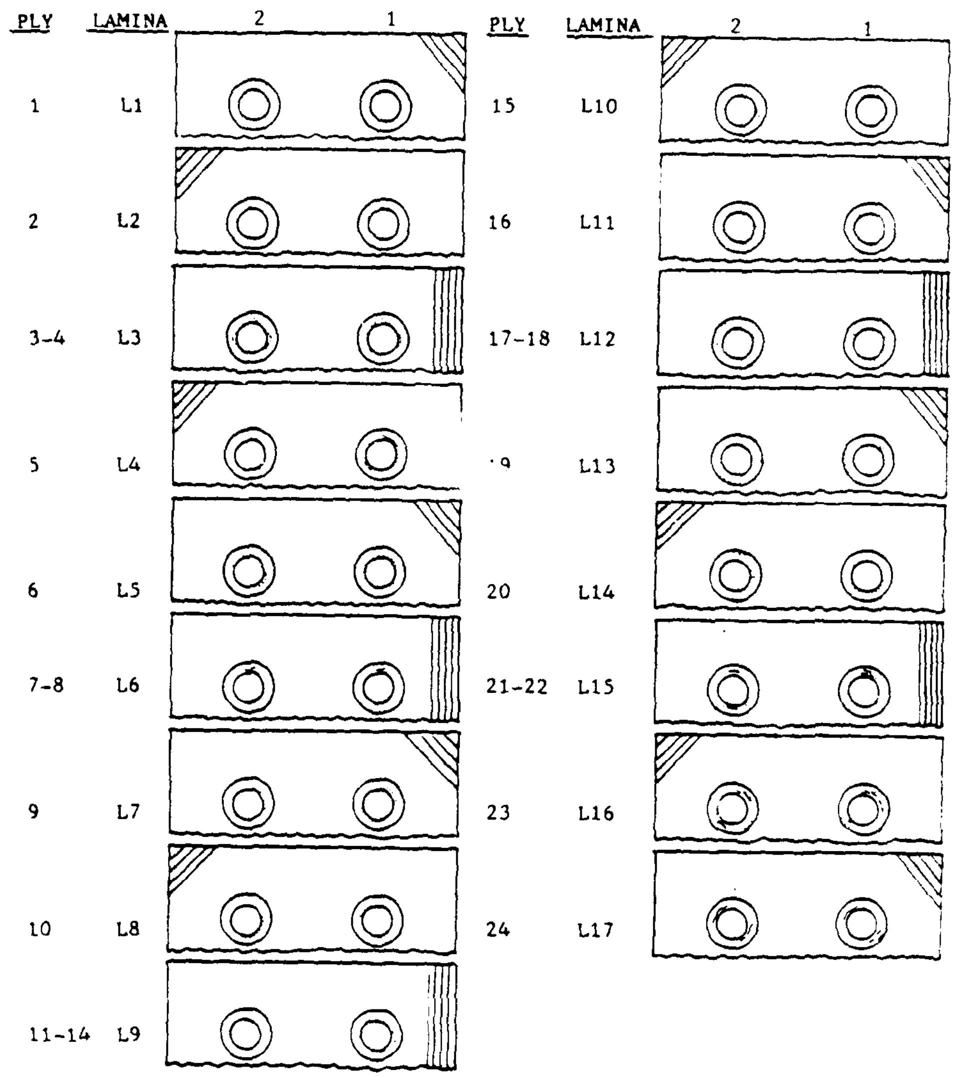


Figure G-30. Lamina Damage Characterization Chart for Specimen
IIB-A-22 Strap B Load Level C

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, $0_2{}^{\circ}$, $\mp 45^{\circ}$, $0_2{}^{\circ}$, $\pm 45^{\circ}$, $0_2{}^{\circ}$)s

LOAD LEVEL - D

POUNDS LOAD - 6238 PERCENT OF ULTIMATE - 80

FIGURE G-31. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-15.

BEFORE LOADING AFTER LOADING

FIGURE G-32. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-15.

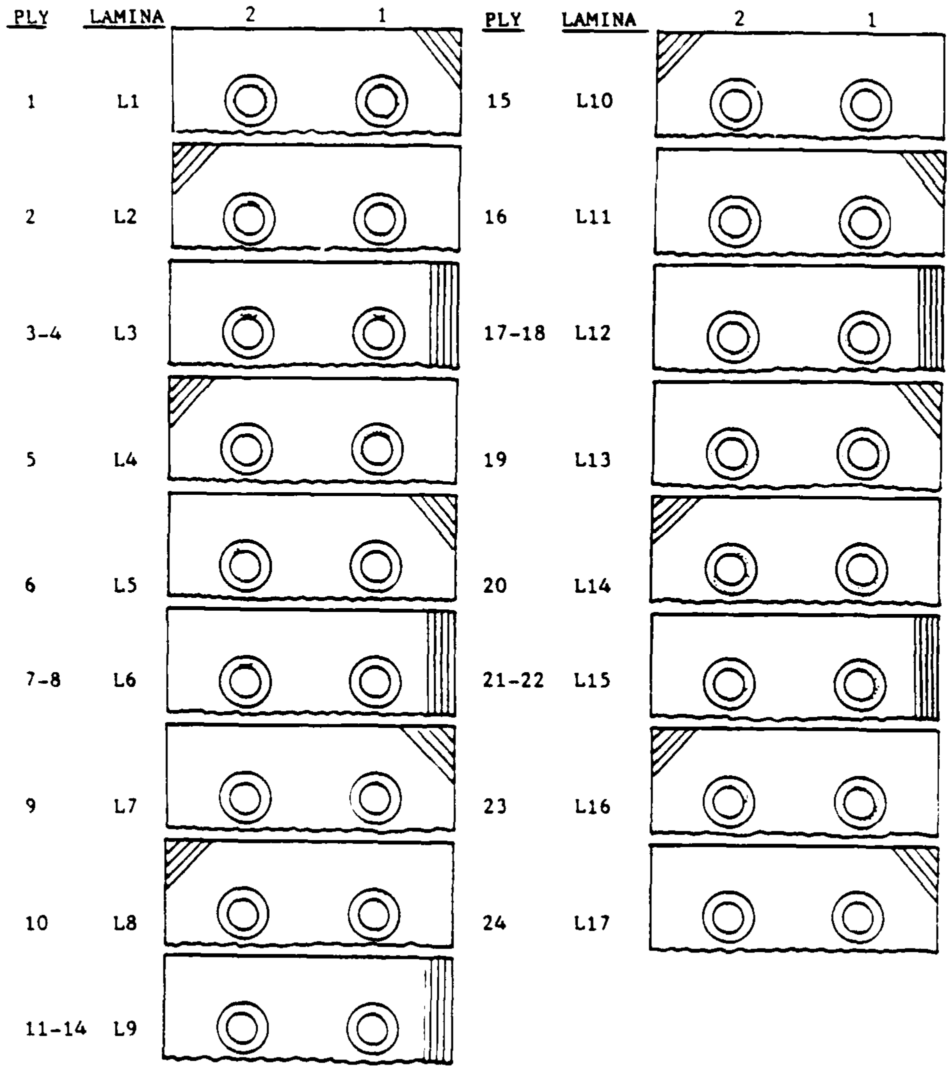


Figure G-33. Lamina Damage Characterization Chart for Specimen IIB-A-15 Strap B Load Level D

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - D

POUNDS LOAD - 6238 PERCENT OF ULTIMATE - 80

FIGURE G-34. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-13.

BEFORE LOADING AFTER LOADING

FIGURE G-35. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-13.

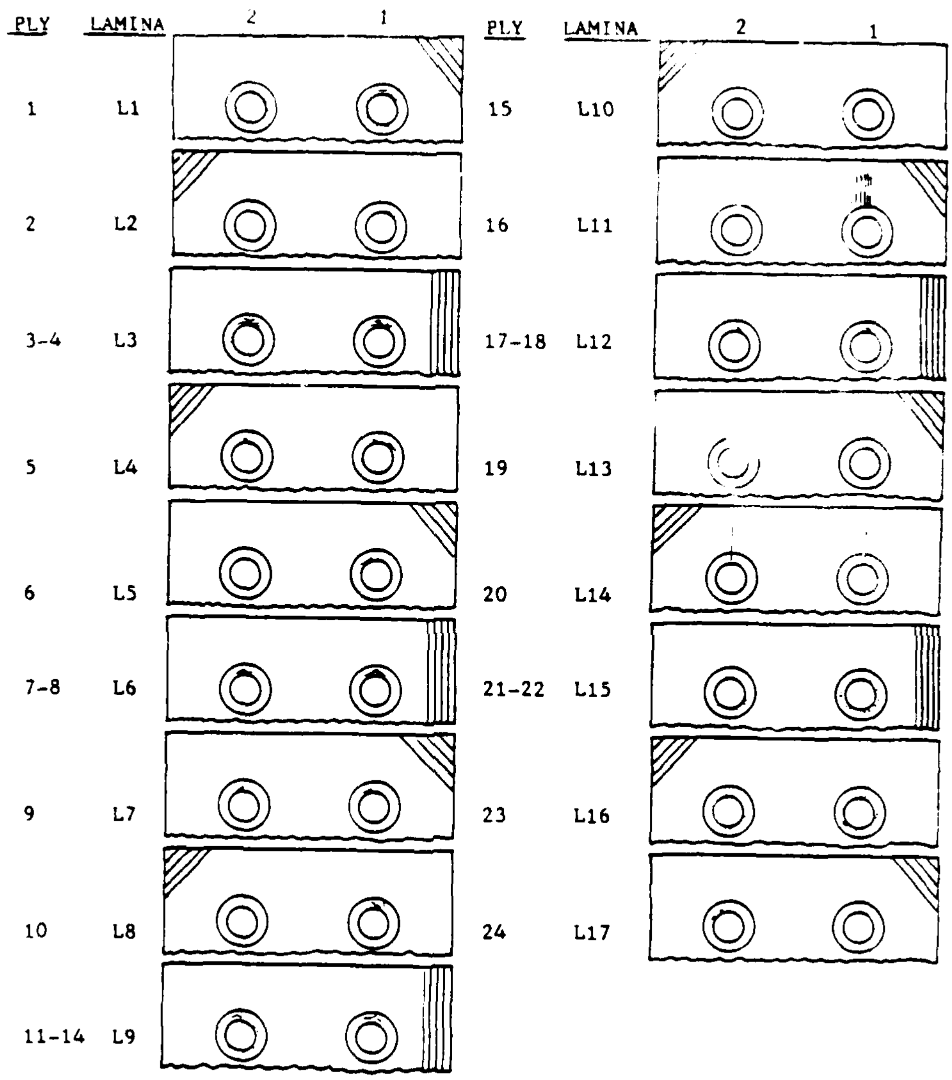


Figure G-36. Lamina Damage Characterization Chart for Specimen
IIB-A-13 Strap A Load Level D

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm 45^\circ$, $0_2{}^\circ$, $\mp 45^\circ$, $0_2{}^\circ$, $\pm 45^\circ$, $0_2{}^\circ$)s

LOAD LEVEL - D

POUNDS LOAD - 6238 PERCENT OF ULTIMATE - 80

FIGURE G-37. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-7.

BEFORE LOADING AFTER LOADING

FIGURE G-38. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-7.

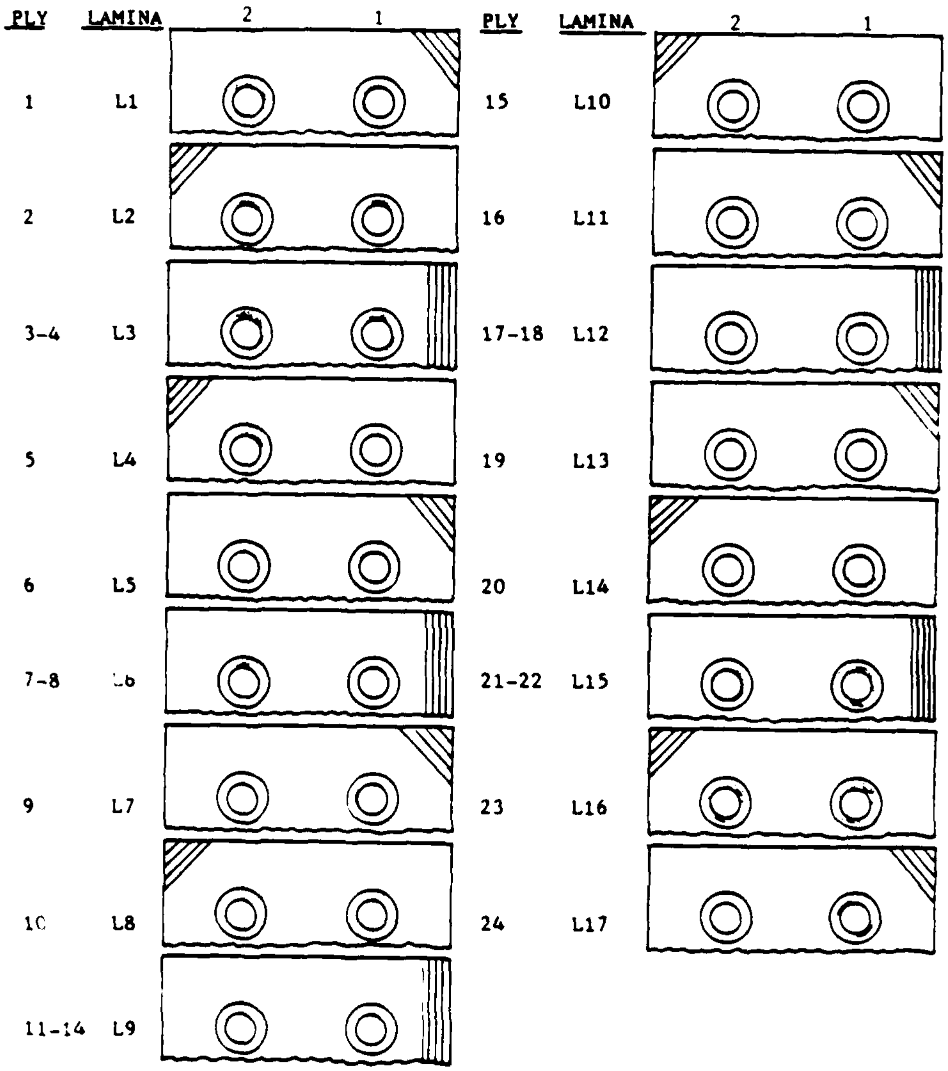


Figure G-39. Lamina Damage Characterization Chart for Specimen
IIB-A-7 Strap B Load Level D

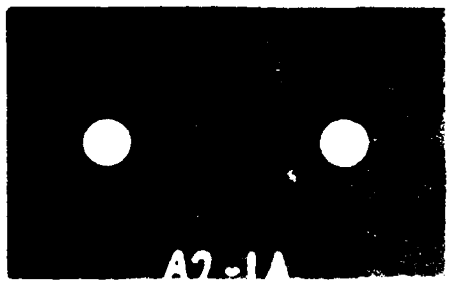
SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - D

POUNDS LOAD - 6238 PERCENT OF ULTIMATE - 80

FIGURE G-40. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-1.



BEFORE LOADING AFTER LOADING

FIGURE G-41. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-1.

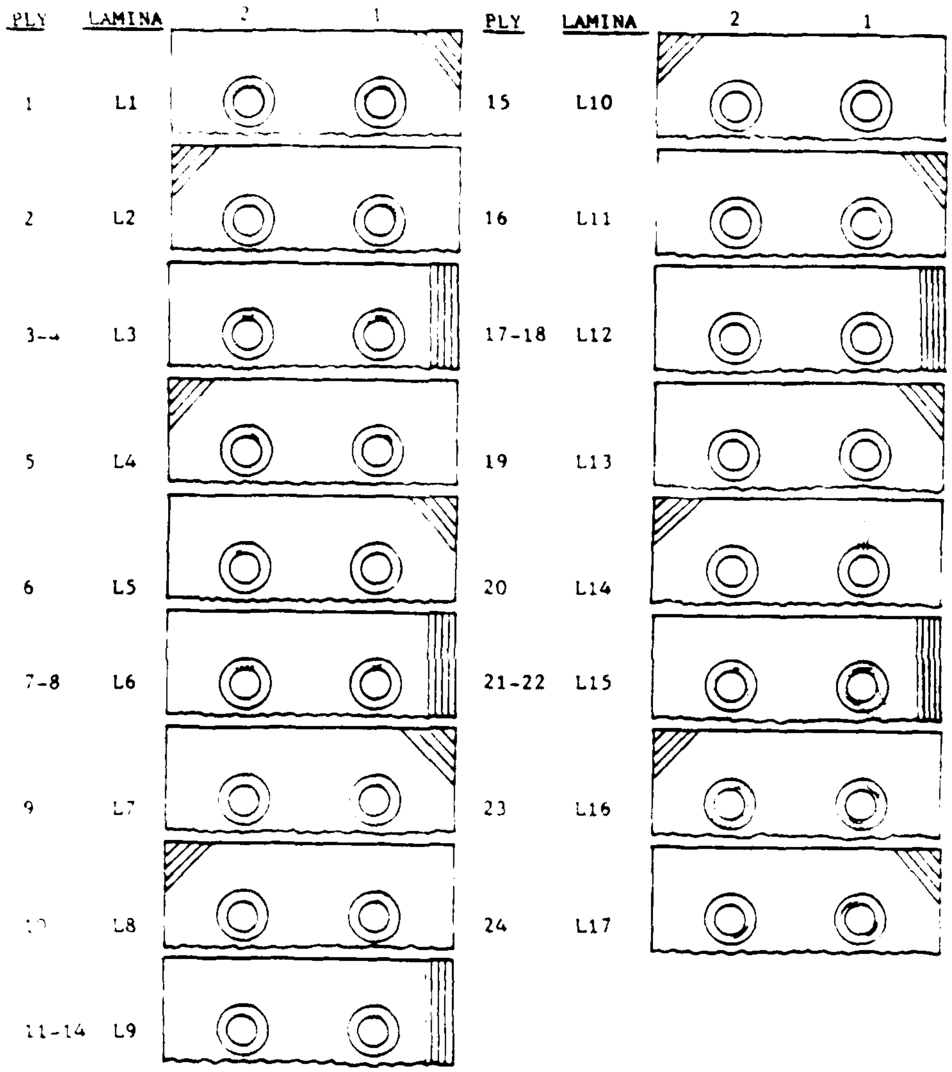


Figure G-42. Lamina Damage Characterization Chart for Specimen
IIB-A 1 Strap A Load Level D

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm 45^\circ$, $0_2{}^\circ$, $\mp 45^\circ$, $0_2{}^\circ$, $\pm 45^\circ$, $0_2{}^\circ$)s

LOAD LEVEL - D

POUNDS LOAD - 6238 PERCENT OF ULTIMATE - 80

FIGURE G-43. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-20.

BEFORE LOADING

AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE G-44. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-20.

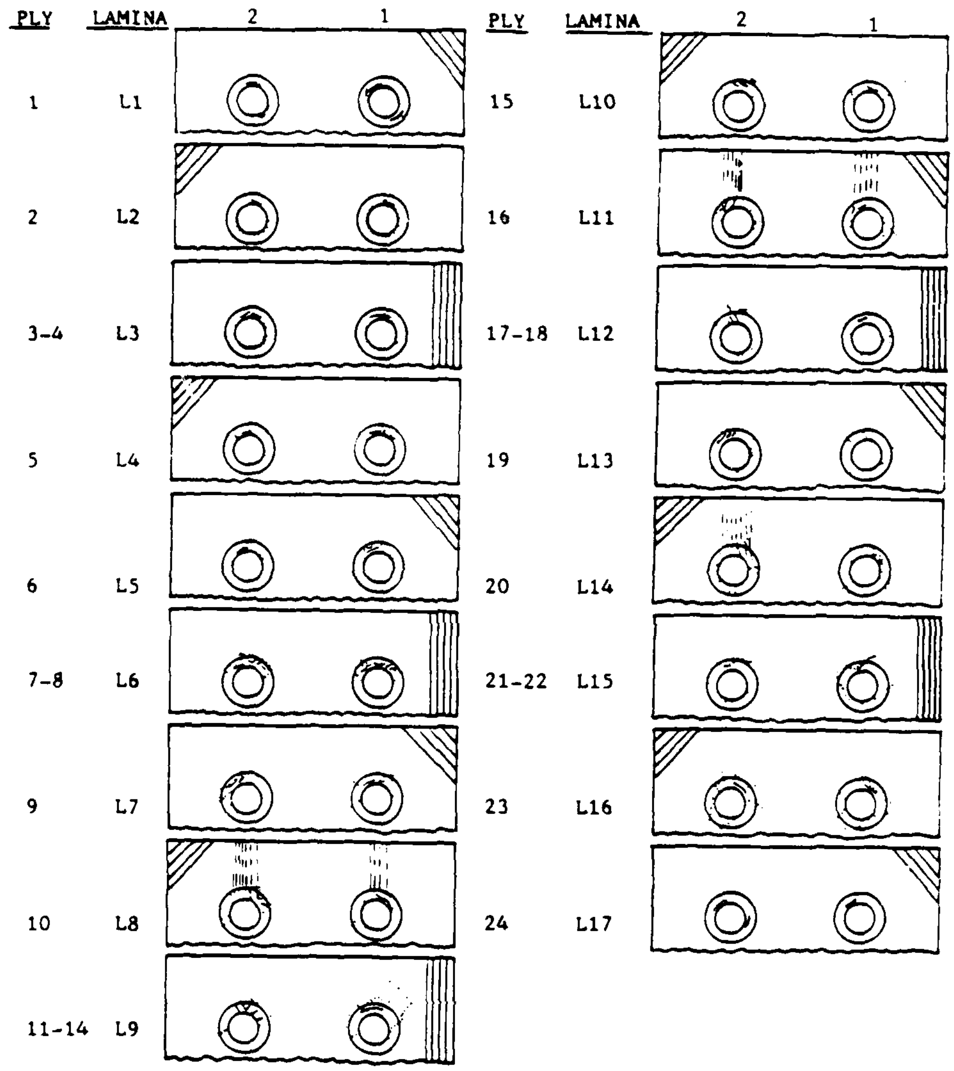


Figure G-45. Lamina Damage Characterization Chart for Specimen
IIB-A-20 Strap B Load Level D

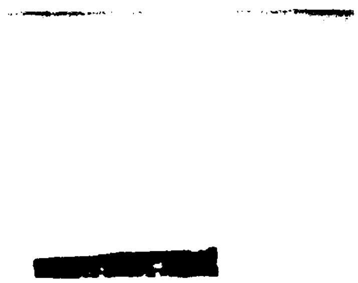
SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm45^\circ$, 0_2°, $\mp45^\circ$, 0_2°, $\pm45^\circ$, 0_2°)s

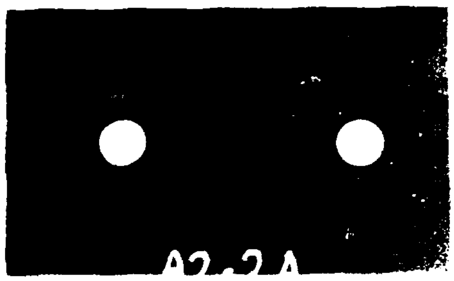
LOAD LEVEL - B

POUNDS LOAD - 6824 PERCENT OF ULTIMATE - 88

FIGURE G-46. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-2.



BEFORE LOADING



AFTER LOADING

FIGURE G-47. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-2.

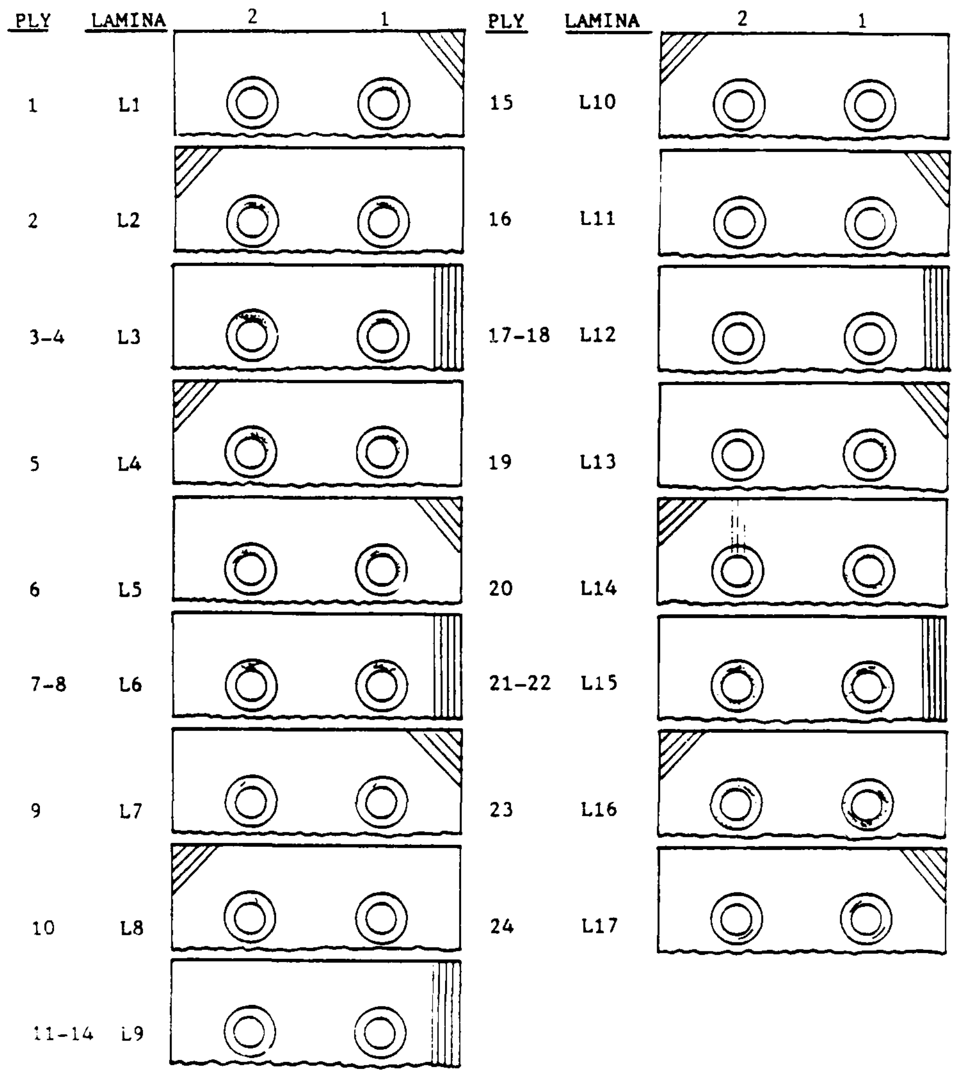


Figure C-48. Lamina Damage Characterization Chart for Specimen
IIB-A-2 Strap A Load Level B

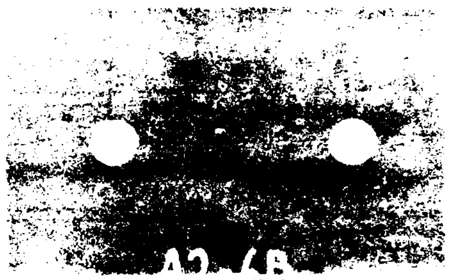
SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - B

POUNDS LOAD - 6824 PERCENT OF ULTIMATE - 88

FIGURE G-49. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-6.



BEFORE LOADING AFTER LOADING

FIGURE G-50. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-6.

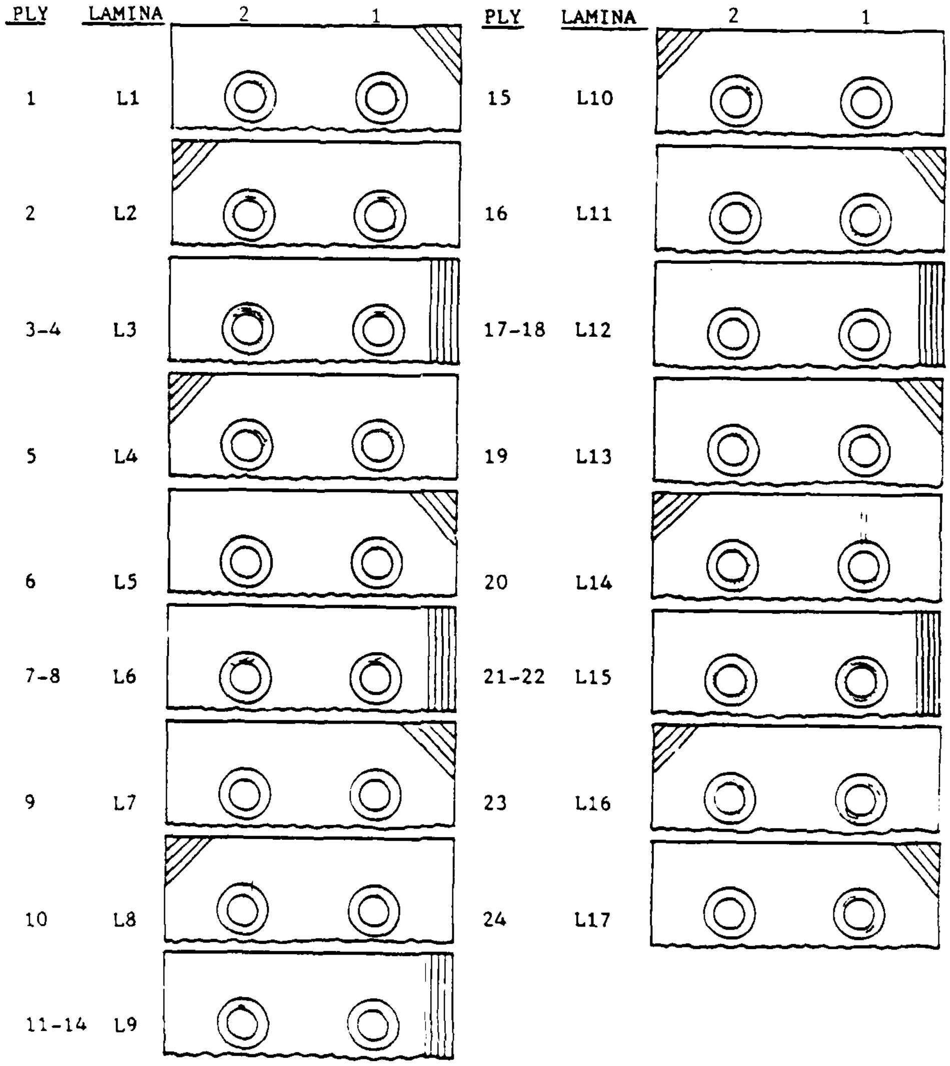


Figure G-51. Lamina Damage Characterization Chart for Specimen
IIB-A-6 Strap B Load Level B

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - B

POUNDS LOAD - 6824 PERCENT OF ULTIMATE - 88

FIGURE G-52. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-11.

BEFORE LOADING AFTER LOADING

FIGURE G-53. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-11.

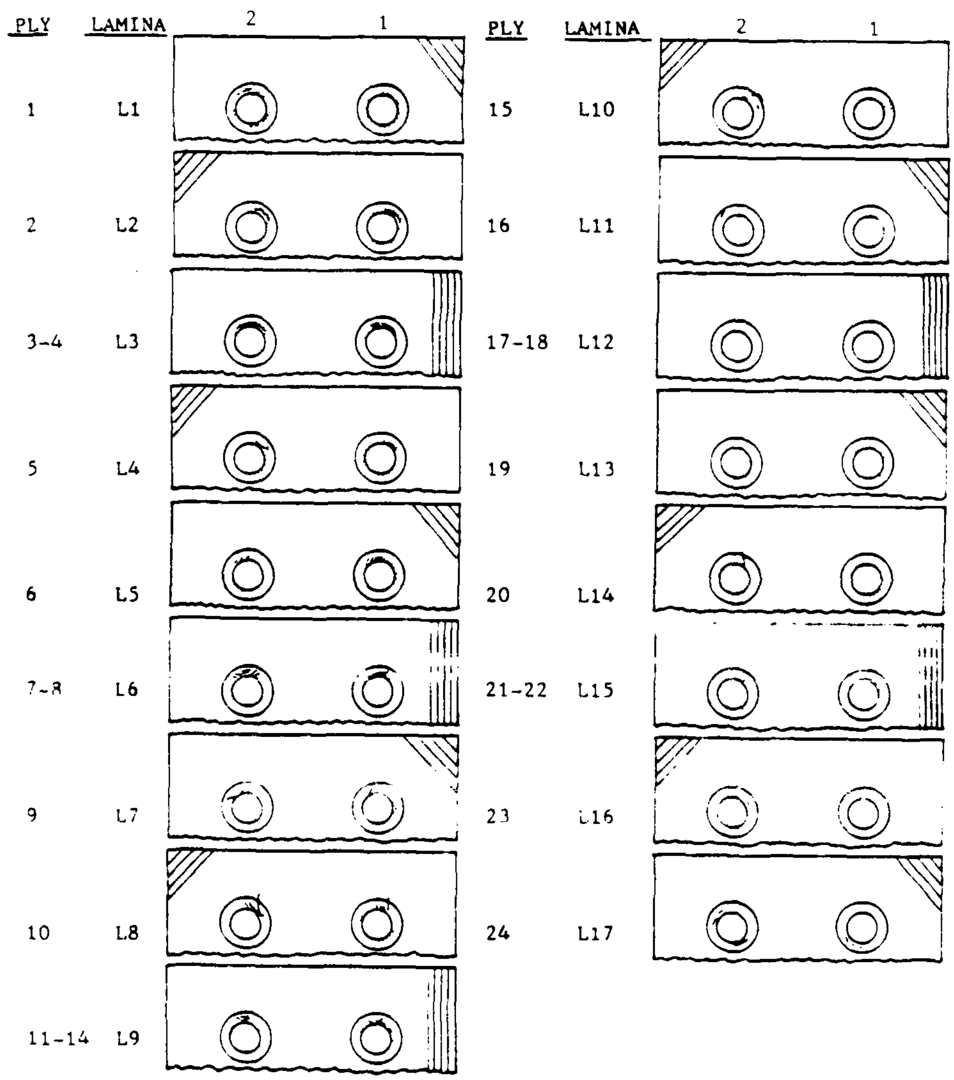


Figure G-34. Lamina Damage Characterization Chart for Specimen
IIB-A-11   Strap A   Load Level B

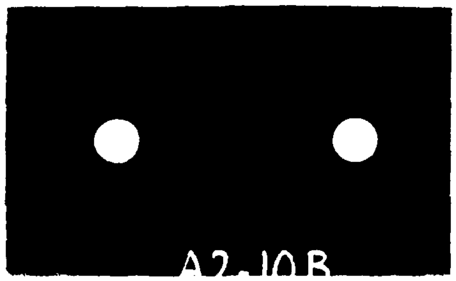
SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm45^{\circ}$, 0_2°, $\mp45^{\circ}$, 0_2°, $\pm45^{\circ}$, 0_2°)s

LOAD LEVEL - B

POUNDS LOAD - 6824 PERCENT OF ULTIMATE - 88

FIGURE G-55. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-10.



BEFORE LOADING AFTER LOADING

FIGURE G-56. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-10.

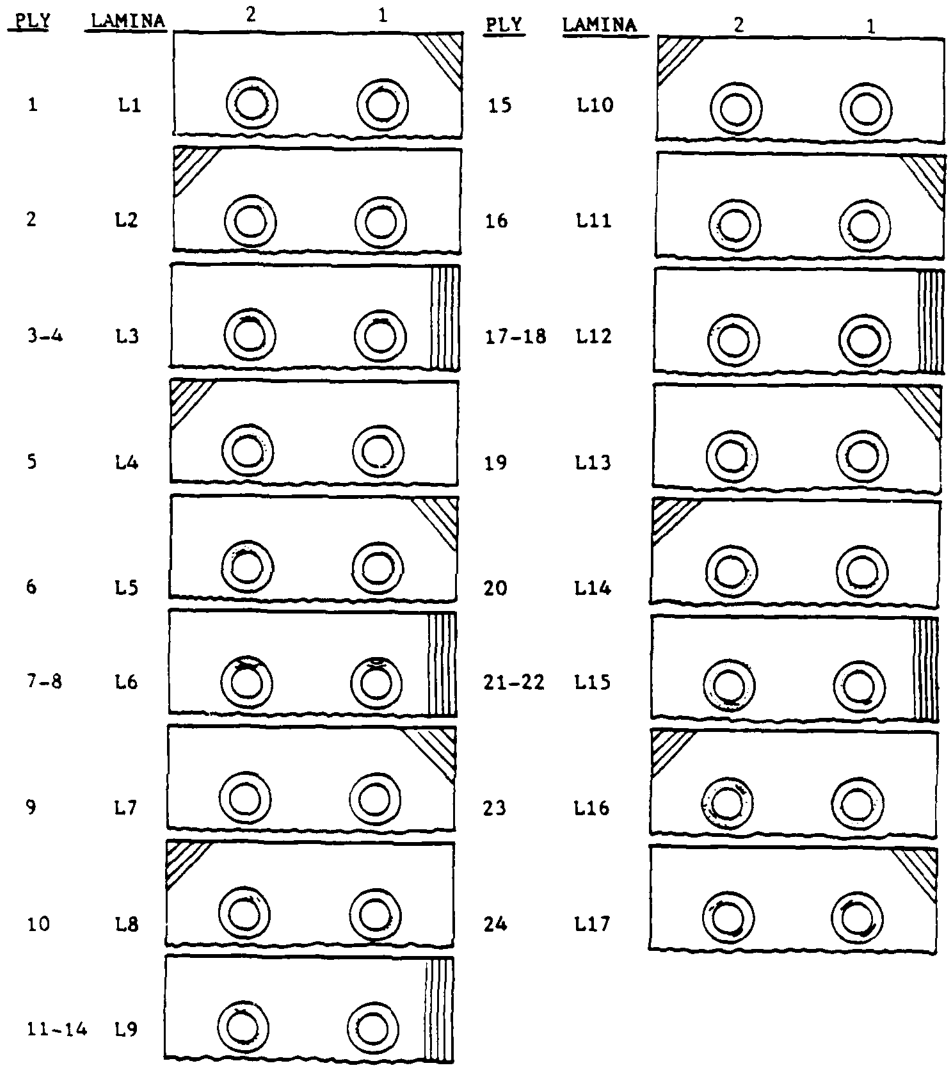


Figure G-57. Lamina Damage Characterization Chart for Specimen IIB-A-10 Strap B Load Level B

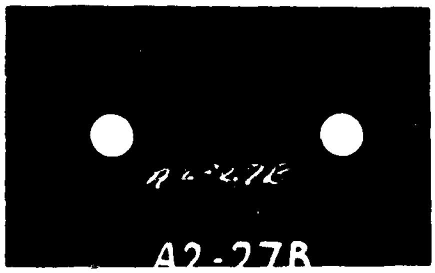
SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - A($\pm 45^{\circ}$, 0_2°, $\mp 45^{\circ}$, 0_2°, $\pm 45^{\circ}$, 0_2°)s

LOAD LEVEL - B

POUNDS LOAD - 6824 PERCENT OF ULTIMATE - 88

FIGURE G-58. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-A-27.



BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE G-59. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-A-27.

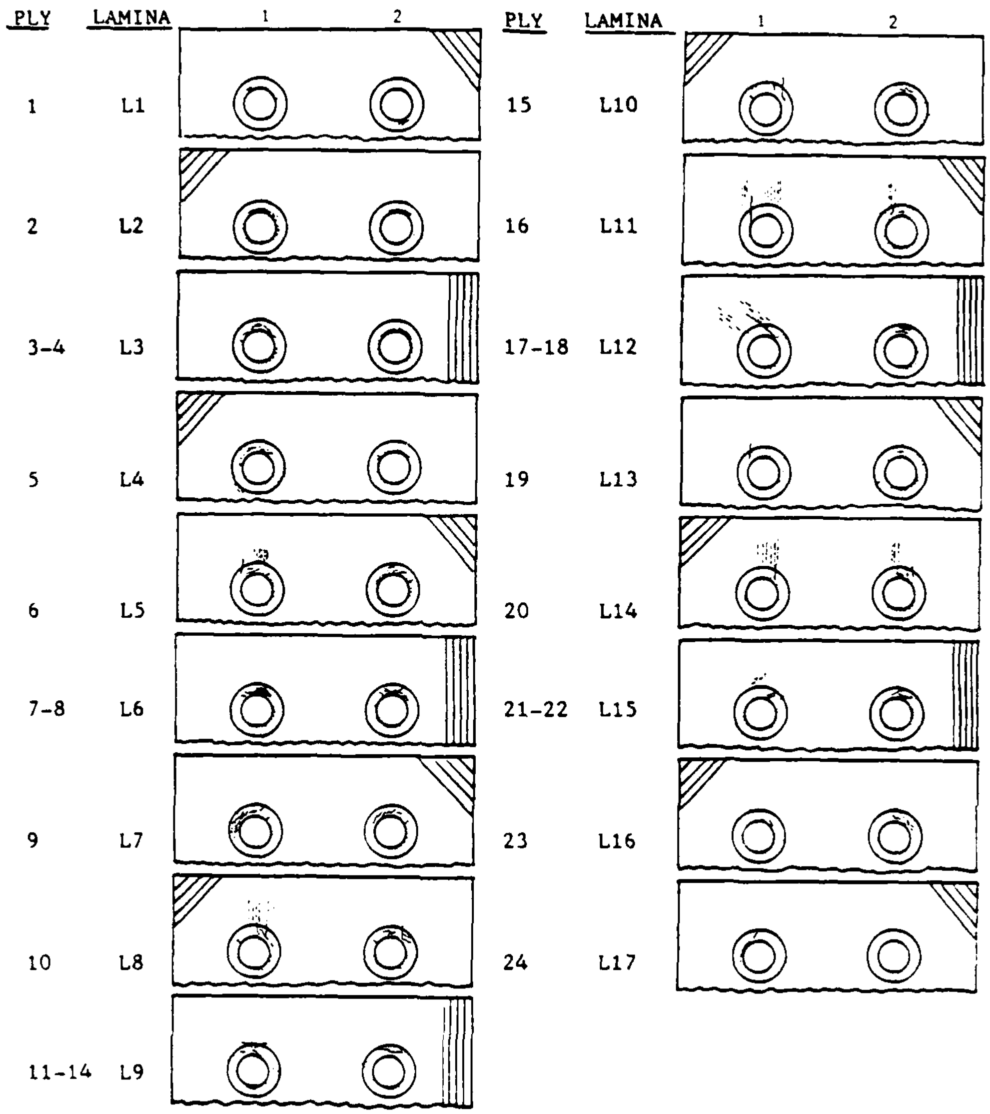
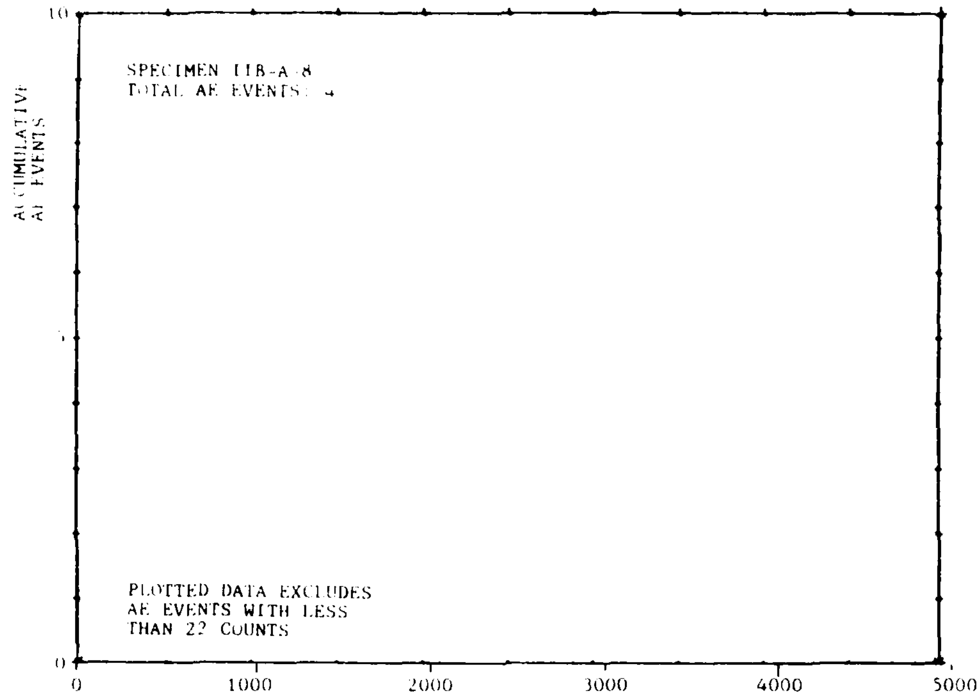


Figure G-60. Lamina Damage Characterization Chart for Specimen
IIB-A-27 Strap B Load Level B



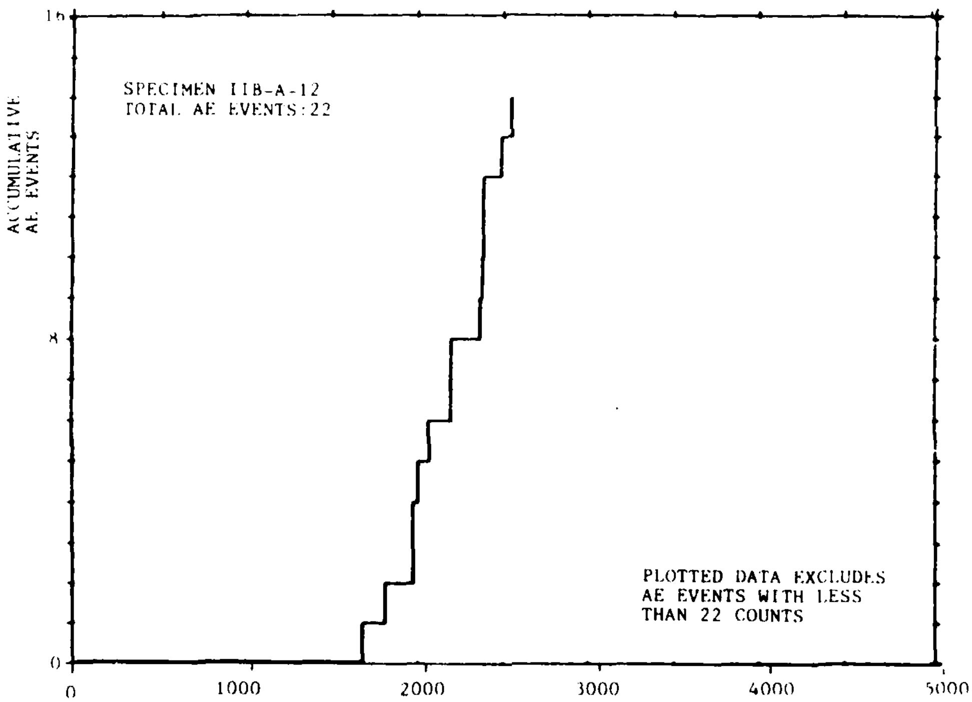


Figure G-61. Plots of Accumulative AE Events vs Applied Load for Type IIB-A Specimens with Minimum and Maximum Response for Load Level A.

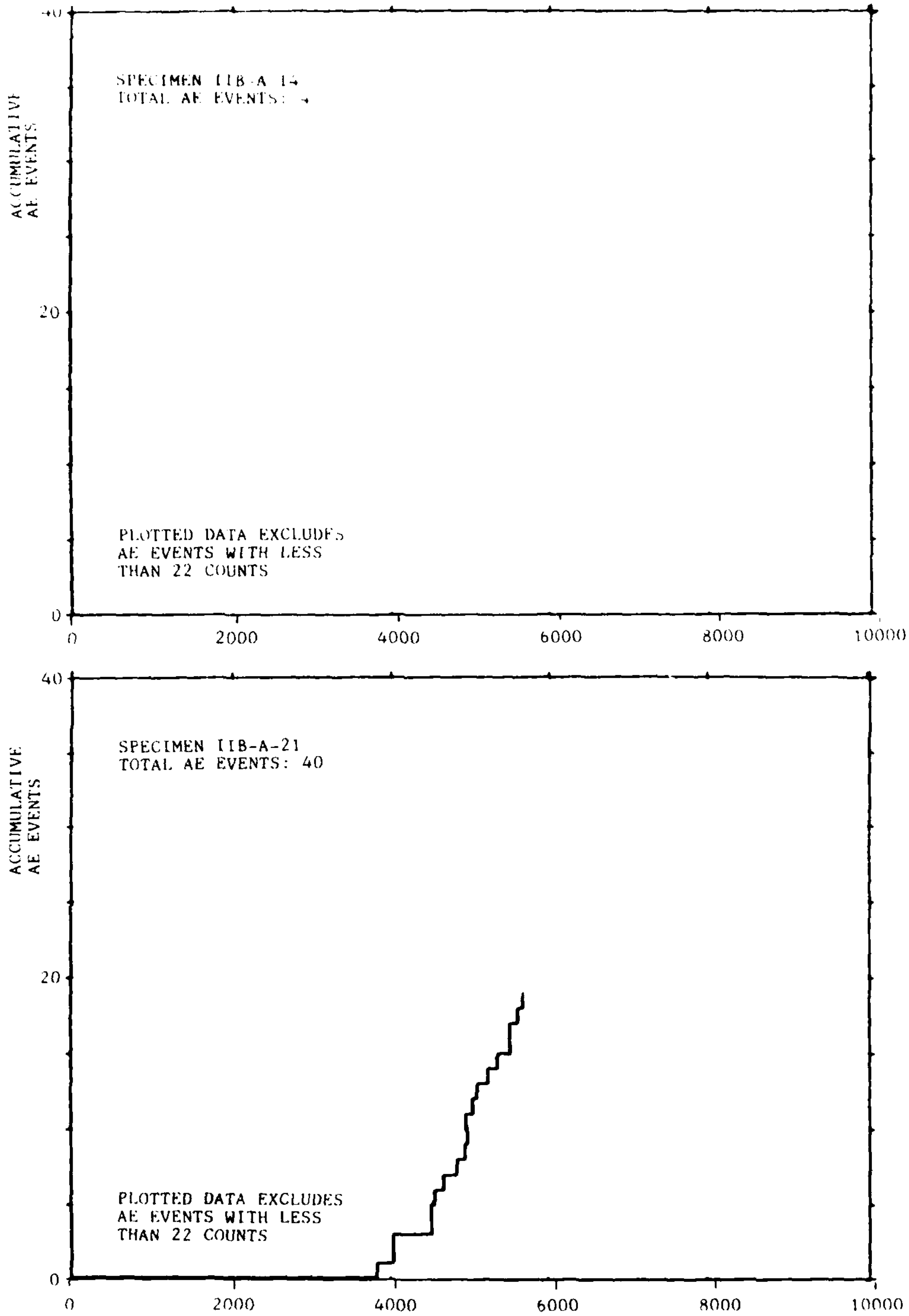


Figure G-62. Plots of Accumulative AE Events vs Applied Load for Type IIB-A Specimens with Minimum and Maximum Response for Load Level C.

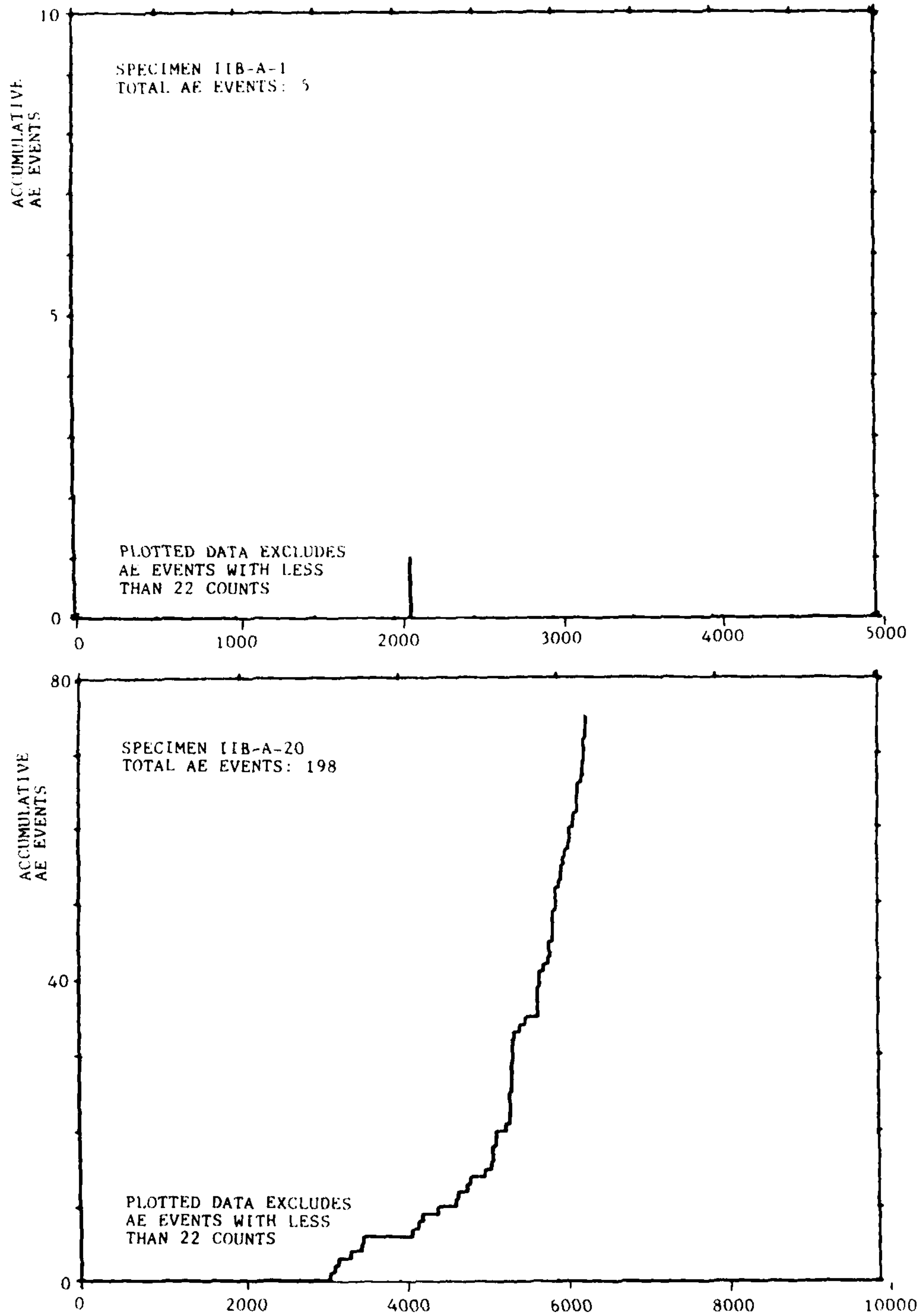


Figure G-63. Plots of Accumulative AE Events vs Applied Load for Type IIB-A Specimens with Minimum and Maximum Response for Load Level D.

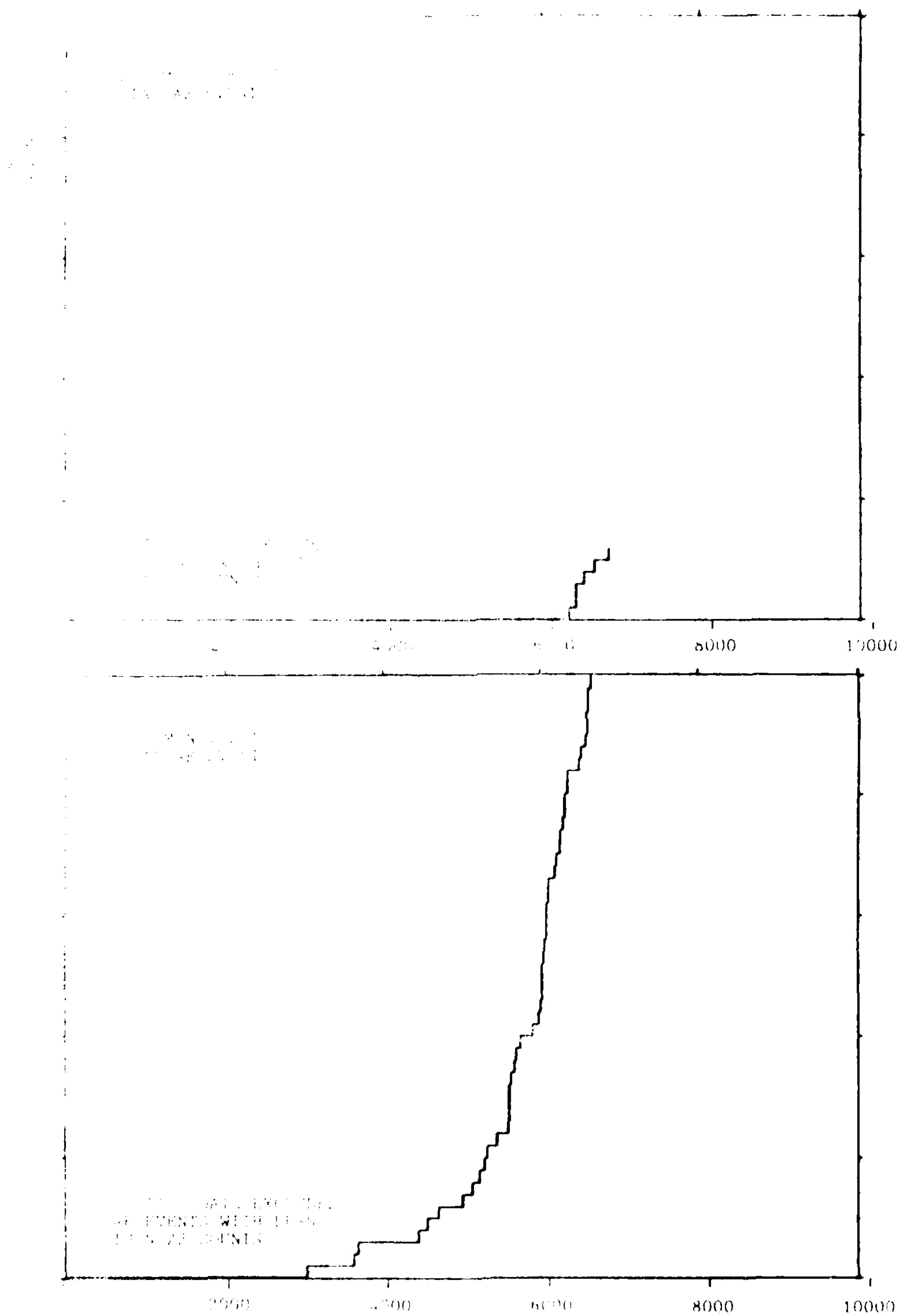


Figure G-64. Plots of Accumulative AE Events vs Applied Load for Type IIB-A Specimens with Minimum and Maximum Response for Load Level B.

APPENDIX H

DETAIL DAMAGE INFORMATION FOR TYPE IIB-C SPECIMENS

The detail information for the Type IIB specimens of Laminate C is presented in this appendix. It is presented in the order of increasing load levels. All specimens of the same load level are grouped together. Three figures are presented for each specimen. The first figure gives specimen type, laminate information and load conditions. The second figure consists of positive prints of enhanced x-ray radiographs made before and after loading. In addition, prints of a stereo x-ray pair are included for one specimen of each load level. The third figure consists of a Lamina Damage Characterization Chart. This chart contains a pictorial sketch for each lamina with fiber orientations indicated on one side or edge of each sketch. Also an outline of the fastener head is shown on these sketches to provide a visual reference as to the magnitude of the damage. The damage observed on each lamina is recorded on the appropriate sketch in a manner to indicate size and location relative to the fastener hole. As shown in these charts lamina No. 1 was adjacent to the joint interface and lamina No. 23 was adjacent to the fastener head.

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm$ 45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)s

LOAD LEVEL - A

POUNDS LOAD - 6850 PERCENT OF ULTIMATE - 76

FIGURE H-1. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-9.

BEFORE LOADING AFTER LOADING

FIGURE H-2. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-9.

PRECEDING PAGE BLANK-NOT FILMED

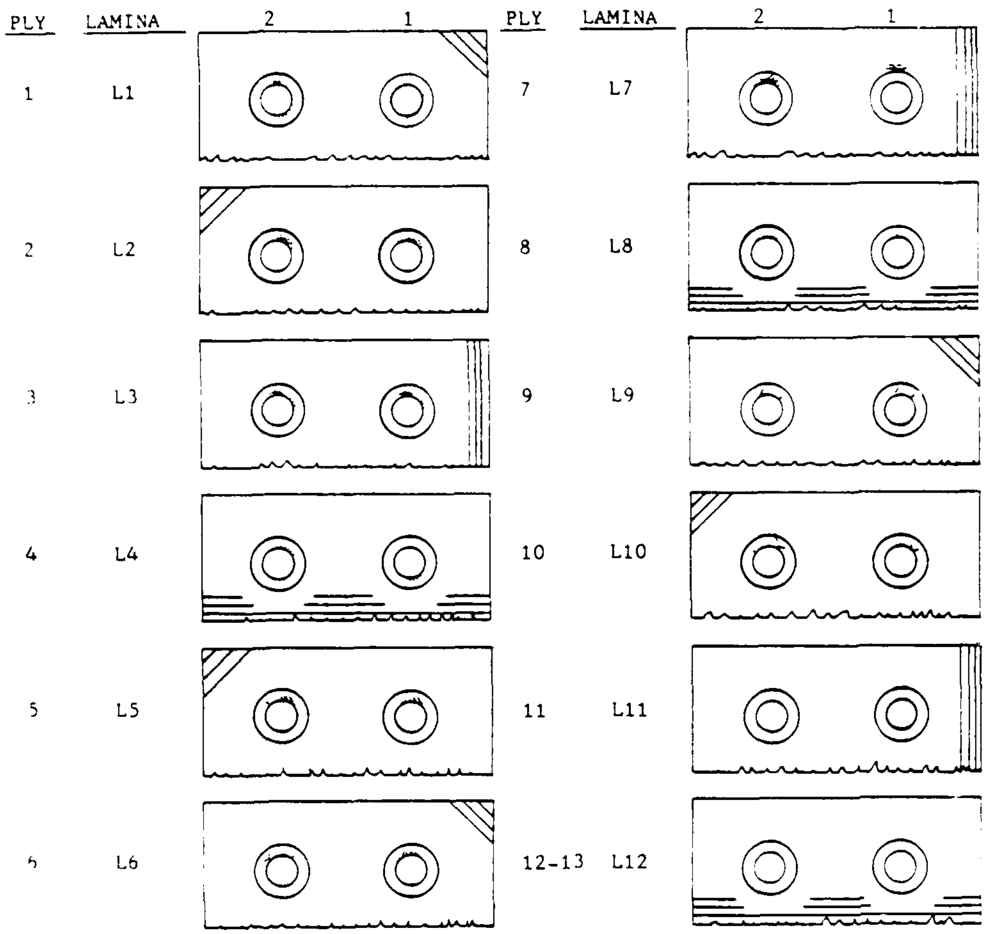


Figure H-3. Lamina Damage Characterization Chart for Specimen

IIB-C-9 Strap B Load Level A

(Continued)

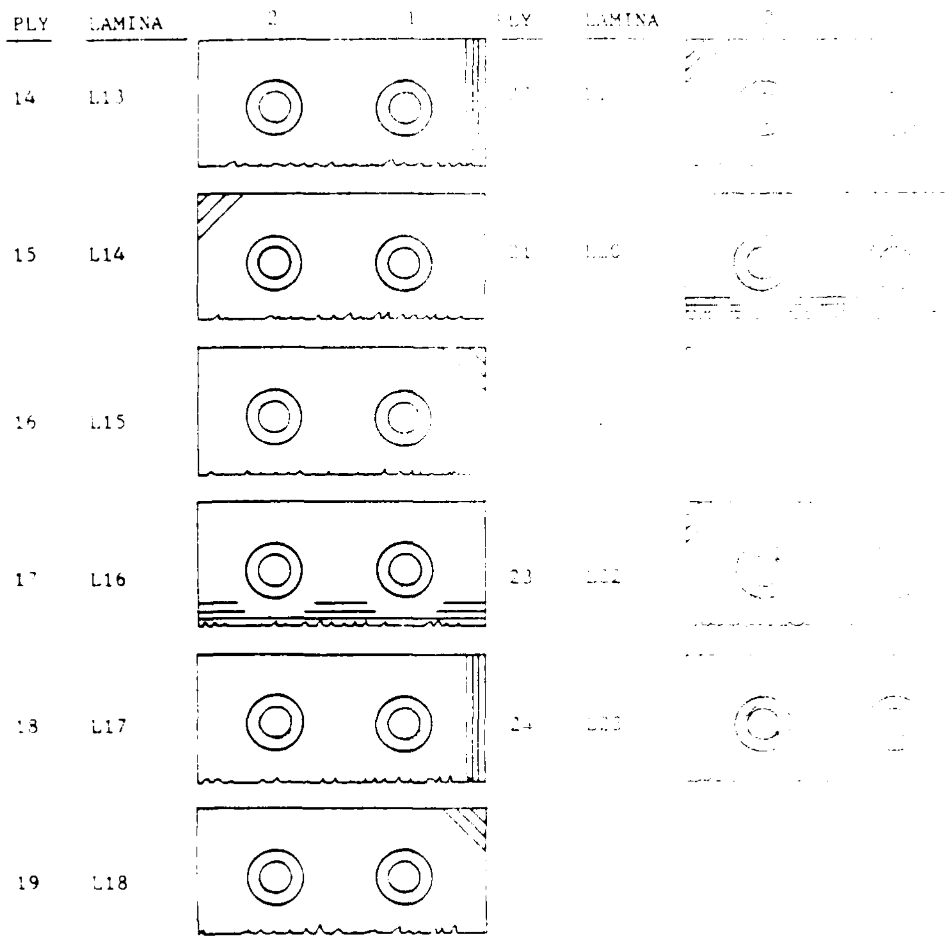


Figure H-3. Lamina Damage Characterization [illegible]

IIB-C-9 Strap [illegible]

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm$ 45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)s

LOAD LEVEL - A

POUNDS LOAD - 6850 PERCENT OF ULTIMATE - 76

FIGURE H-4. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-19.

BEFORE LOADING AFTER LOADING

FIGURE H-5. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-19.

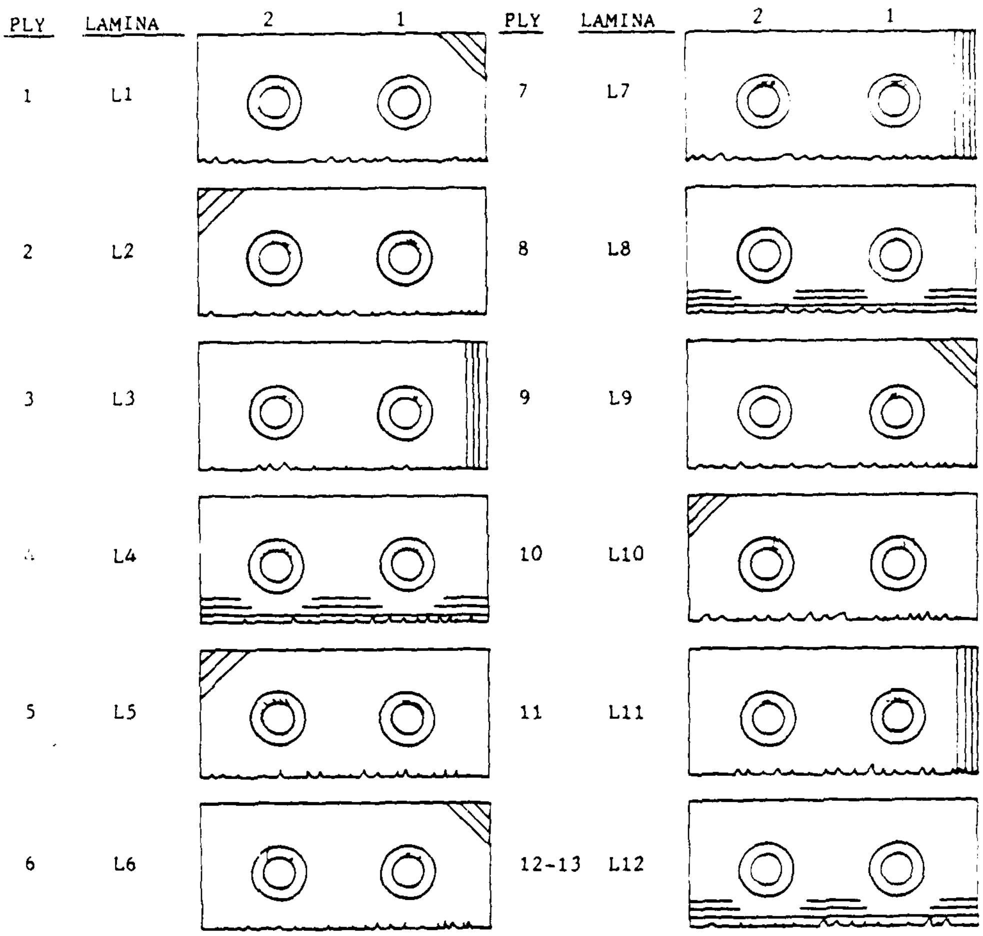


Figure H-6. Lamina Damage Characterization Chart for Specimen

IIB-C-19 Strap A Load Level A

(Continued)

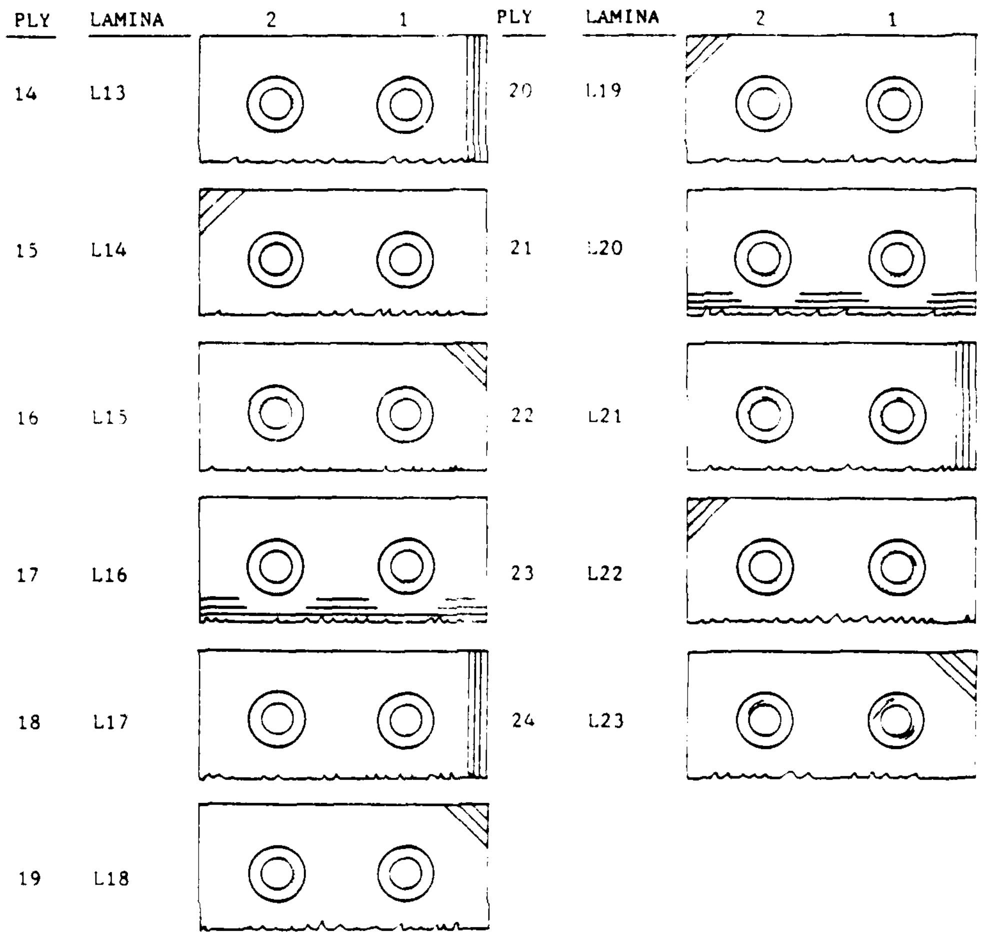


Figure H-6. Lamina Damage Characterization Chart for Specimen

IIB-C-19 Strap A Load Level A

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm$ 45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)s

LOAD LEVEL - A

POUNDS LOAD - 6850 PERCENT OF ULTIMATE - 76

FIGURE H-7. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-12.

BEFORE LOADING AFTER LOADING

FIGURE H-8. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-12.

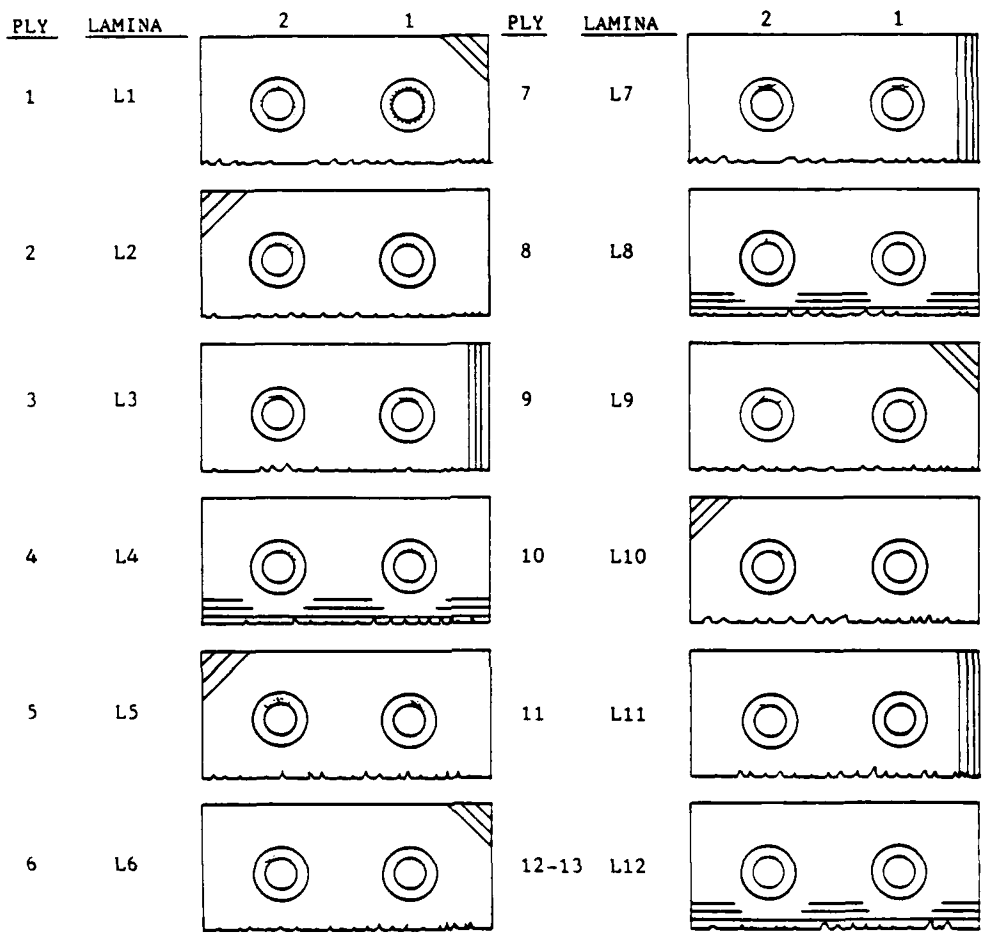


Figure H-9. Lamina Damage Characterization Chart for Specimen

IIB-C-12 Strap B Load Level A

(Continued)

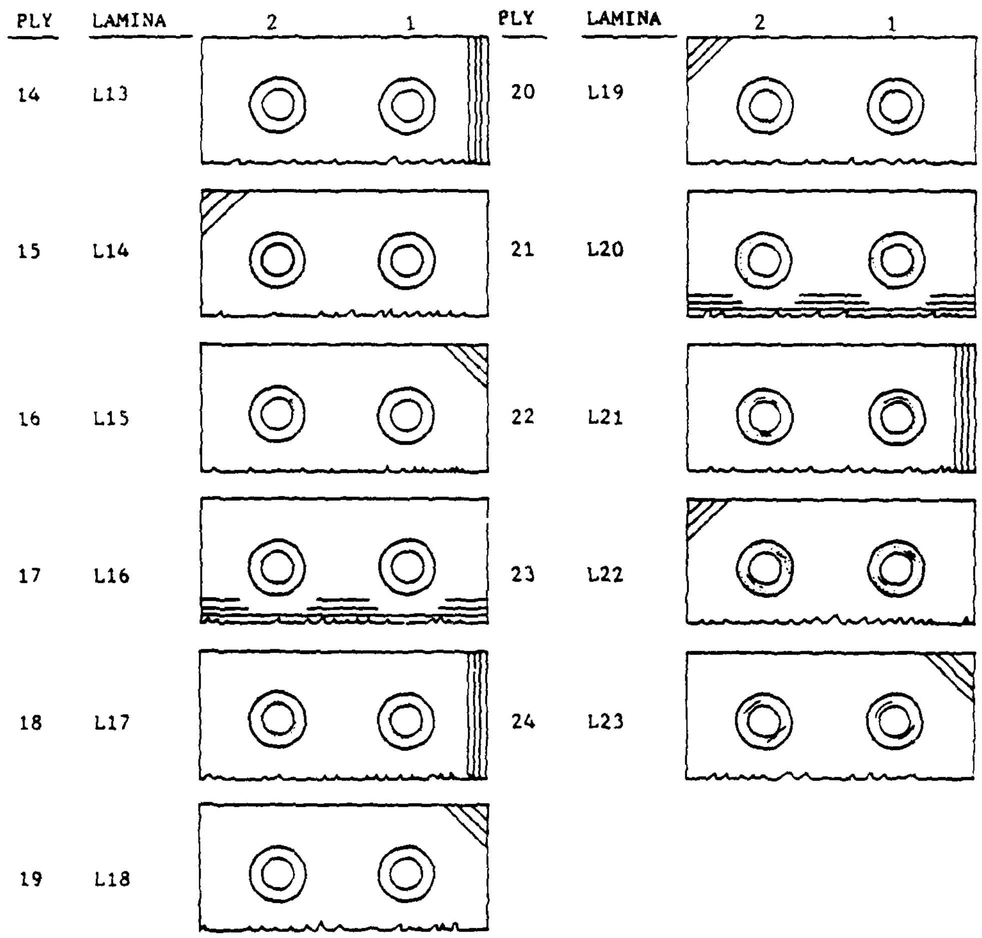


Figure H-9. Lamina Damage Characterization Chart for Specimen

IIB-C-12 Strap B Load Level A

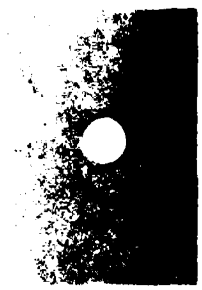
SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm$ 45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)s

LOAD LEVEL - A

POUNDS LOAD - 6850 PERCENT OF ULTIMATE - 76

FIGURE H-10. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-8.



BEFORE LOADING AFTER LOADING

FIGURE H-11. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-8.

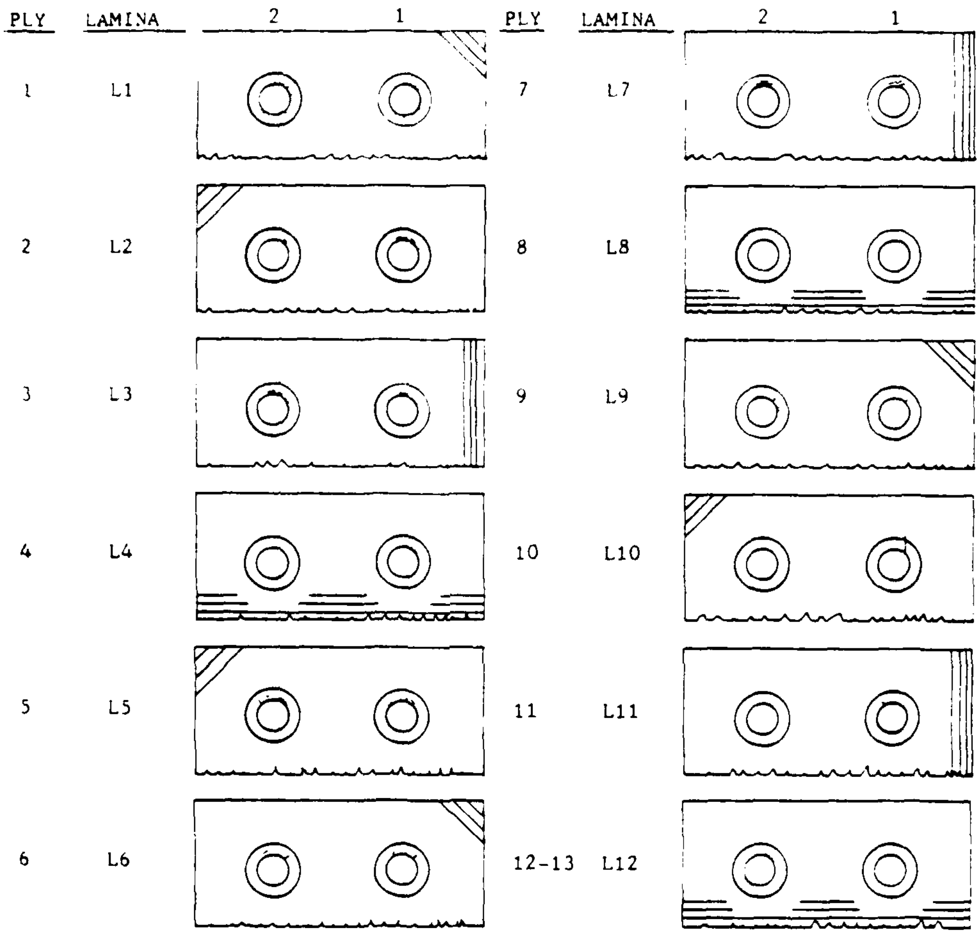


Figure H-12. Lamina Damage Characterization Chart for Specimen

IIB-C-8 Strap A Load Level A

(Continued)

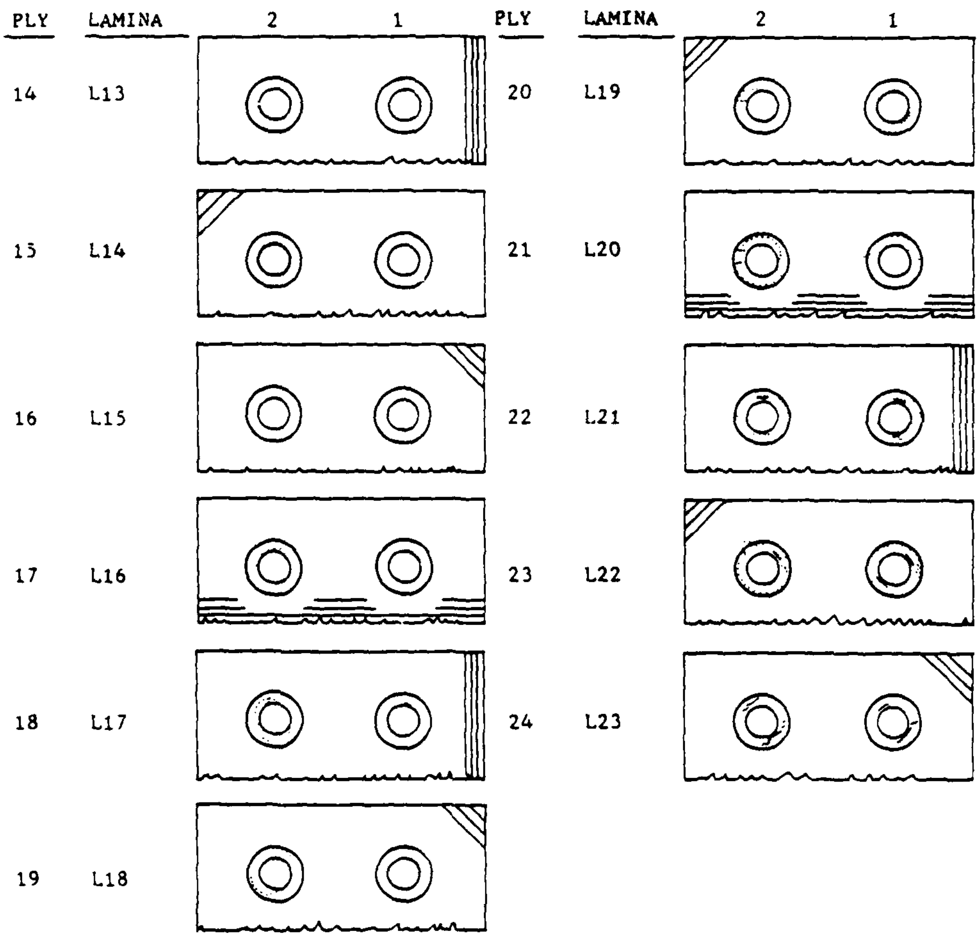


Figure H-12. Lamina Damage Characterization Chart for Specimen

IIB-C- 8 Strap A Load Level A

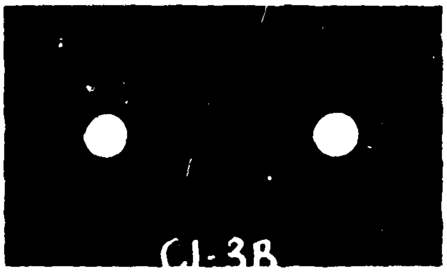
SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm$45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)s

LOAD LEVEL - A

POUNDS LOAD - 6850 PERCENT OF ULTIMATE - 76

FIGURE H-13. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-3.



BEFORE LOADING

AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE H-14. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-3.

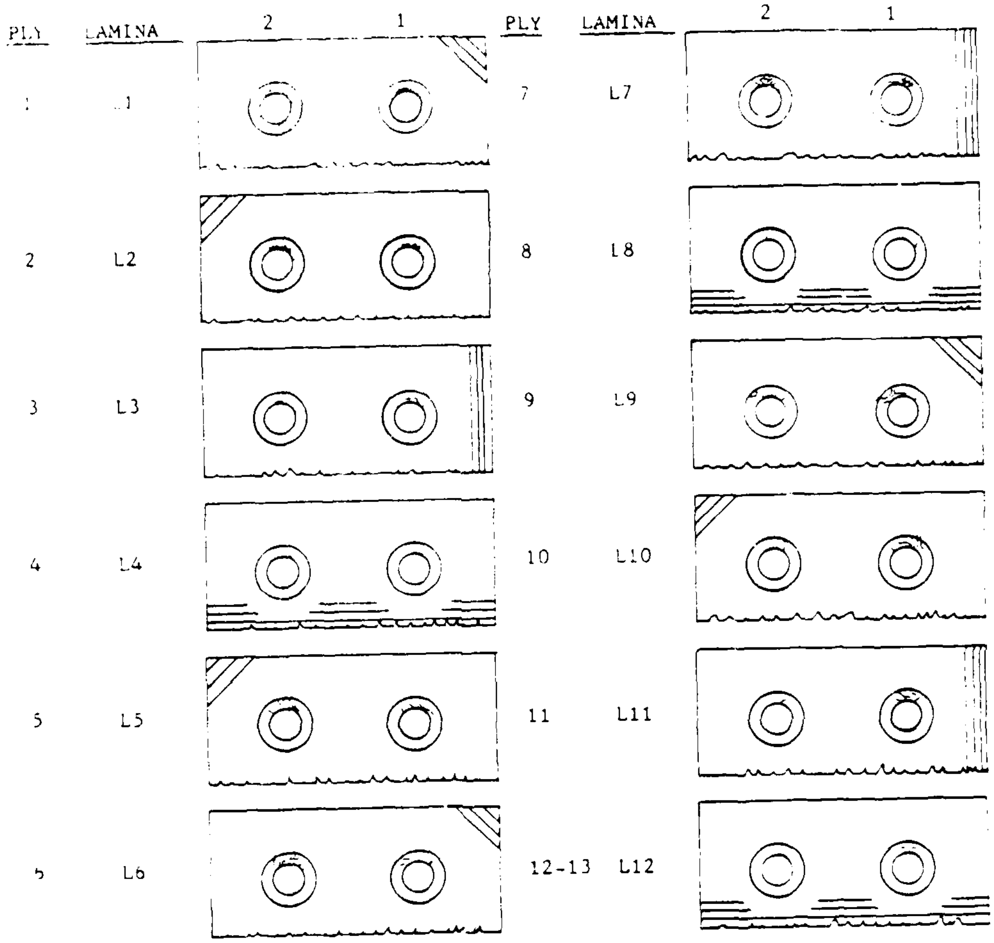


Figure H-15. Lamina Damage Characterization Chart for Specimen

IIB-C-3 Strap B Load Level A

(Continued)

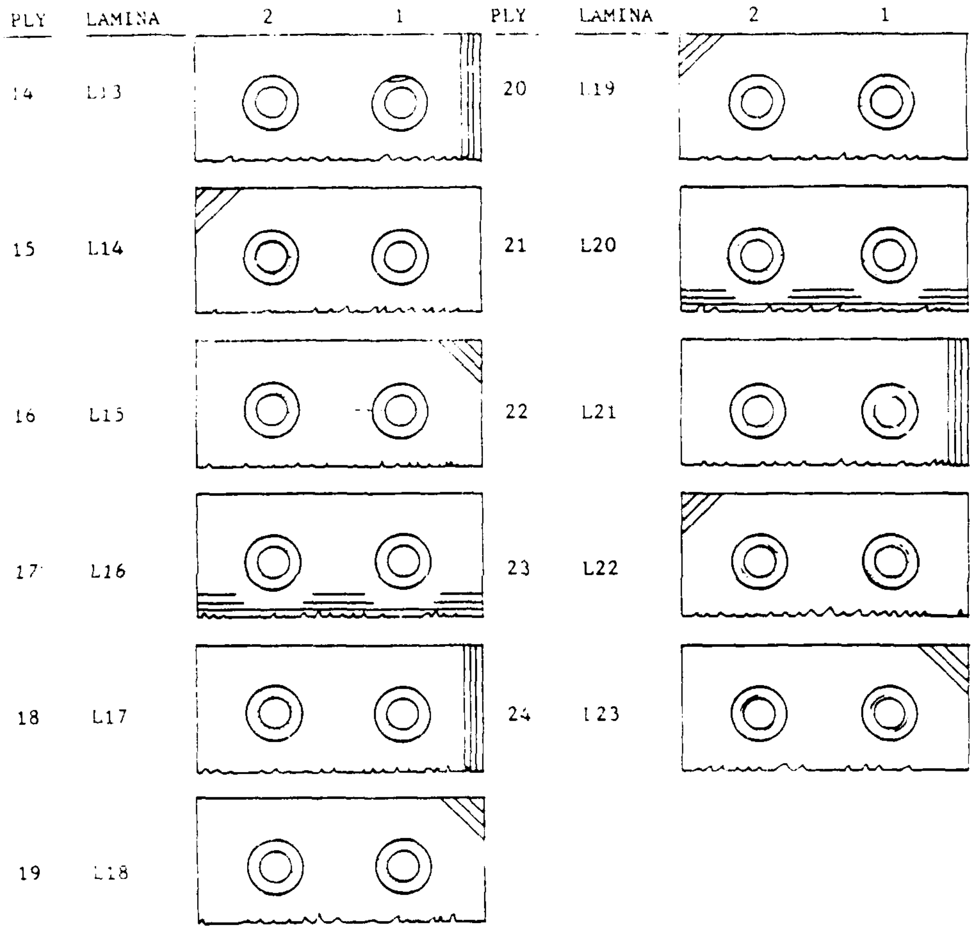


Figure H-15. Lamina Damage Characterization Chart for Specimen

IIB-C-3 Strap B Load Level A

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm$ 45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)s

LOAD LEVEL - C

POUNDS LOAD - 7000 PERCENT OF ULTIMATE - 78

FIGURE H-16. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-14.

BEFORE LOADING AFTER LOADING

FIGURE H-17. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-14.

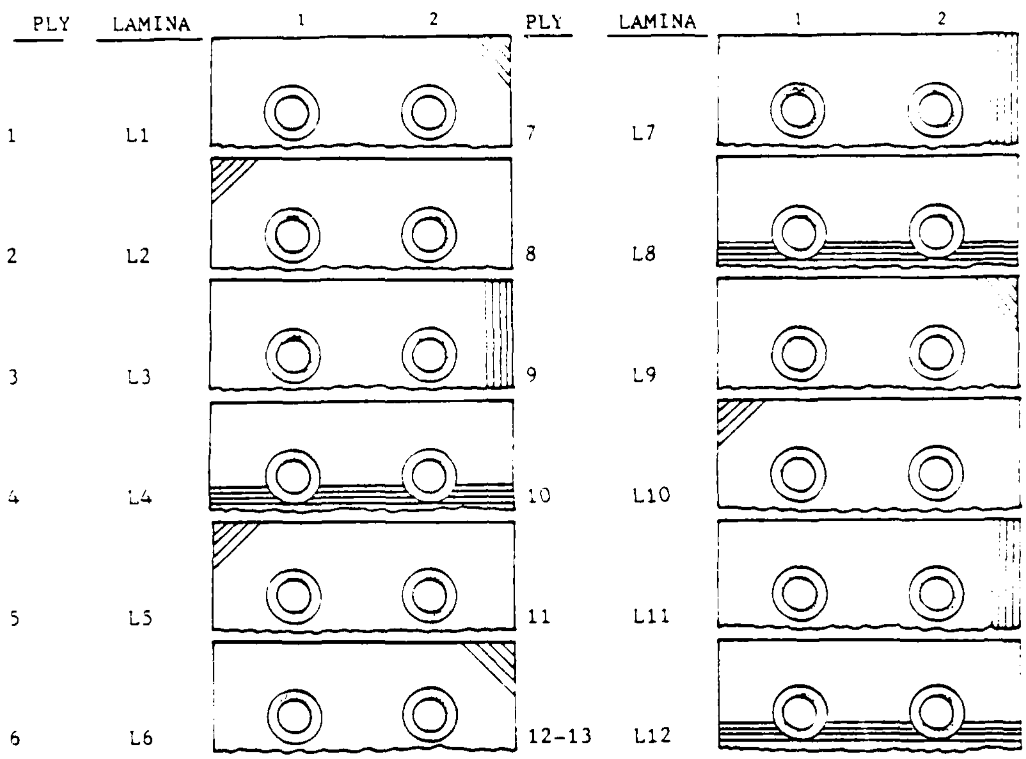


Figure H-18. Lamina Damage Characterization Chart for Specimen IIB-C-14 Strap B Load Level C (Continued)

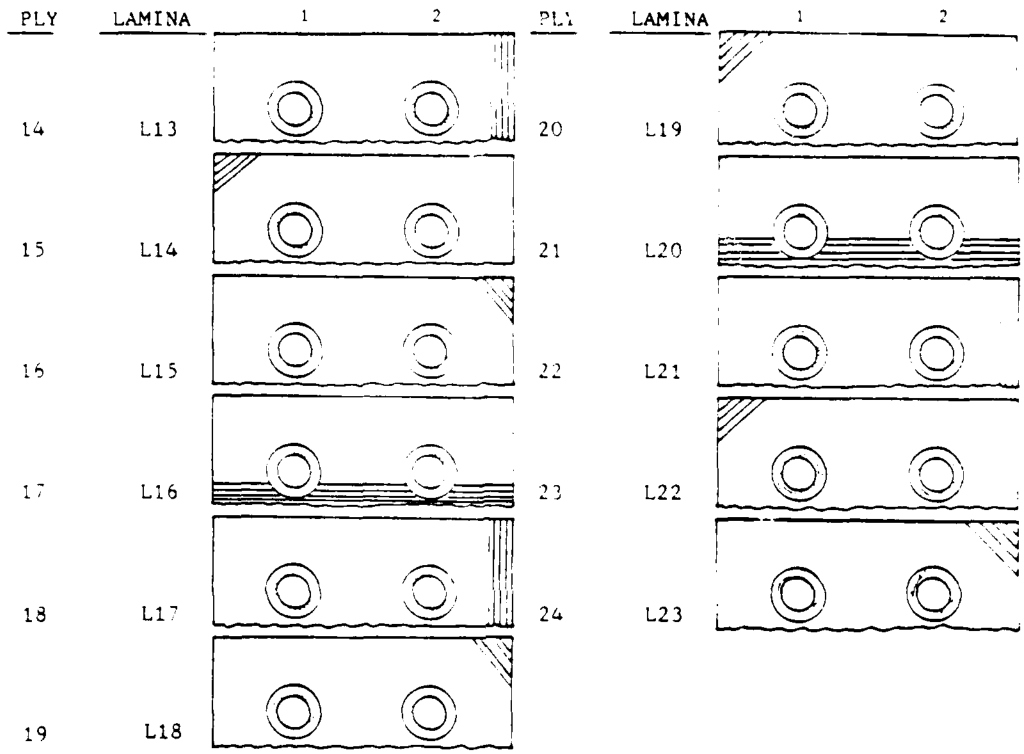


Figure H-18. Lamina Damage Characterization Chart for Specimen IIB-C-14 Strap B Load Level C

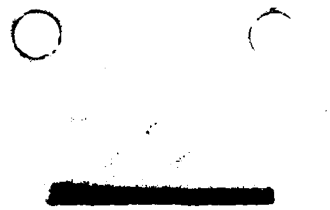
SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm$ 45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)s

LOAD LEVEL - C

POUNDS LOAD - 7000 PERCENT OF ULTIMATE - 78

FIGURE H-19. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-21.



BEFORE LOADING AFTER LOADING

FIGURE H-20. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-21.

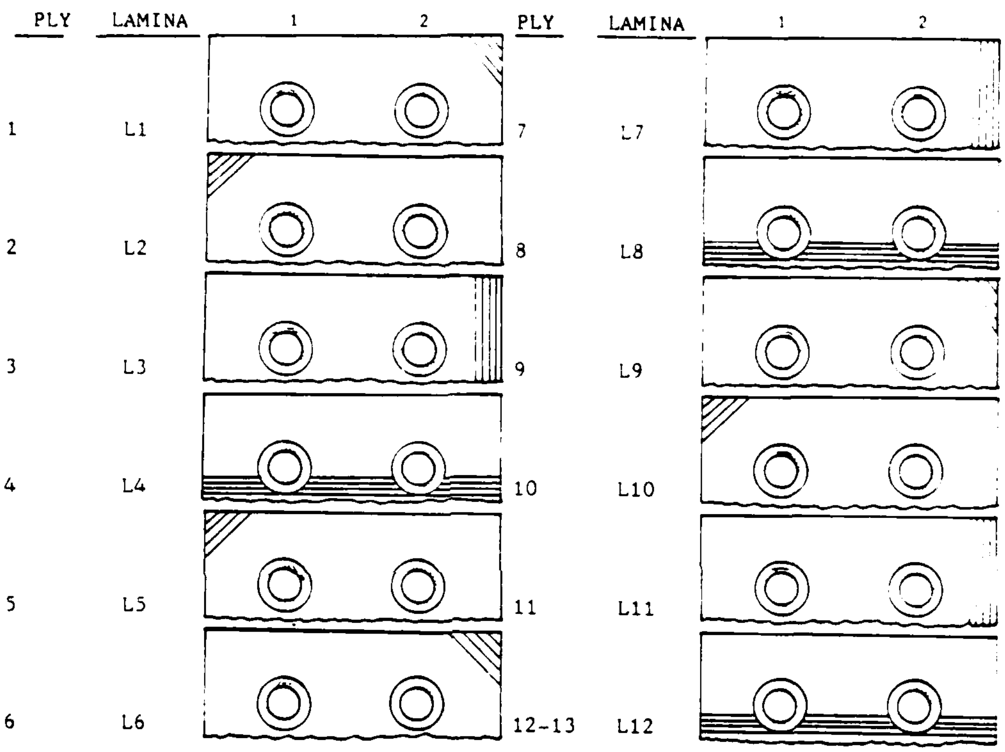


Figure H-21. Lamina Damage Characterization Chart for Specimen IIB-C-21 Strap B Load Level C (continued)

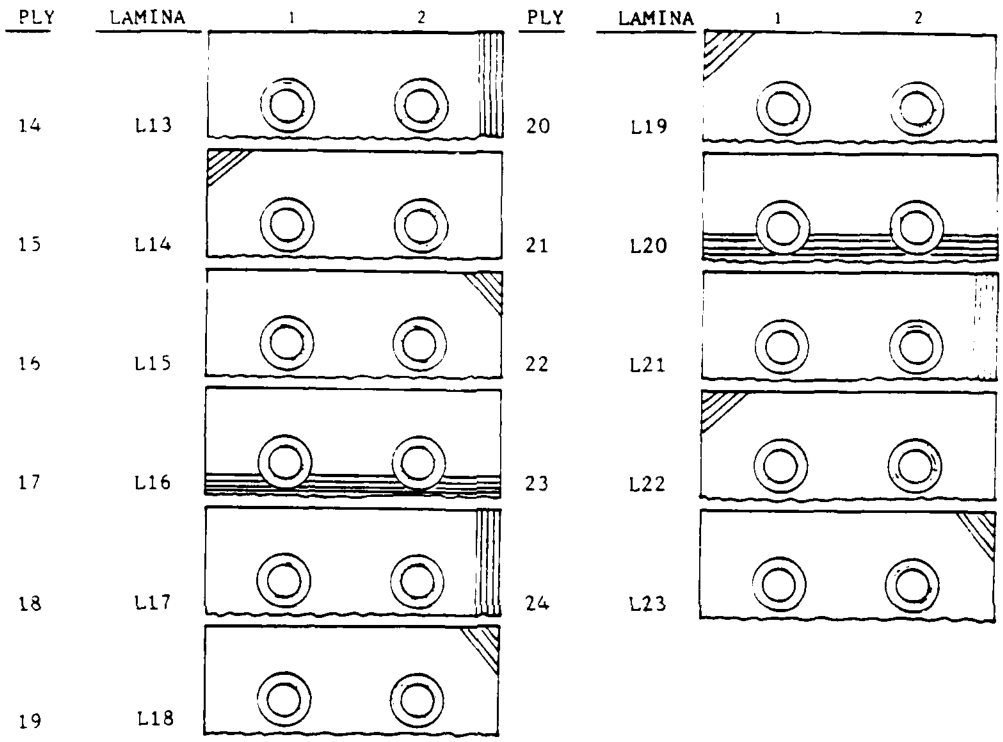


Figure H-21 Lamina Damage Characterization Chart for Specimen IIB-C-21 Strap B Load Level C (continued)

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm 45^{\circ}$, 0°, 90°, $\mp 45^{\circ}$, 0°, 90°, $\pm 45^{\circ}$, 0°, 90°)s

LOAD LEVEL - C

POUNDS LOAD - 7000 PERCENT OF ULTIMATE - 78

FIGURE H-22. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-16.

BEFORE LOADING AFTER LOADING

FIGURE H-23. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-16.

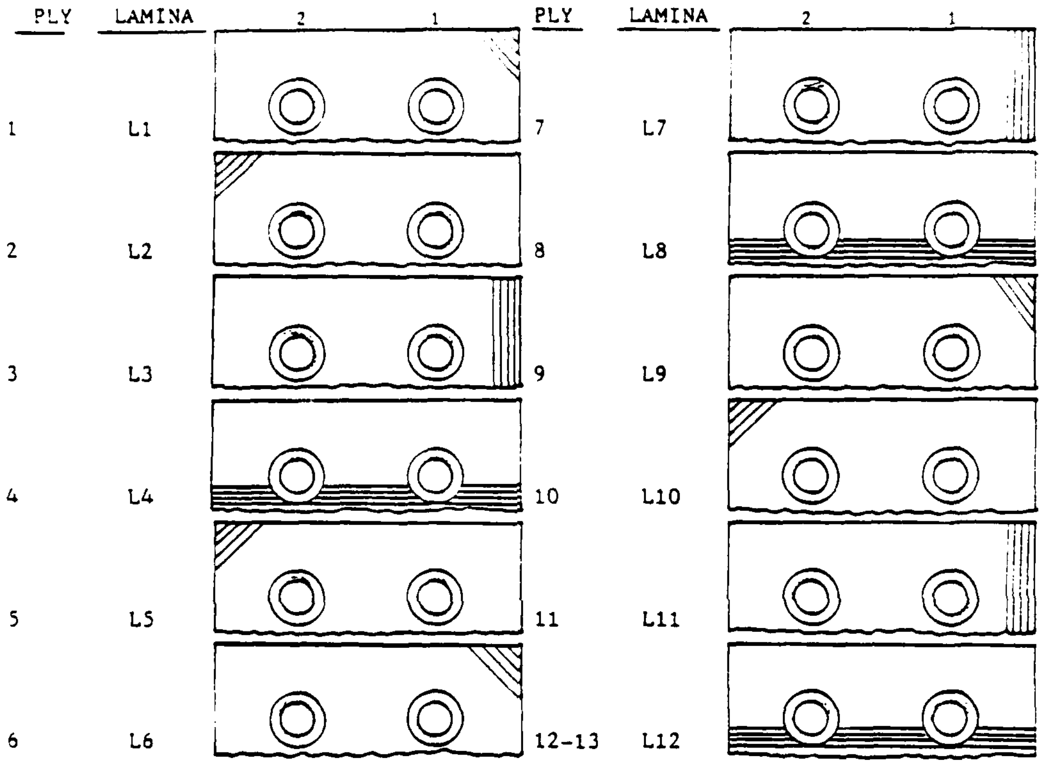


Figure H-24. Lamina Damage Characterization Chart for Specimen

IIB-C-16 Strap A Load Level C (Continued)

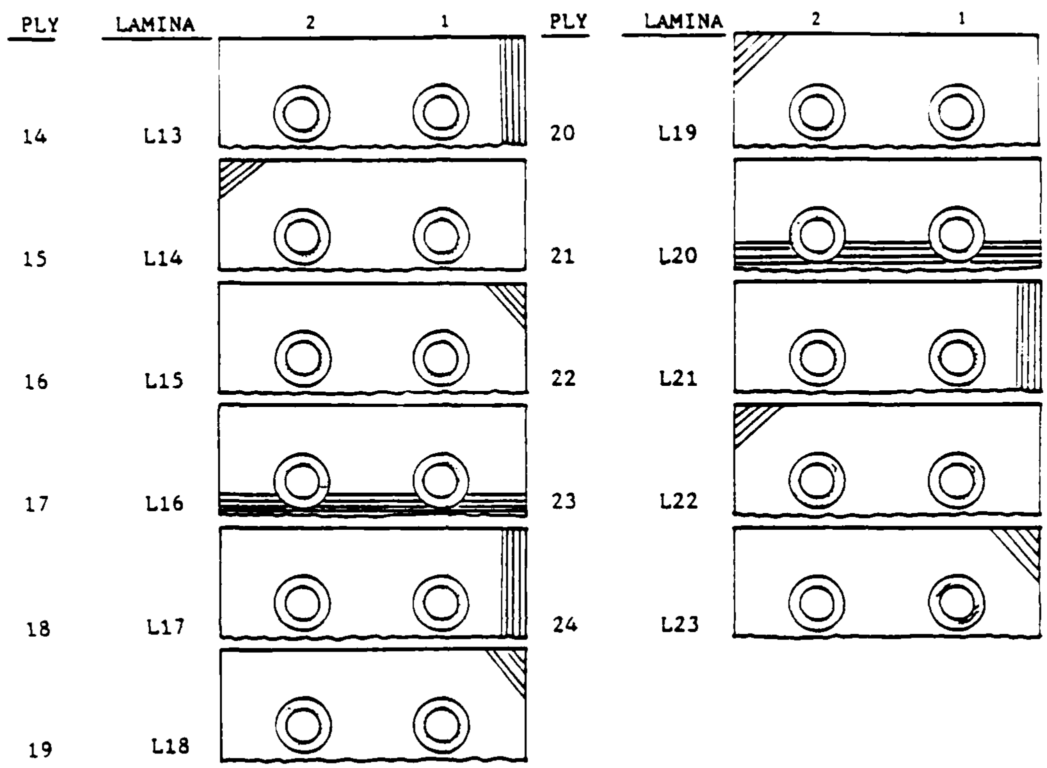


Figure H-24. Lamina Damage Characterization Chart for Specimen IIB-C-16 Strap A Load Level C

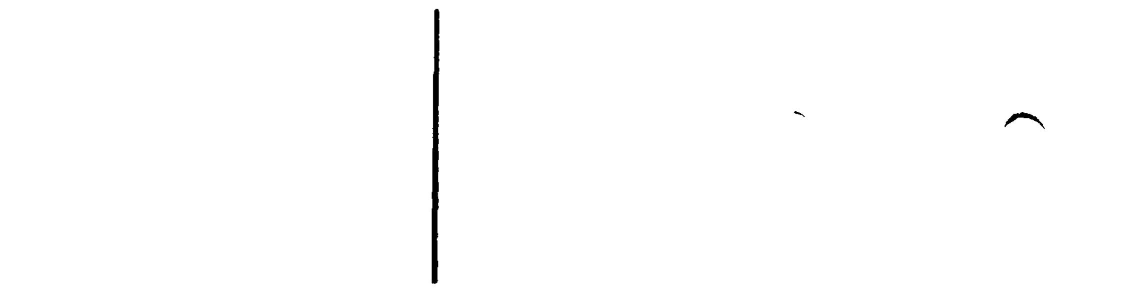
SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm$ 45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)s

LOAD LEVEL - C

POUNDS LOAD - 7000 PERCENT OF ULTIMATE - 78

FIGURE H-25. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-22.



BEFORE LOADING AFTER LOADING

FIGURE H-26. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-22.

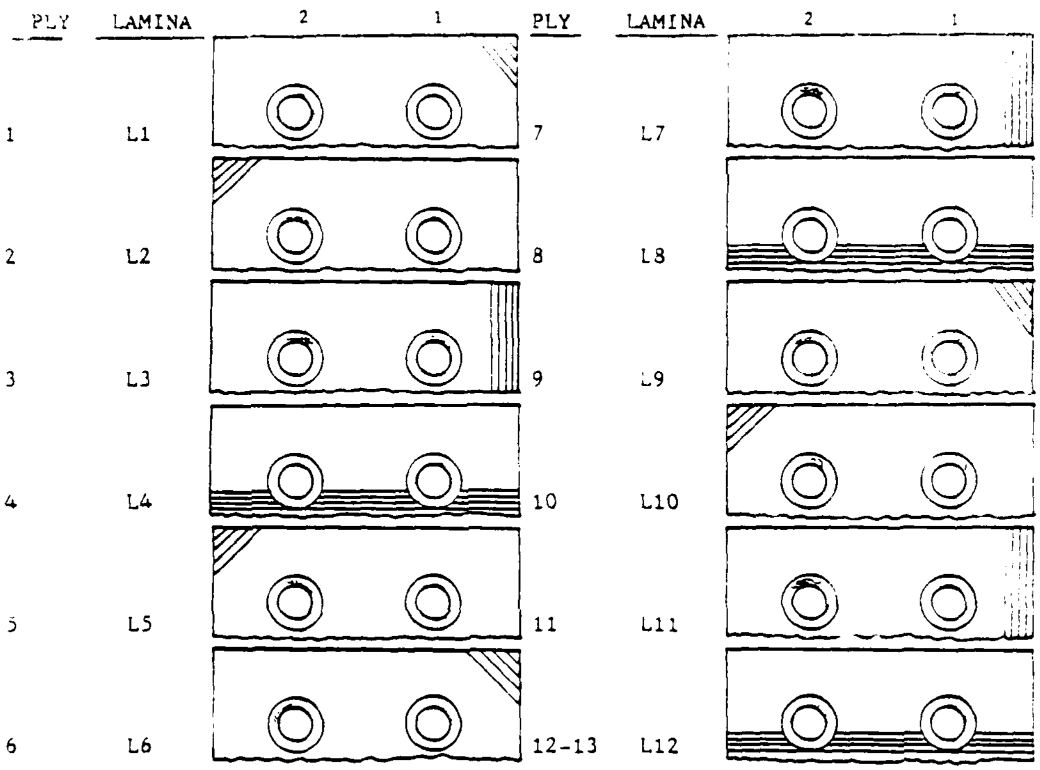


Figure H-27. Lamina Damage Characterization Chart for Specimen IIB-C-22 Strap A Load Level C (Continued)

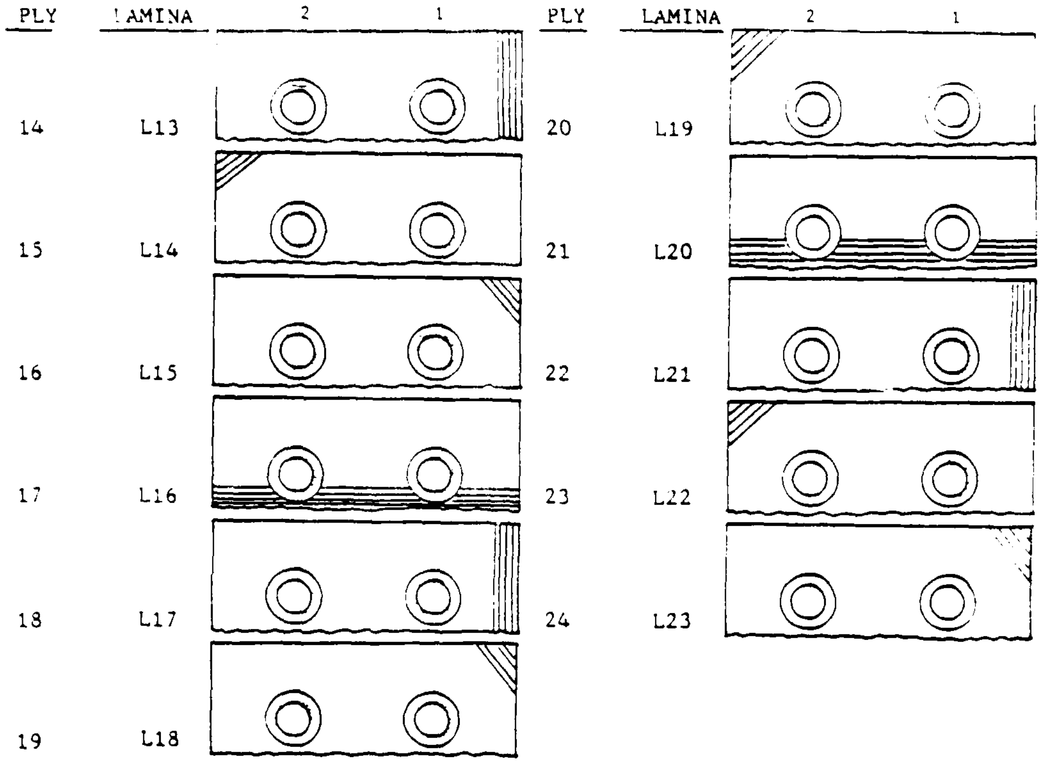


Figure H-27. Lamina Damage Characterization Chart for Specimen
IIB-C-22 Strap A Load Level C

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm45^\circ$, 0°, 90°, $\mp45^\circ$, 0°, 90°, $\pm45^\circ$, 0°, 90°)s

LOAD LEVEL - C

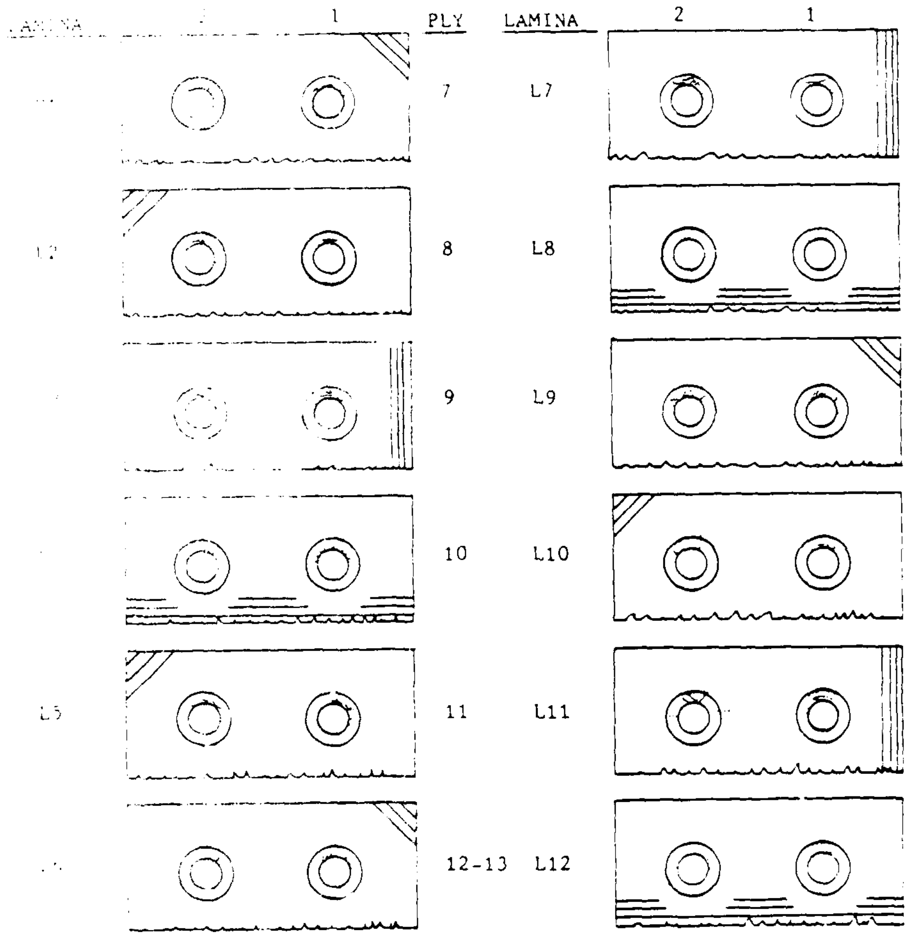
POUNDS LOAD - 7000 PERCENT OF ULTIMATE - 78

FIGURE H-28. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-24.

BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE H-29. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-24.



Lamina Damage Characterization Chart for Specimen

IIB-C-24 Strap A Load Level C

(Continued)

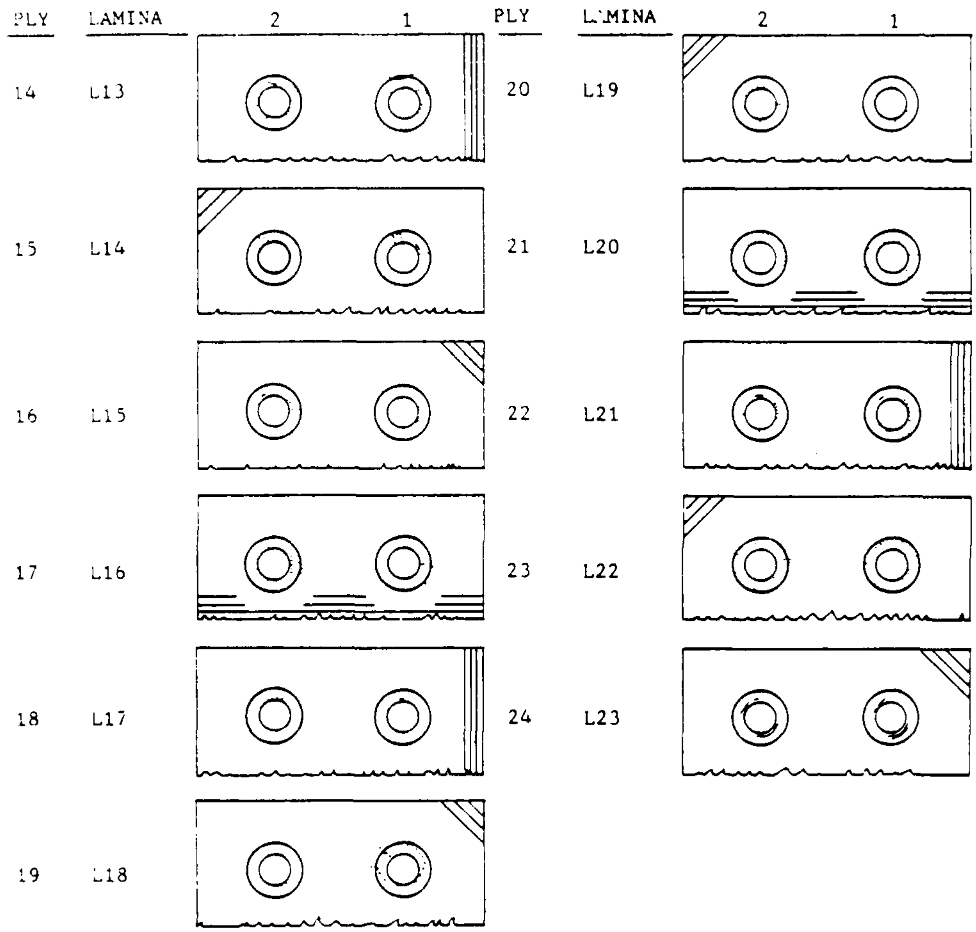


Figure H-30. Lamina Damage Characterization Chart for Specimen

IIB-C-24 Strap A Load Level C

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm$ 45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)$_s$

LOAD LEVEL - D

POUNDS LOAD - 7149 PERCENT OF ULTIMATE - 79

FIGURE H-31. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-15.

BEFORE LOADING AFTER LOADING

FIGURE H-32. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-15.

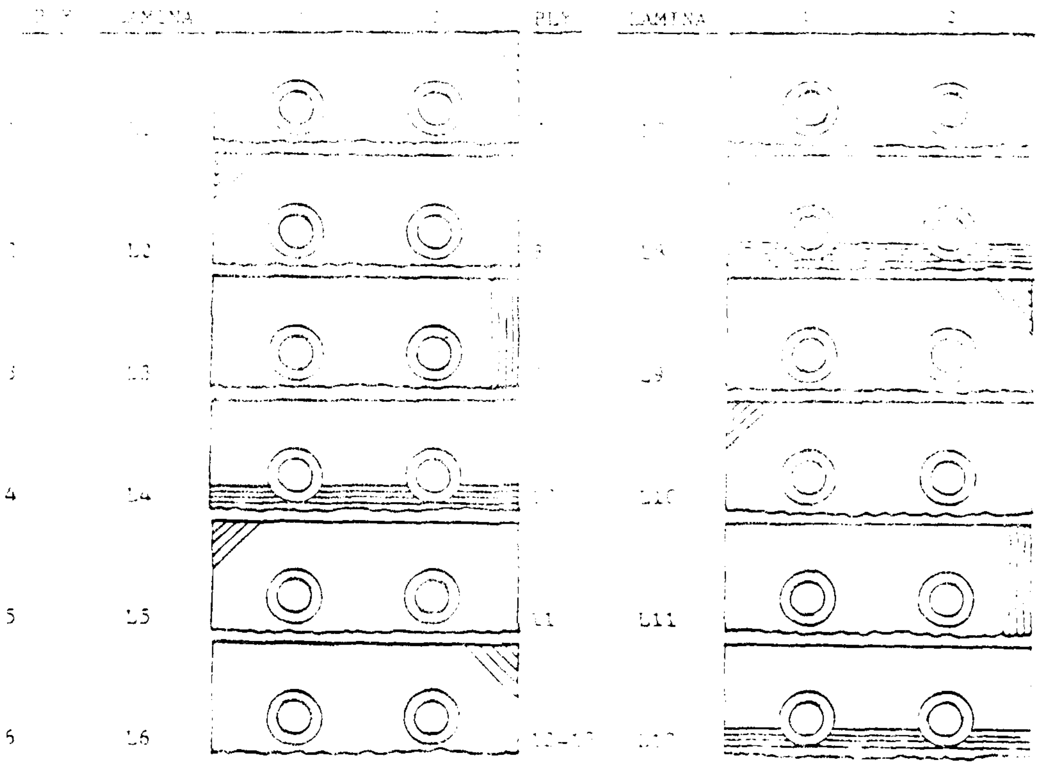


Figure H-33. Lamina Damage Characterization Chart for Specimen

IIB-C-15 Strap B Load Level D (Continued)

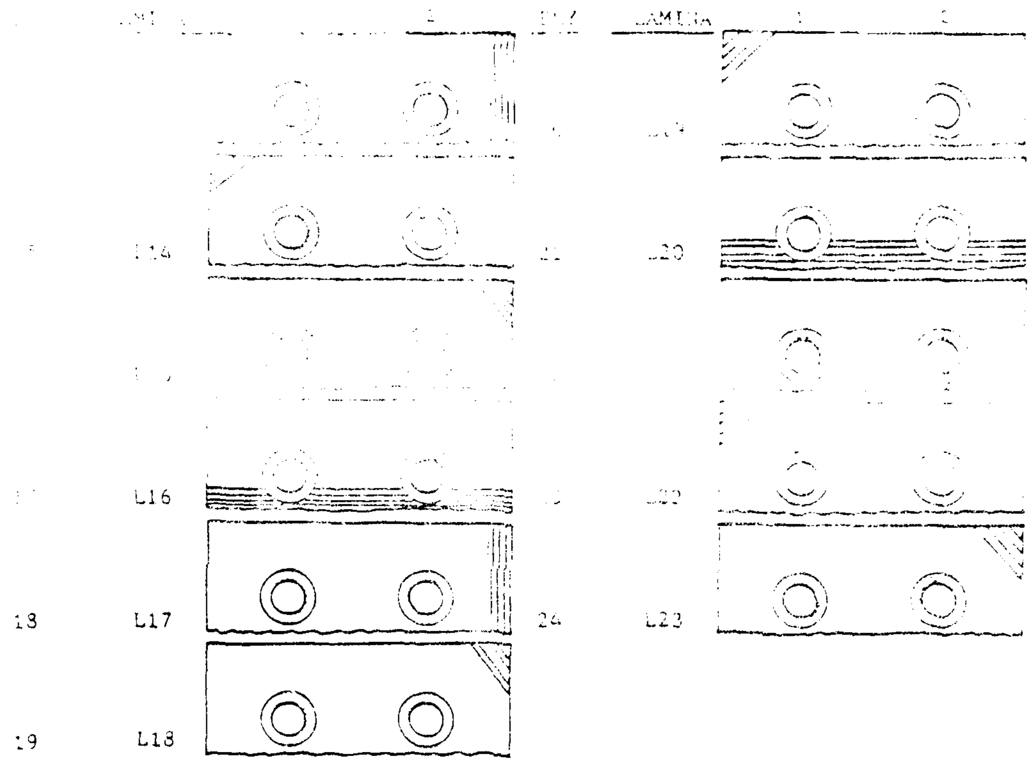


Figure H-33. Lamina Damage Characterization Chart for Specimen
IIB-C-15 Strap B Load Level D

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm$ 45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)s

LOAD LEVEL - D

POUNDS LOAD - 7149   PERCENT OF ULTIMATE - 79

FIGURE H-34. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-20.

BEFORE LOADING   AFTER LOADING

FIGURE H-35. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-20.

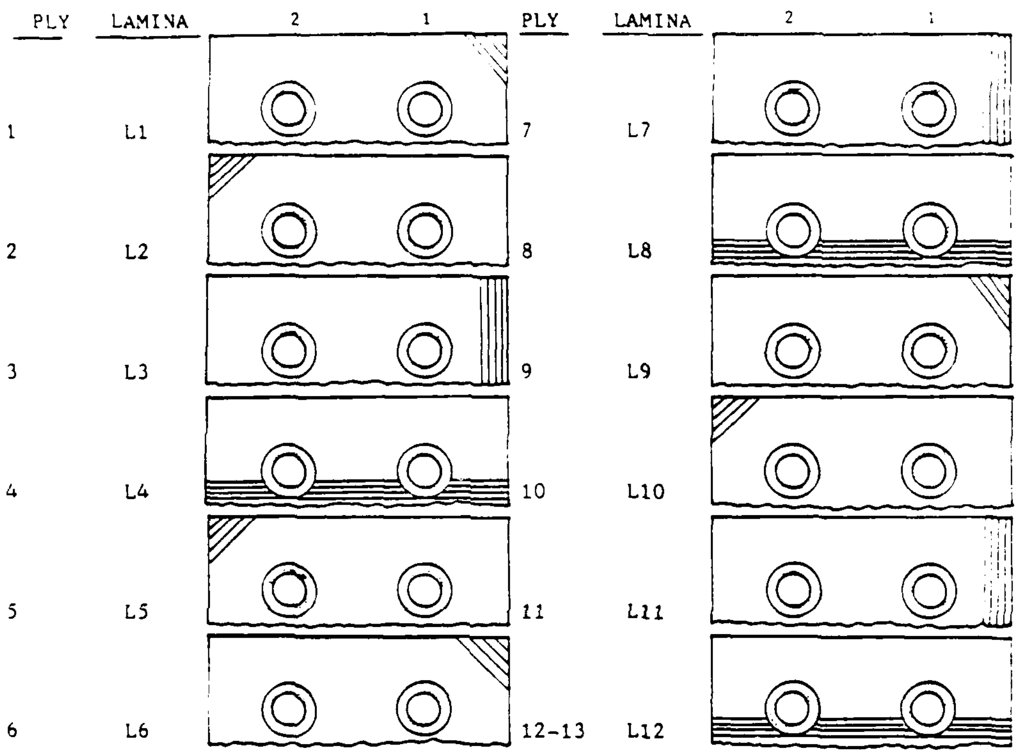


Figure H-36. Lamina Damage Characterization Chart for Specimen

IIB-C-20 Strap A Load Level D (Continued)

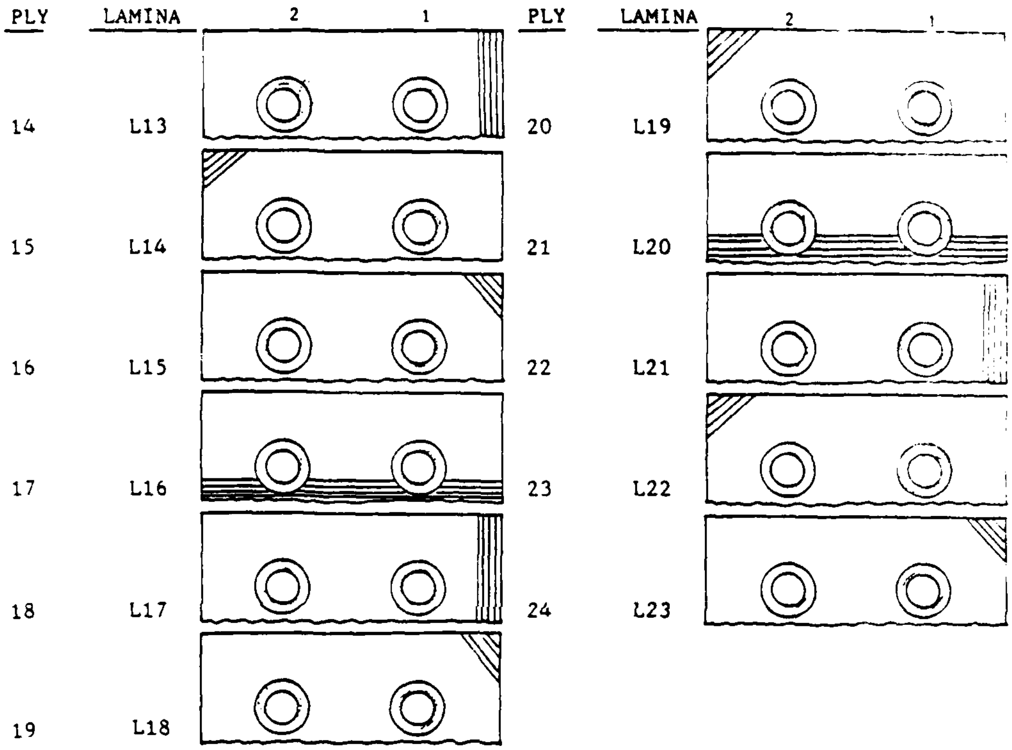


Figure H-36. Lamina Damage Characterization Chart for Specimen IIB-C-20 Strap A Load Level D

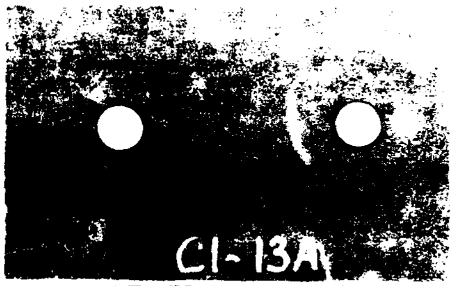
SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm$45°, 0°, 90°, $\pm$45°, 0°, 90°, $\pm$45°, 0°, 90°)

LOAD LEVEL - D

POUNDS LOAD - 7149 PERCENT OF ULTIMATE - 79

FIGURE H-37. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-13.



BEFORE LOADING AFTER LOADING

FIGURE H-38. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-13.

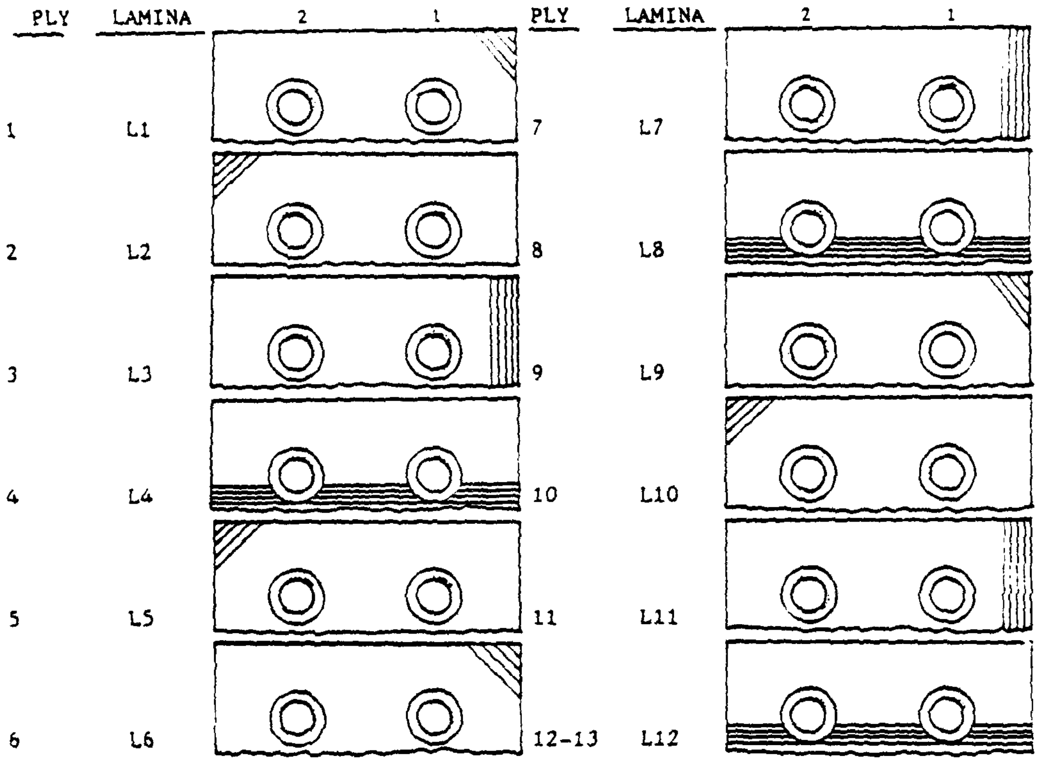


Figure H-39. Lamina Damage Characterization Chart for Specimen

IIB-C -13 Strap A Load Level D (Continued)

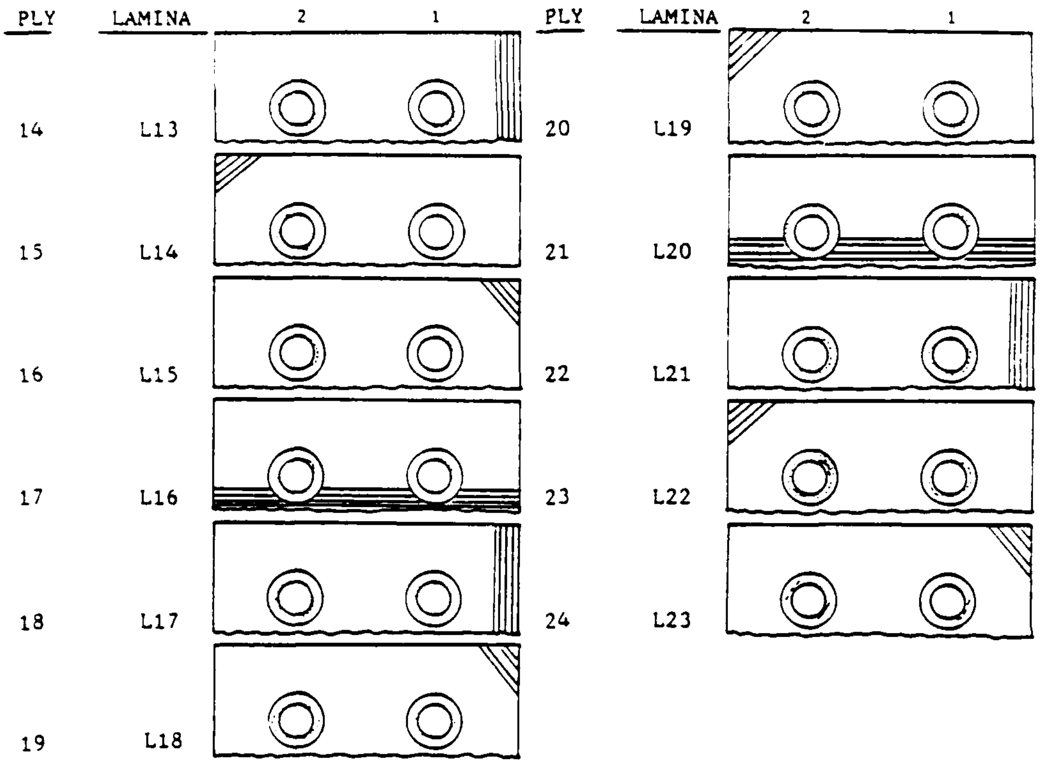


Figure H-39. Lamina Damage Characterization Chart for Specimen
IIB-C-13 Strap A Load Level D

C(± 45°, ..., 90°, ..., 0°, 90° ±45°, 0°, 90°)s

...VEL ...

...OUNDS LOAD - 7149 PER... OF ULTIMATE - 7...

FIGURE H-40. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-7.

BEFORE LOADING AFTER LOADING

FIGURE H-41. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-7.

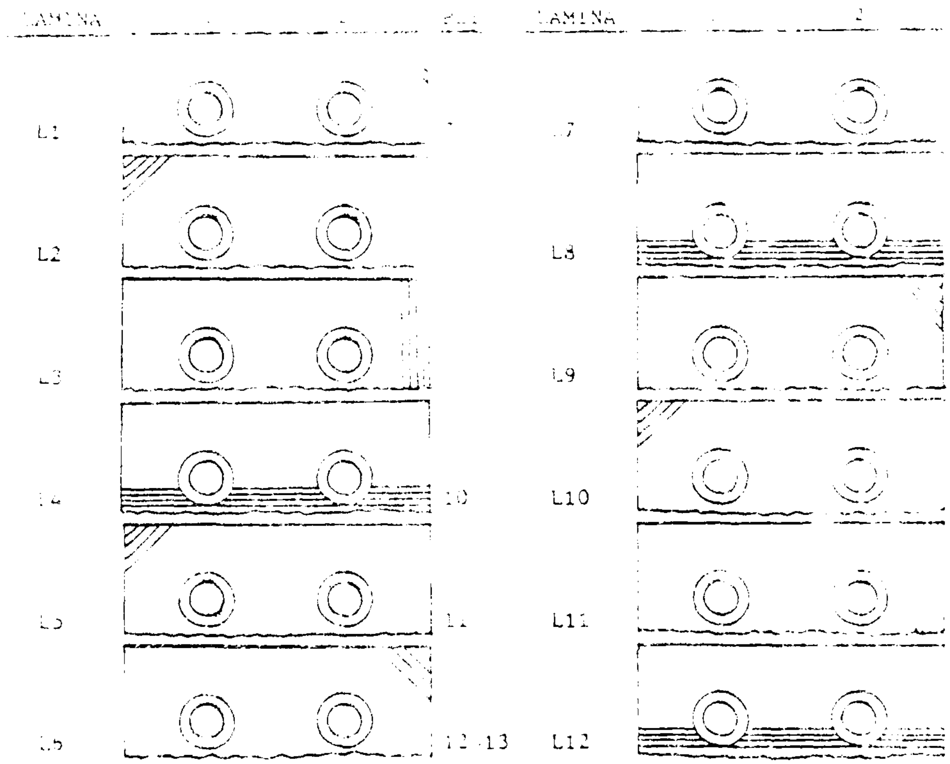


Figure B-42. Lamina Damage Characterization Chart for Specimen

I1B-C-7 Strap B Load Level D (Continued)

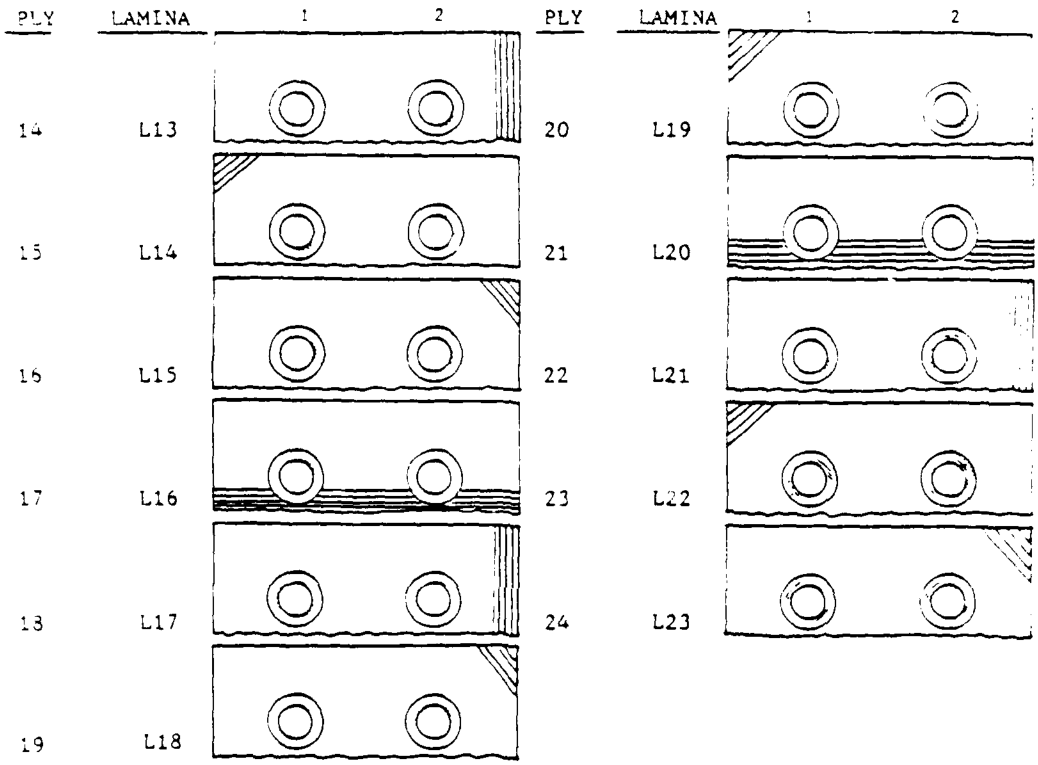


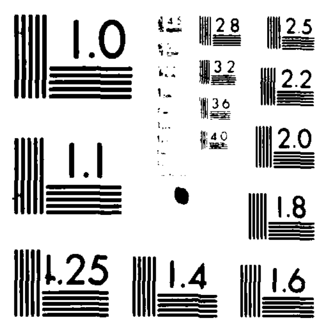
Figure H-42. Lamina Damage Characterization Chart for Specimen IIB-C-7 Strap B Load Level D

AD-A116 120   LOCKHEED-GEORGIA CO MARIETTA   F/G 11/4
DAMAGE PROGRESSION IN GRAPHITE-EPOXY BY A DEPLYING TECHNIQUE.(U)
DEC 81   S M FREEMAN   F33615-80-C-3224
UNCLASSIFIED   LG-81ER0245   AFWAL-TR-81-3157   NL

6 of 6
AD
A116120

END
DATE
FILMED
7-82
DTIC

116120



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm 45^{\circ}$, 0°, 90°, $\mp 45^{\circ}$, 0°, 90°, $\pm 45^{\circ}$, 0°, 90°)s

LOAD LEVEL - D

POUNDS LOAD - 7149 PERCENT OF ULTIMATE - 79

FIGURE H-43. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-1.

BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE H-44. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-1.

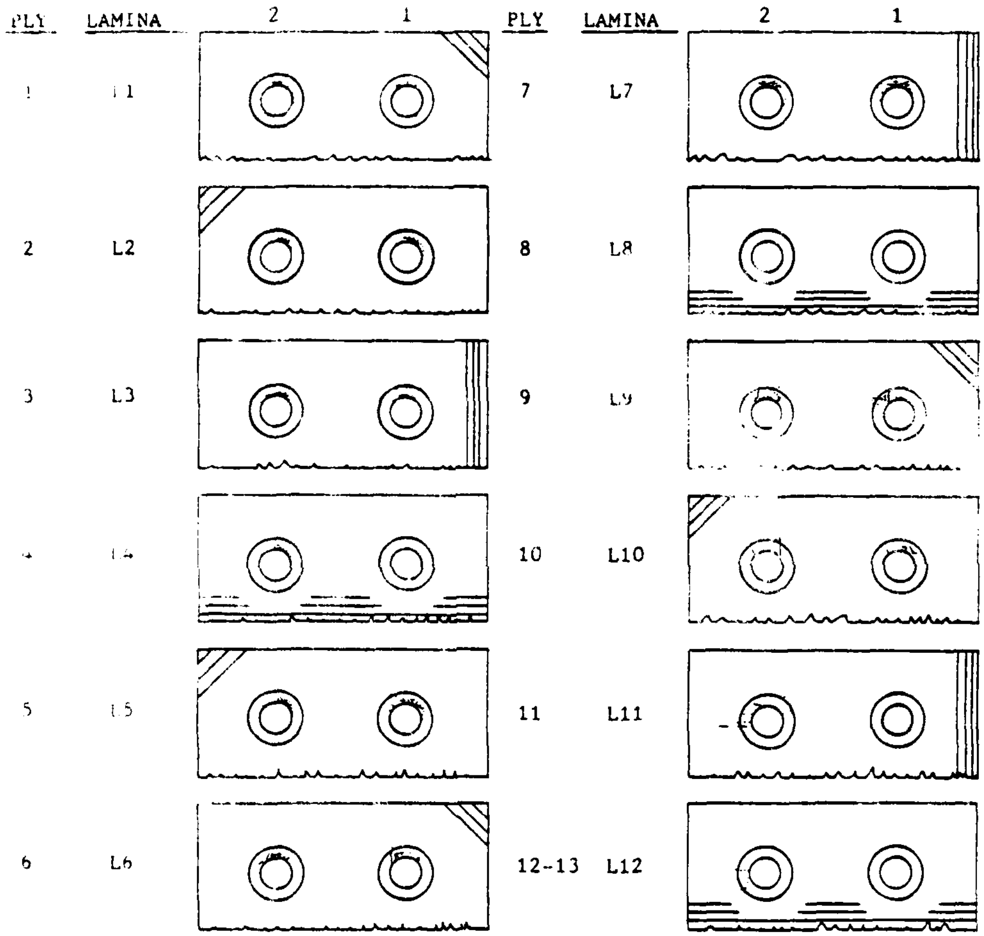


Figure B.4.. Lamina Damage Characterization Chart for Specimen

I.B-C-1 Strap B Load Level D

(Continued)

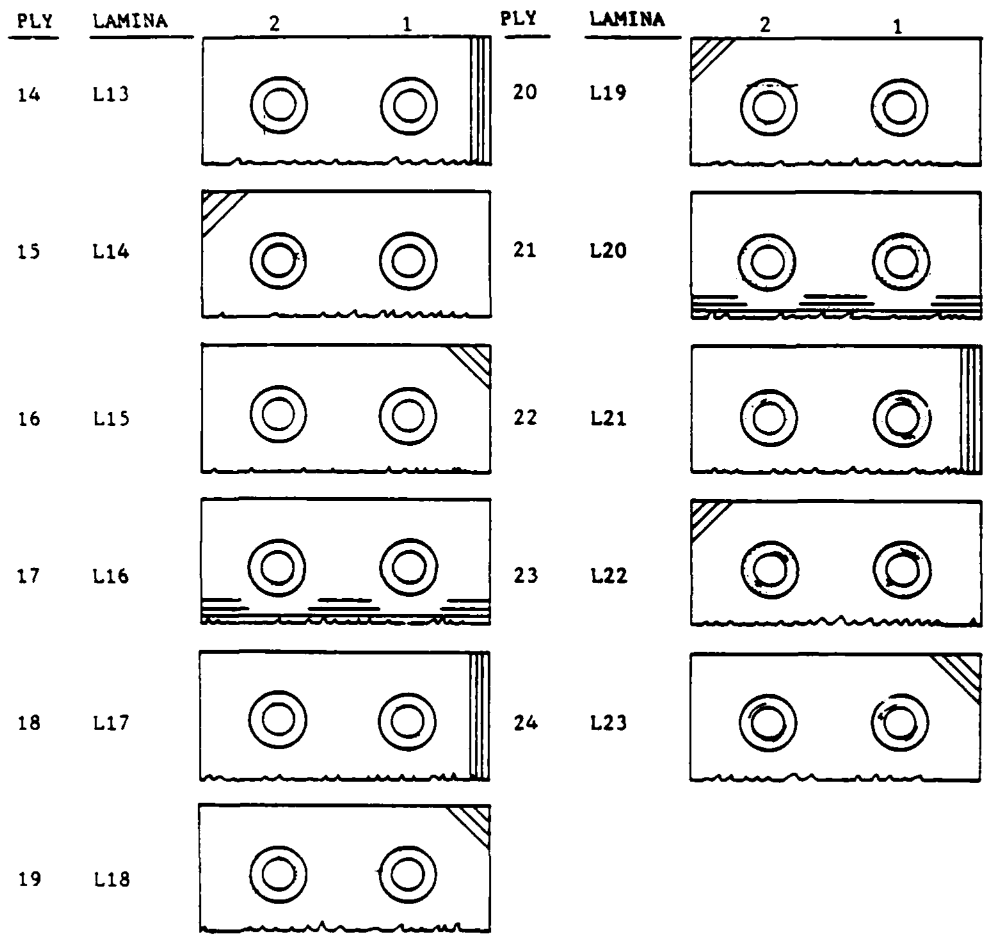


Figure H-45. Lamina Damage Characterization Chart for Specimen

IIB-C-1 Strap B Load Level D

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm$ 45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)s

LOAD LEVEL - B

POUNDS LOAD - 7255 PERCENT OF ULTIMATE - 81

FIGURE H-46. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-2.

BEFORE LOADING AFTER LOADING

FIGURE H-47. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-2.

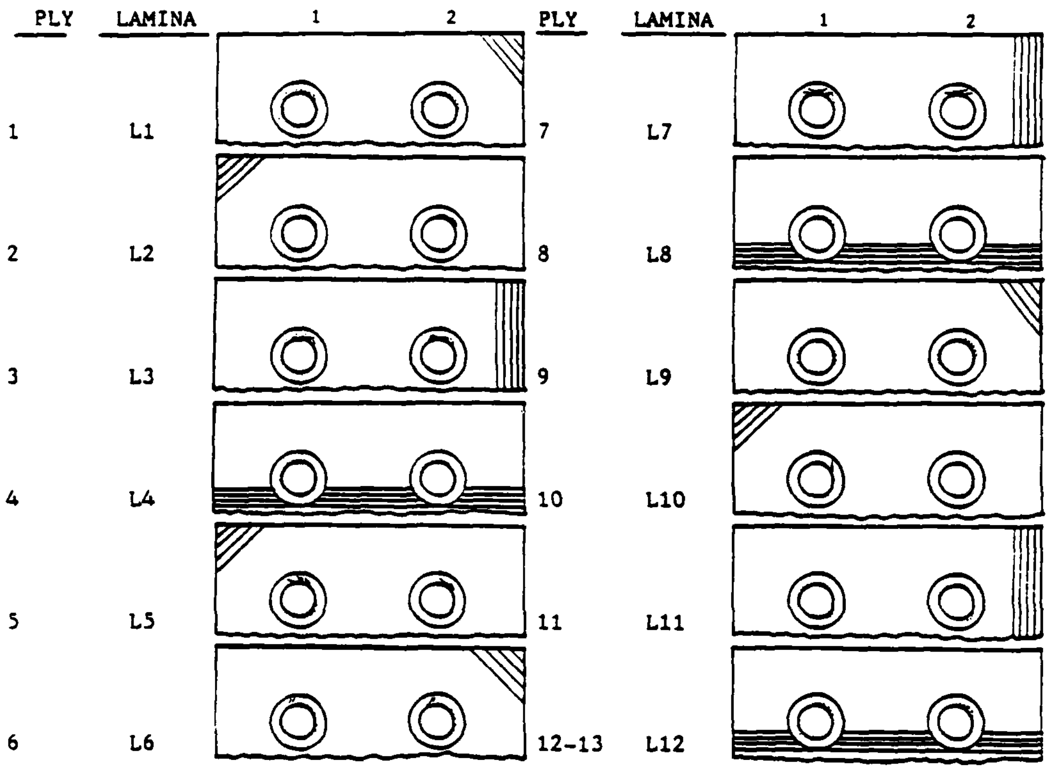


Figure H-48. Lamina Damage Characterization Chart for Specimen IIB-C-2 Strap B Load Level B (Continued)

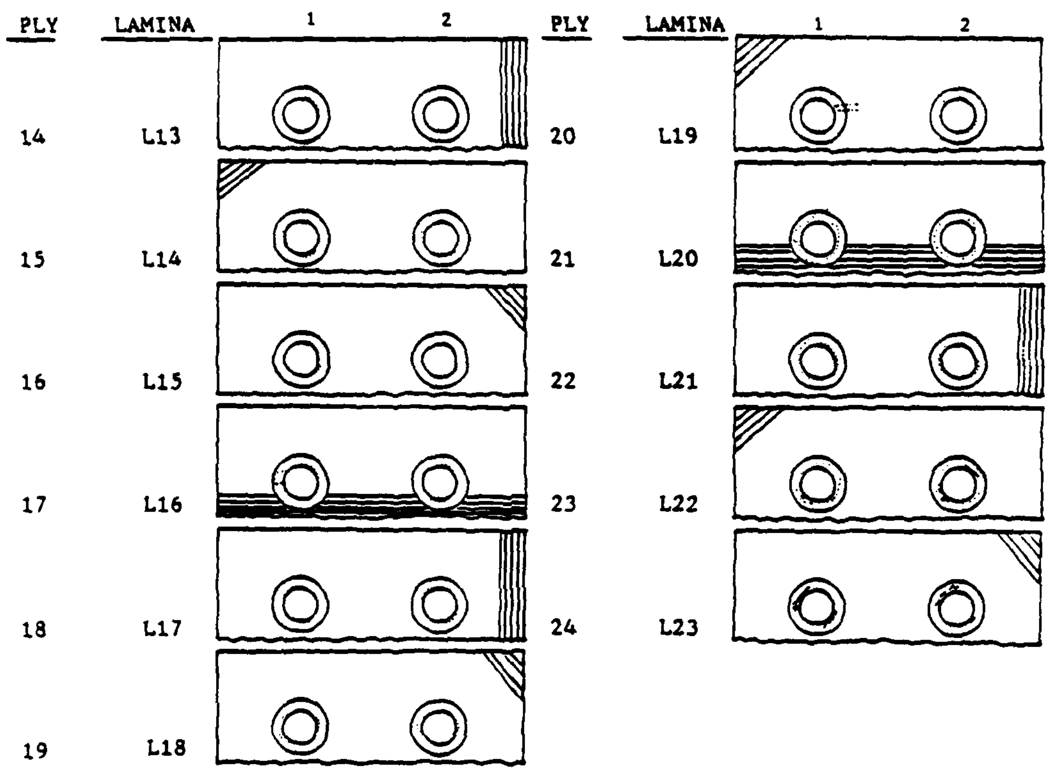


Figure H-48. Lamina Damage Characterization Chart for Specimen IIB-C-2 Strap B Load Level B

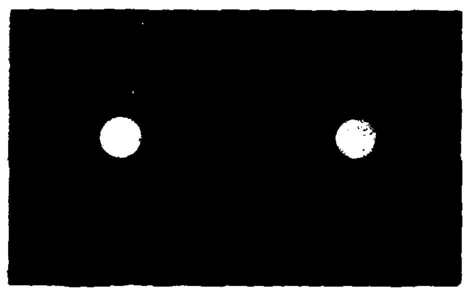
SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm$ 45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)s

LOAD LEVEL - B

POUNDS LOAD - 7255 PERCENT OF ULTIMATE - 81

FIGURE H-49. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-27.



BEFORE LOADING AFTER LOADING

FIGURE H-50. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-27.

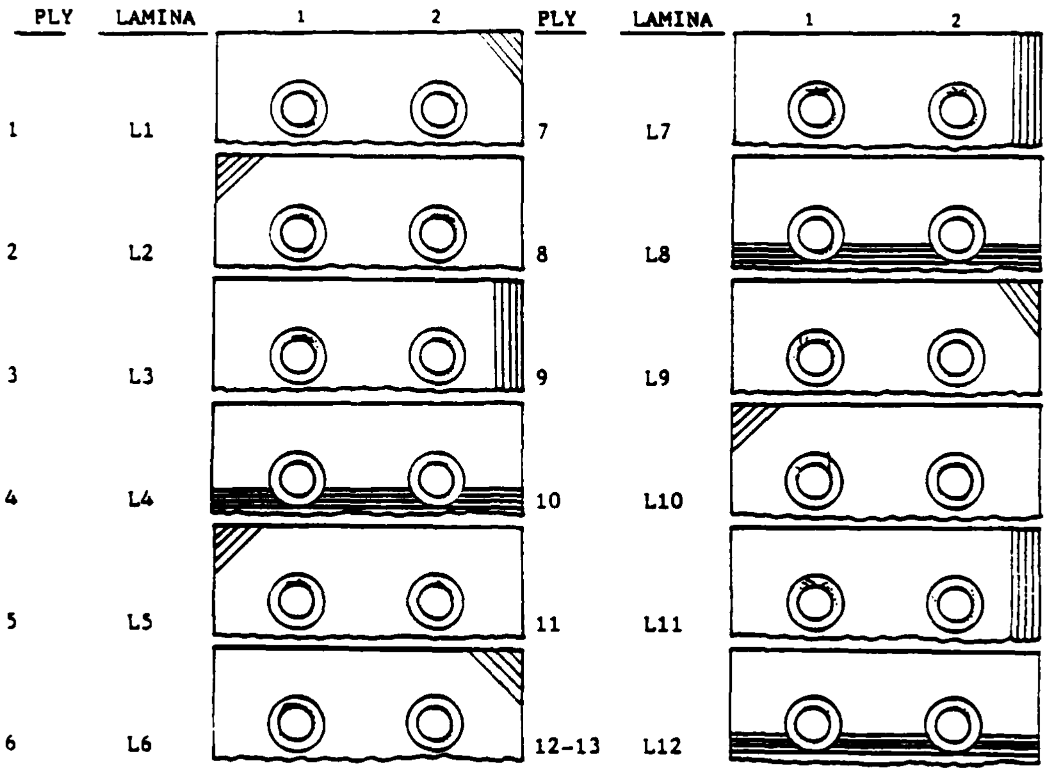


Figure H-51. Lamina Damage Characterization Chart for Specimen

IIB-C-27 Strap B Load Level B (Continued)

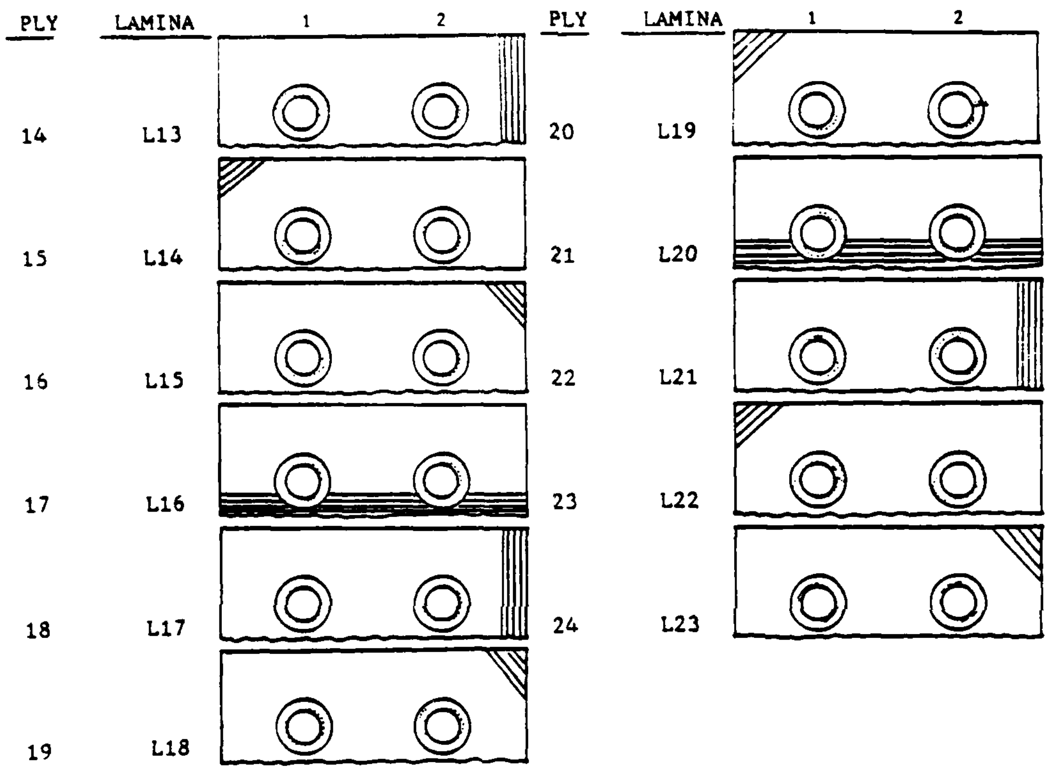


Figure H-51. Lamina Damage Characterization Chart for Specimen
IIB-C-27 Strap B Load Level B

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm$ 45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)s

LOAD LEVEL - B

POUNDS LOAD - 7255 PERCENT OF ULTIMATE - 81

FIGURE H-52. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-11.

BEFORE LOADING AFTER LOADING

FIGURE H-53. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-11.

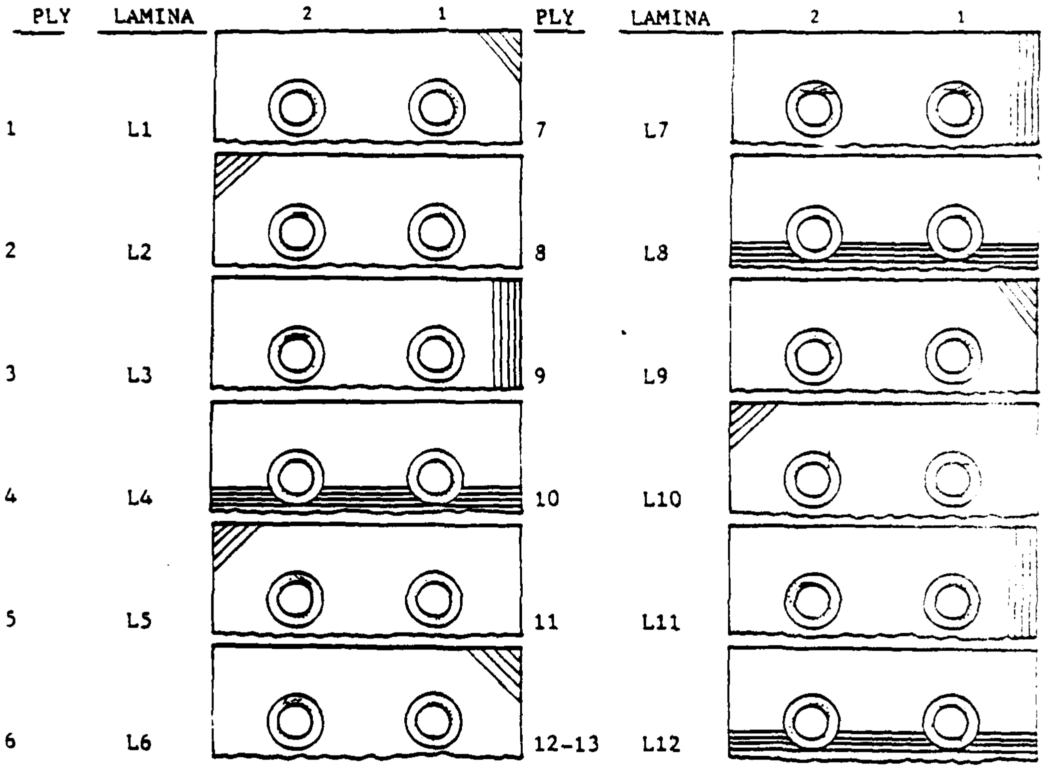


Figure H-54. Lamina Damage Characterization Chart for Specimen IIB-C-11 Strap A Load Level B (Continued)

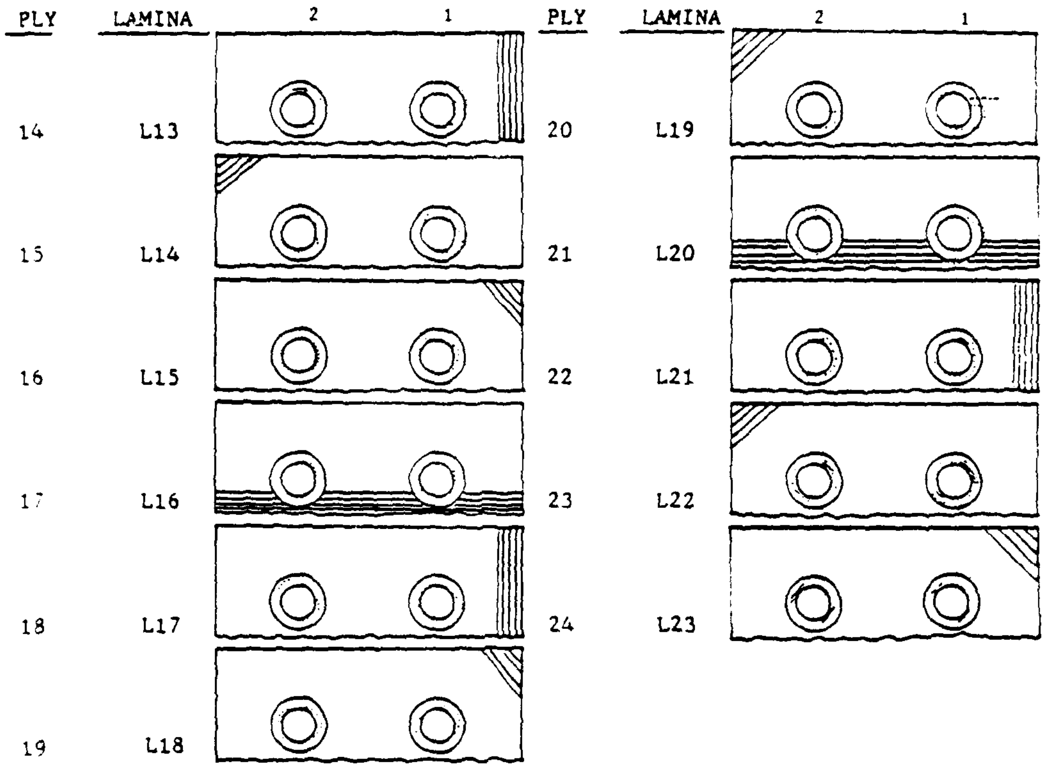


Figure H-54. Lamina Damage Characterization Chart for Specimen IIB-C-11 Strap A Load Level B

SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm$ 45°, 0°, 90°, $\mp$45°, 0°, 90°, $\pm$45°, 0°, 90°)s

LOAD LEVEL - B

POUNDS LOAD - 7255 PERCENT OF ULTIMATE - 81

FIGURE H-55. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-10.

BEFORE LOADING AFTER LOADING

FIGURE H-56. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-10.

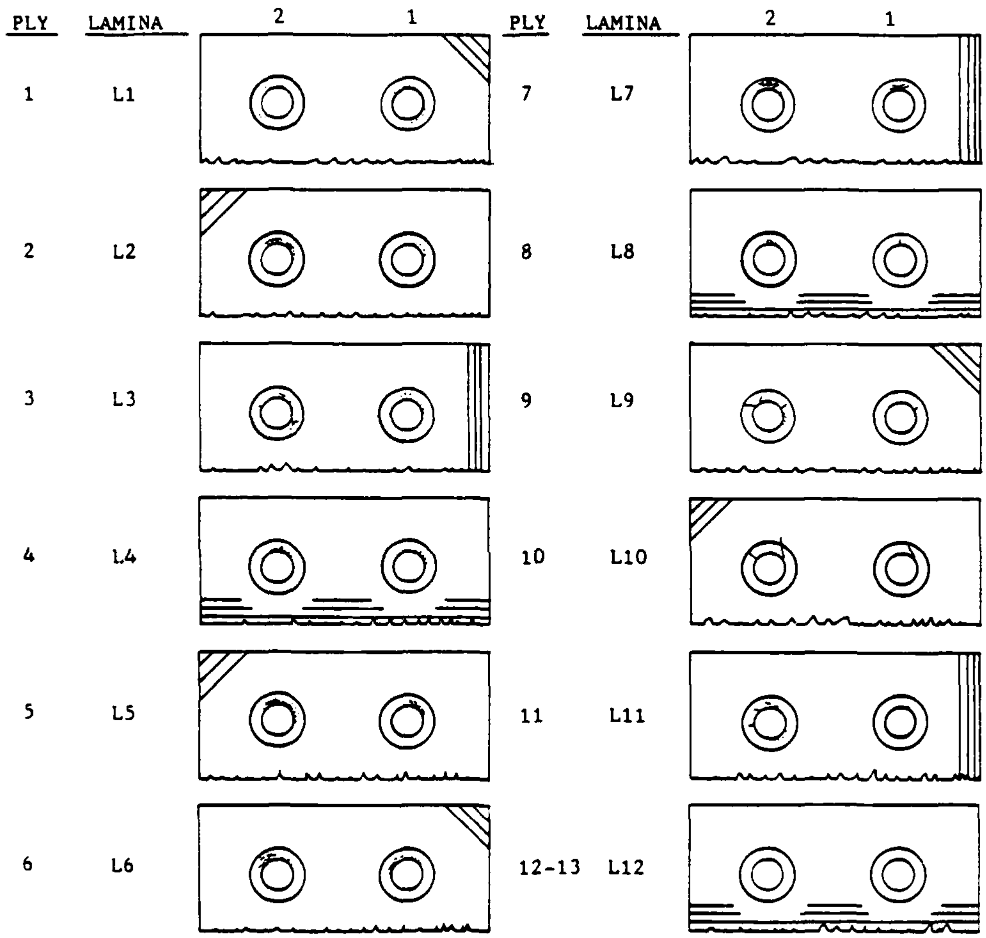


Figure H-57. Lamina Damage Characterization Chart for Specimen

IIB-C-10 Strap A Load Level B

(Continued)

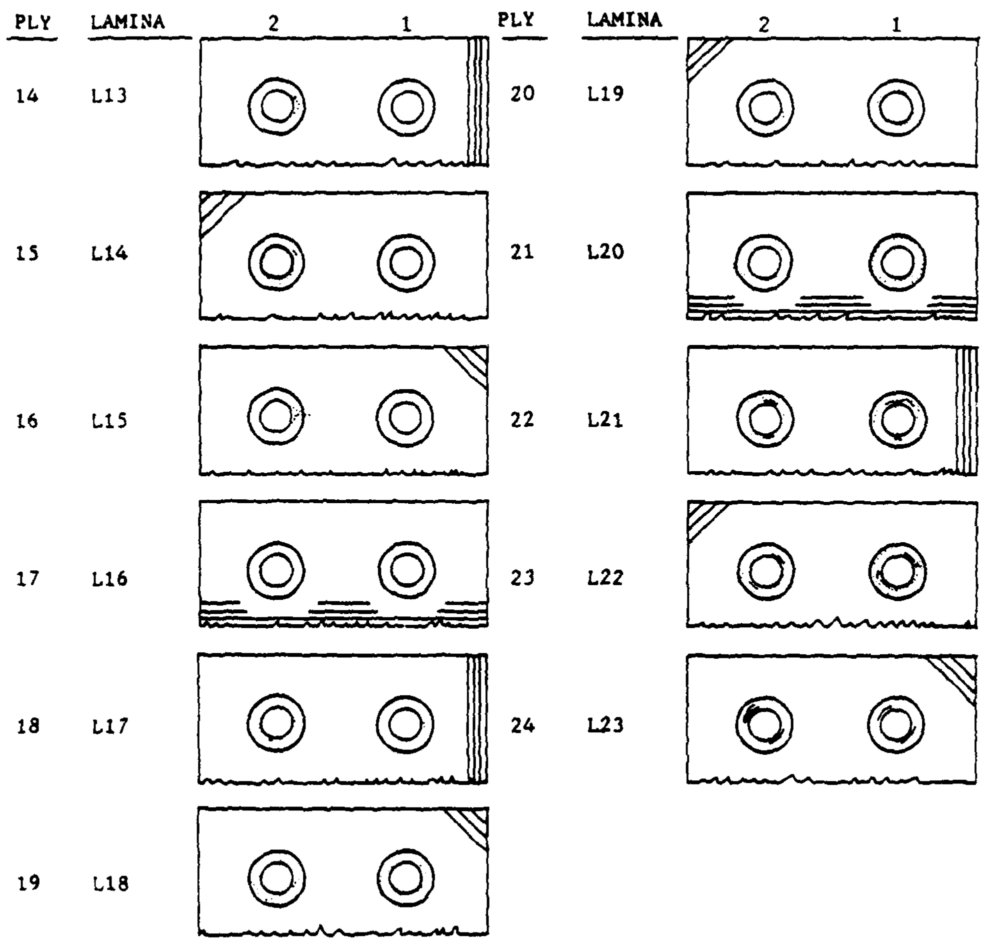


Figure H-57. Lamina Damage Characterization Chart for Specimen

IIB-C-10 Strap A Load Level B

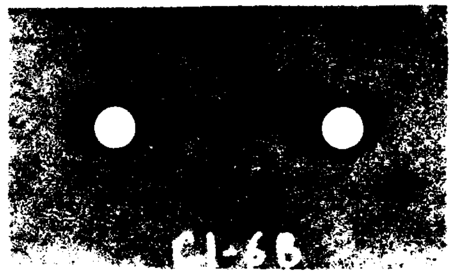
SPECIMEN TYPE - IIB (BOLTED JOINT)

LAMINATE - C($\pm 45^\circ$, 0°, 90°, $\mp 45^\circ$, 0°, 90°, $\pm 45^\circ$, 0°, 90°)s

LOAD LEVEL - B

POUNDS LOAD - 7255 PERCENT OF ULTIMATE - 81

FIGURE H-58. SPECIMEN TYPE, LAMINATE STACKING SEQUENCE AND TEST LOAD FOR SPECIMEN IIB-C-6.



BEFORE LOADING AFTER LOADING

STEREO X-RAY PAIR AFTER LOADING

FIGURE H-59. PRINTS OF RADIOGRAPHS FOR SPECIMEN IIB-C-6.

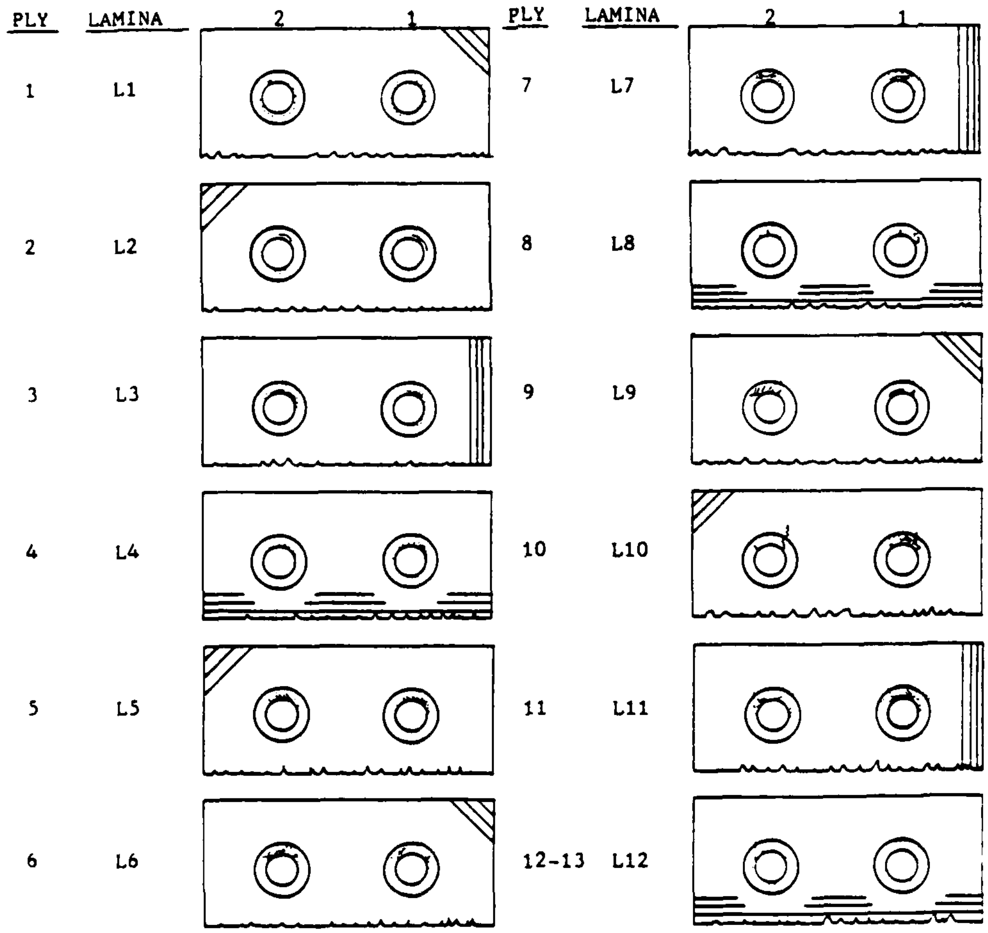


Figure H-60. Lamina Damage Characterization Chart for Specimen

IIB-C-6 Strap B Load Level B

(Continued)

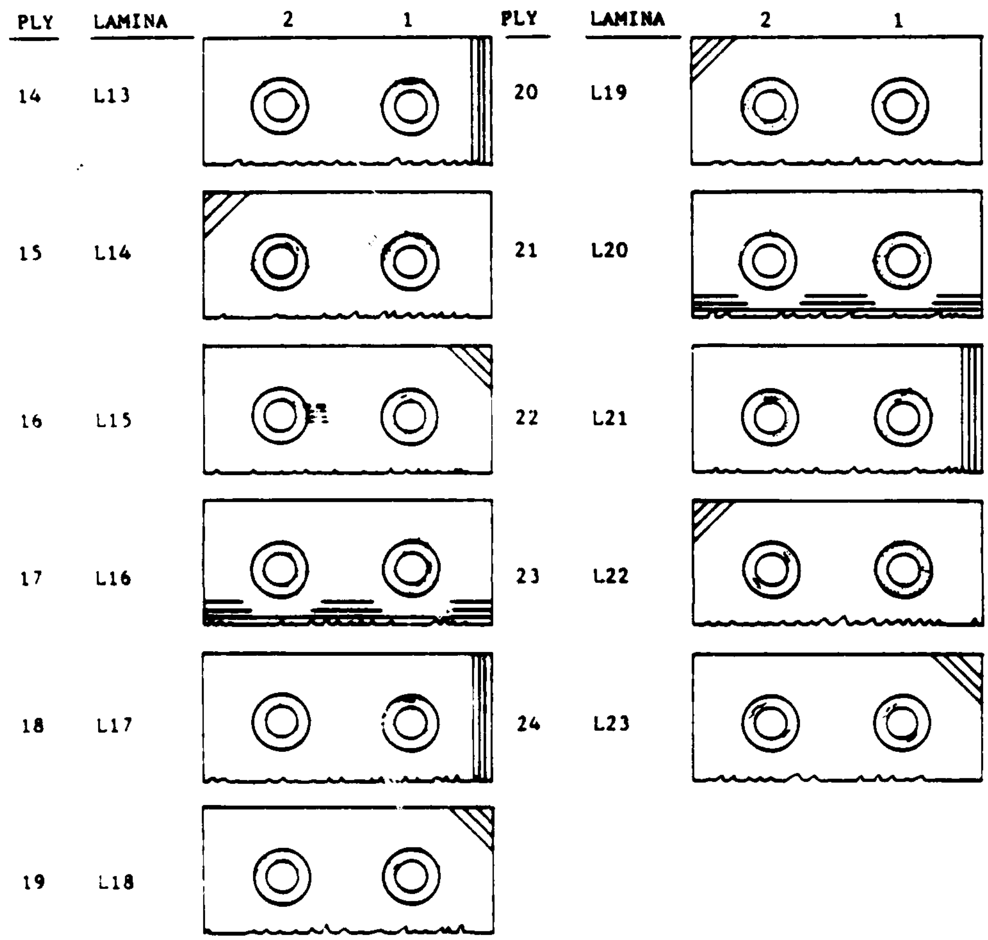
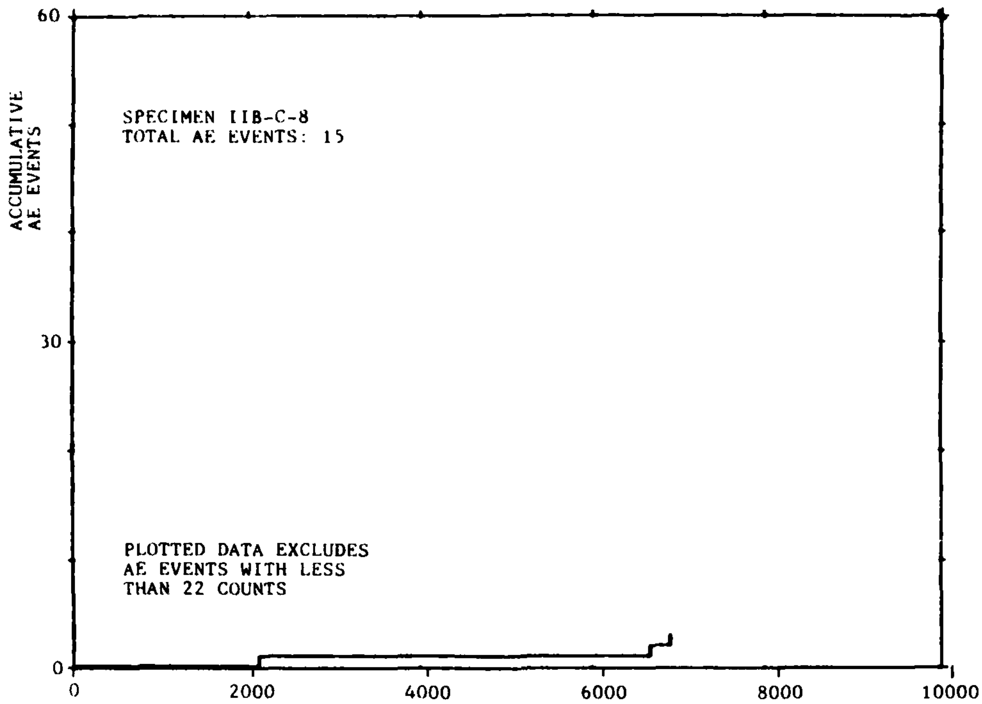


Figure H-60. Lamina Damage Characterization Chart for Specimen

IIB-C- 6 Strap B Load Level B



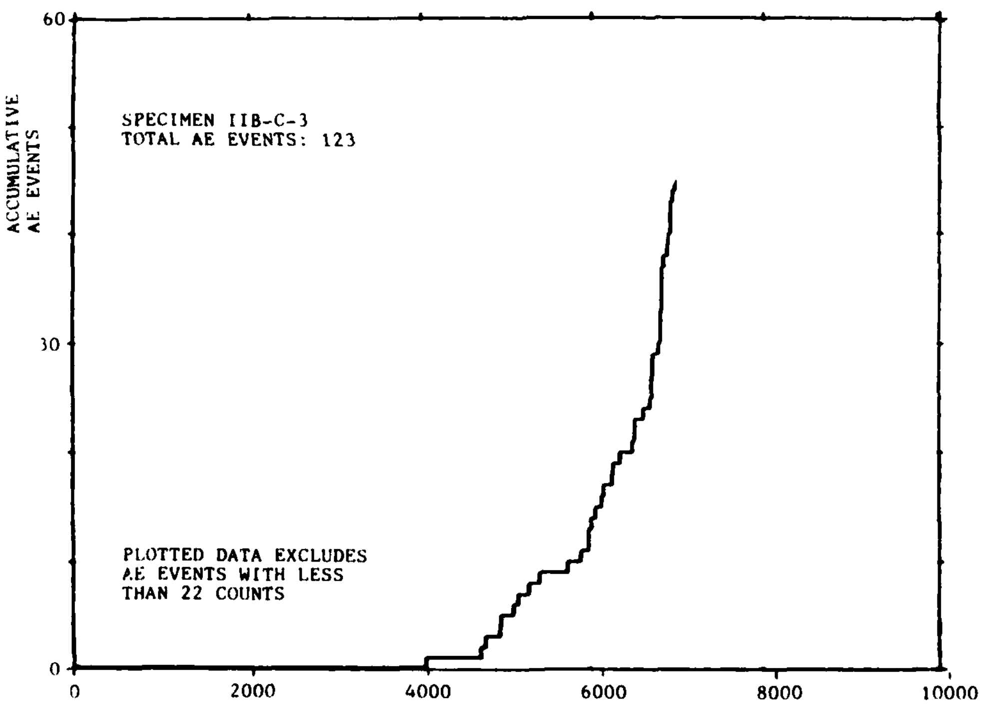
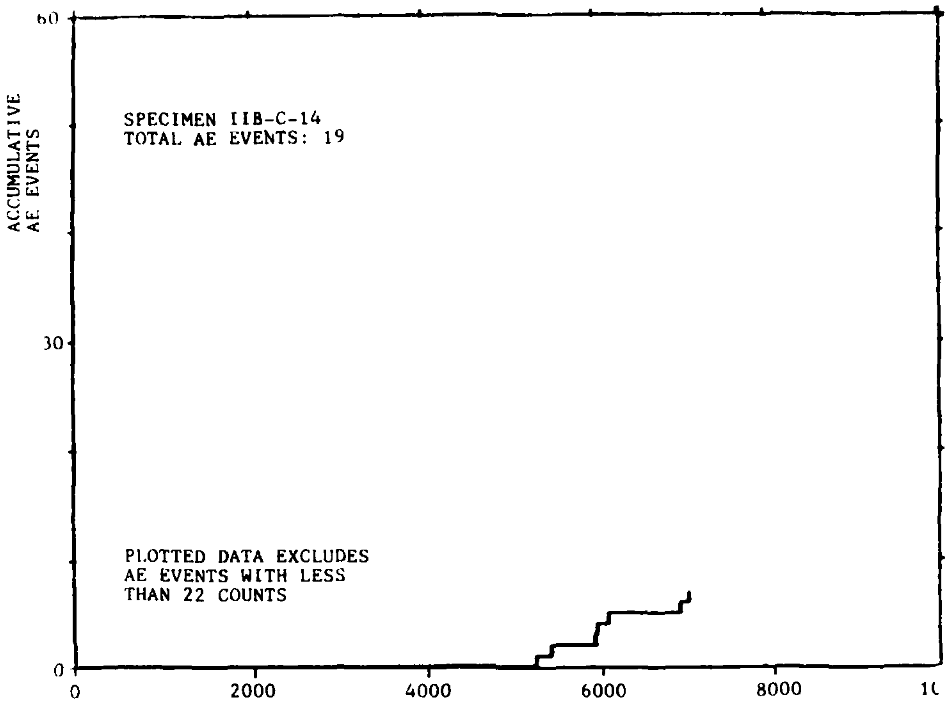


Figure H-61. Plots of Accumulative AE Events vs Applied Load for Type IIB-C Specimens with Minimum and Maximum Response for Load Level A.



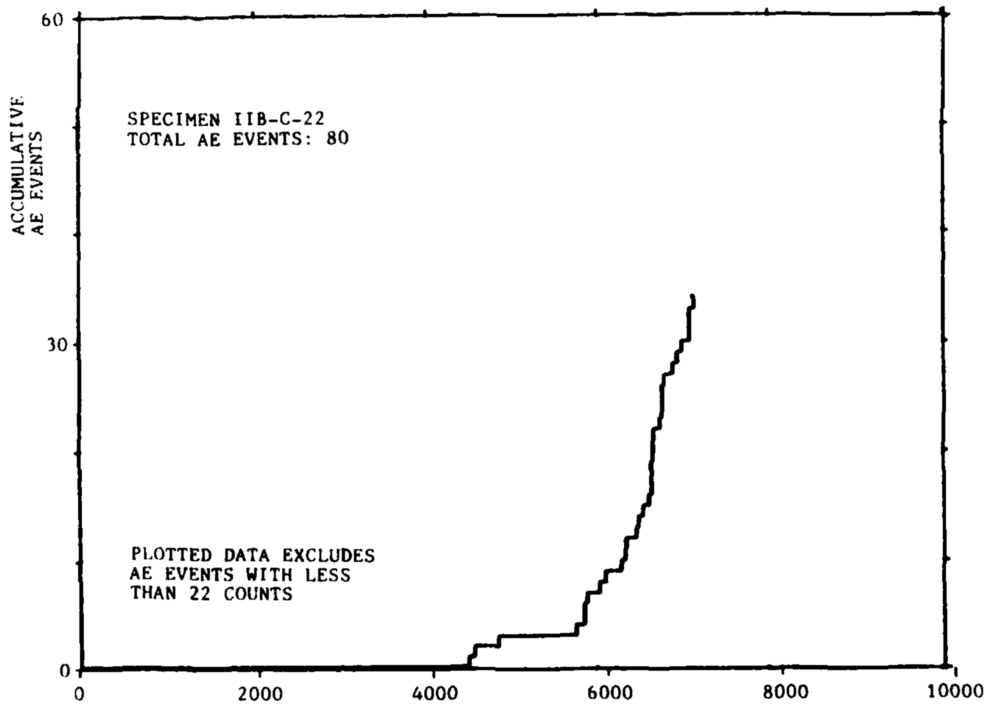
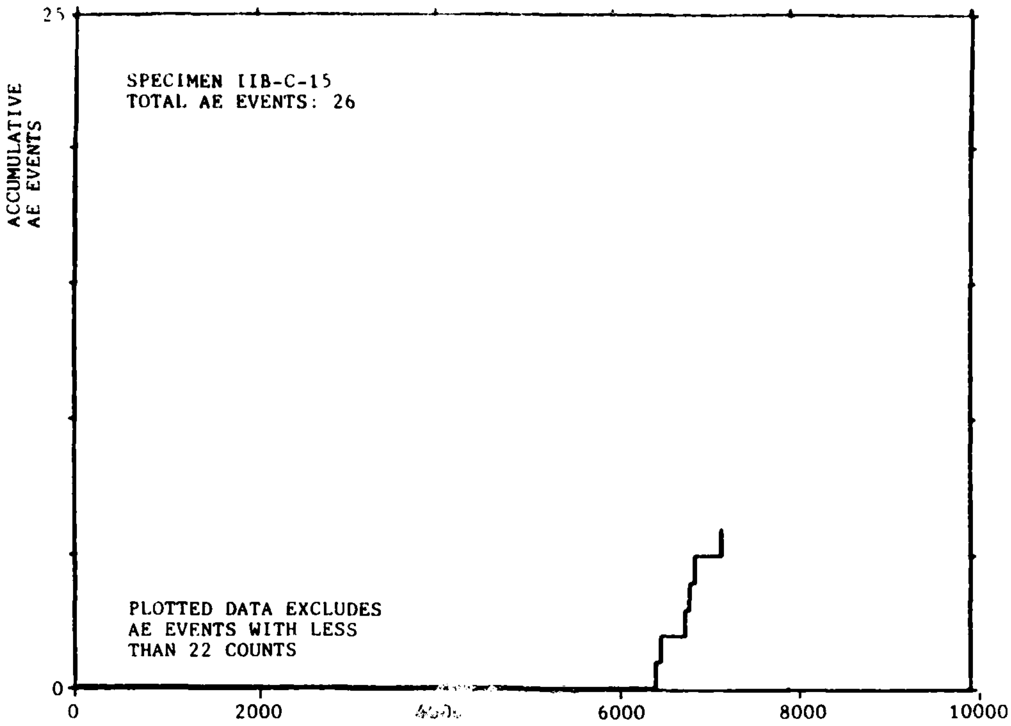


Figure H-62. Plots of Accumulative AE Events vs Applied Load for Type IIB-C Specimens with Minimum and Maximum Response for Load Level C.



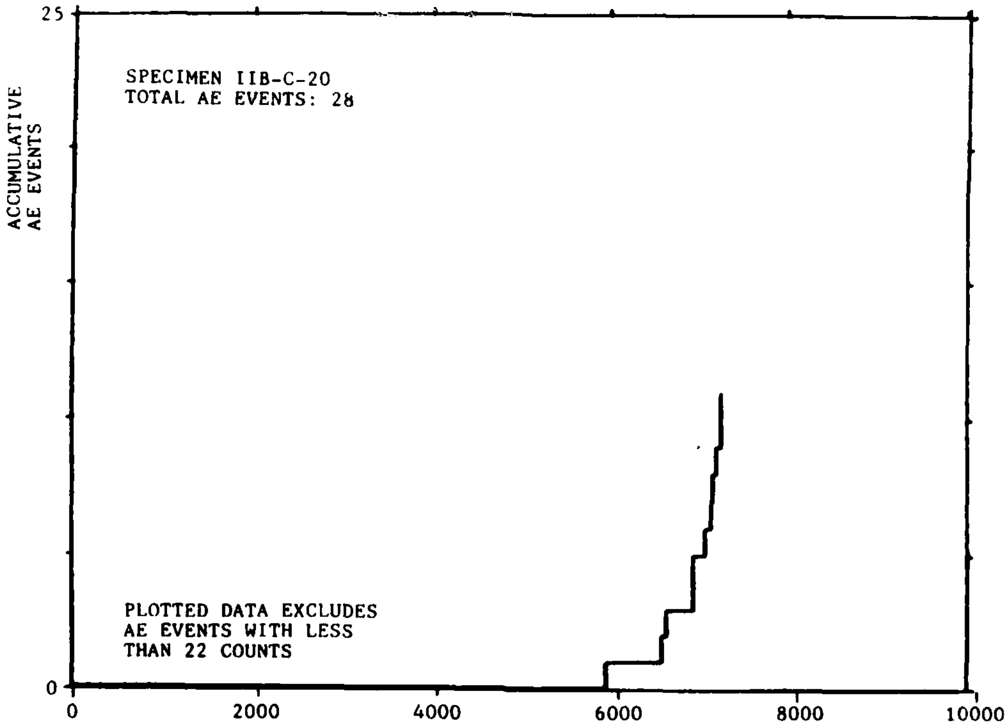


Figure H-63. Plots of Accumulative AE Events vs Applied Load for Type IIB-C Specimens with Minimum and Maximum Response for Load Level D.

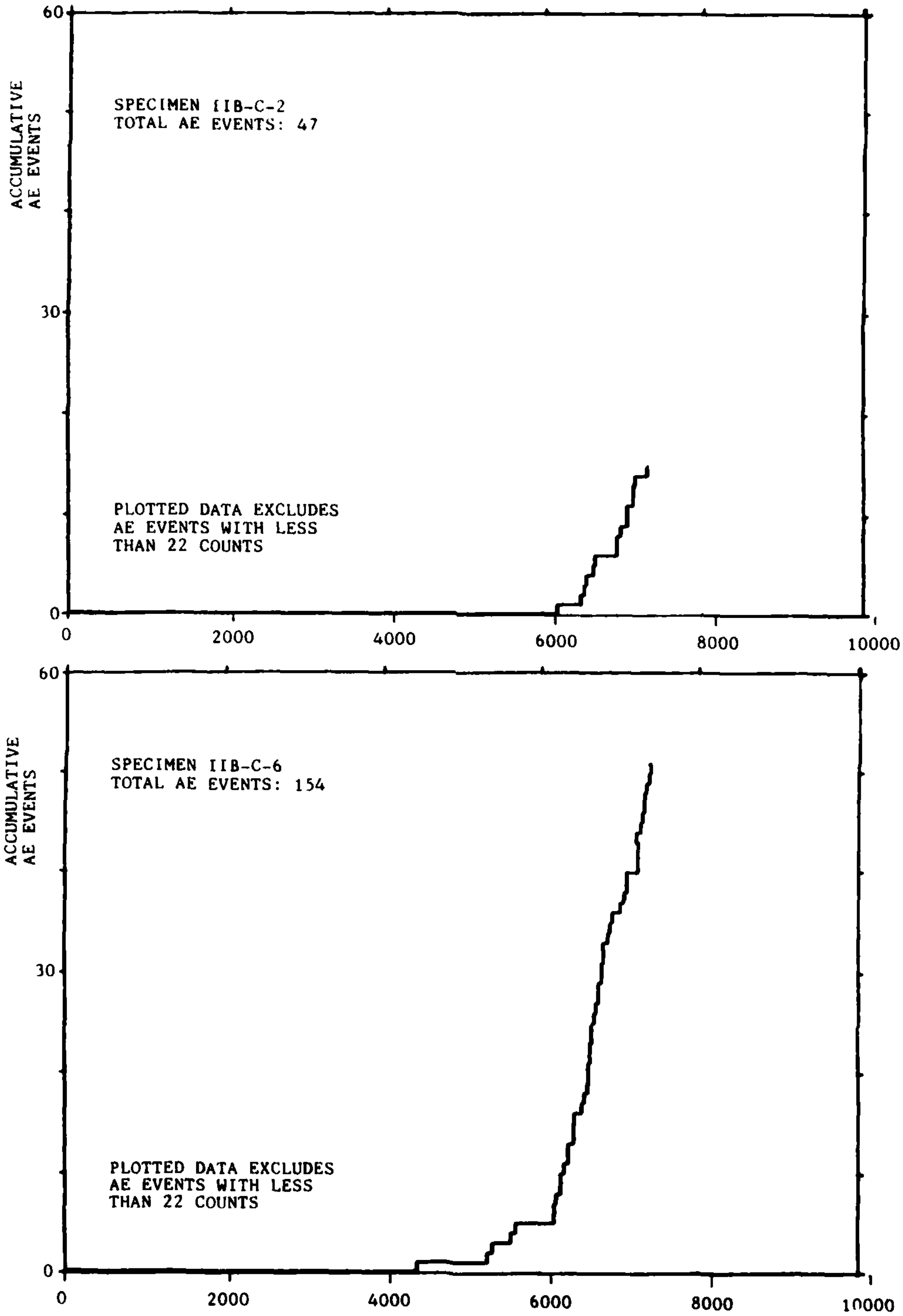


Figure H-64. Plots of Accumulative AE Events vs Applied Load for Type IIB-C Specimens with Minimum and Maximum Response for Load Level B.

☆U.S.Government Printing Office: 1982 — 559-005/4064