

NO-A181 241

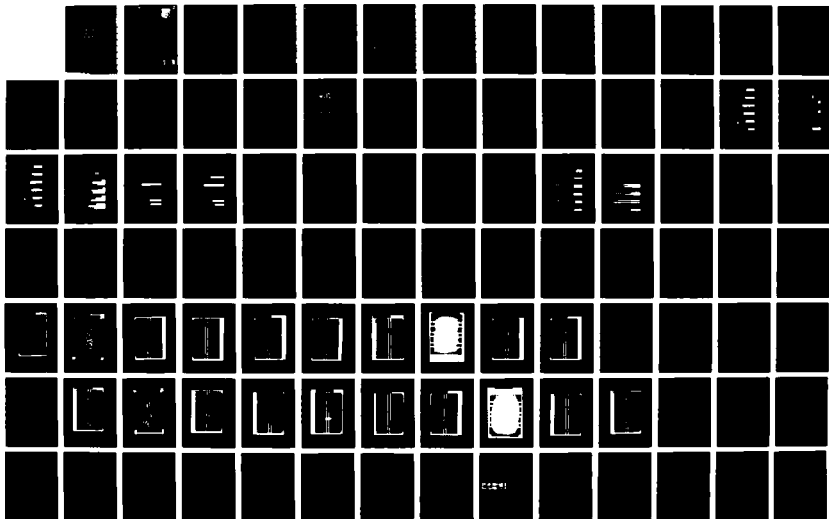
EVALUATION OF 350F CURING ADHESIVE SYSTEMS ON
PHOSPHORIC ACID ANODIZED AL. (U) DAYTON UNIV OH
RESEARCH INST D R ASKINS ET AL AUG 86 UDR-TR-85-120
AFMRL-TR-86-4039 F33615-84-C-5130

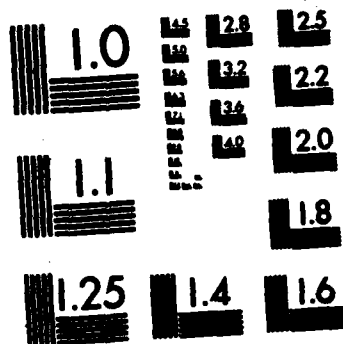
1/2

UNCLASSIFIED

F/G 11/1

NL





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

DTIC FILE COPY

2



AD-A181 241

AFWAL-TR- 86-4039

EVALUATION OF 350°F CURING
ADHESIVE SYSTEMS ON PHOSPHORIC
ACID ANODIZED ALUMINUM SUBSTRATES

D. Robert Askins
Donald R. Byrge

University of Dayton
Research Institute
300 College Park Avenue
Dayton, OH 45469

AUGUST 1986

Interim Technical Report - September 1982-June 1984

Approved for public release; distribution unlimited

MATERIALS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-6533

DTIC
ELECTE
JUN 15 1987
S D
E

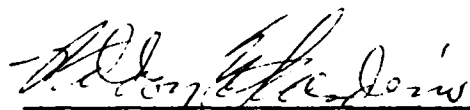
87 6 12 101

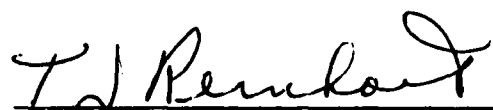
NOTICE

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.

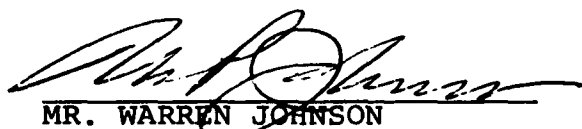
This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

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


WELDON SCARDINO, AFWAL/MLJ
Materials Engineer


T.J. REINHART, AFWAL/MLSE
Chief, Materials Engineering
Branch

FOR THE COMMANDER:


MR. WARREN JOHNSON
Chief
Systems Support Division

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/MLSE, 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.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AD A181 241

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S) UDR-TR-85-120			5. MONITORING ORGANIZATION REPORT NUMBER(S) AFWAL-TR-86-4039		
6a. NAME OF PERFORMING ORGANIZATION University of Dayton Research Institute		6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION AFWAL/MLSE		
6c. ADDRESS (City, State and ZIP Code) 300 College Park Avenue Dayton, OH 45469			7b. ADDRESS (City, State and ZIP Code) Wright-Patterson Air Force Base, OH 45433-6533		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Materials Laboratory (AFWAL/MLSE)		8b. OFFICE SYMBOL (If applicable) (AFWAL/MLSE)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F33615-82-C-5039 and F33615-84-C-5130		
8c. ADDRESS (City, State and ZIP Code) Air Force Systems Command Wright-Patterson AFB, Ohio 45433-6533			10. SOURCE OF FUNDING NOS.		
			PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.
			62102F	2418	04
11. TITLE (Include Security Classification) (over)			WORK UNIT NO. 37		
12. PERSONAL AUTHOR(S) D. Robert Askins and Donald R. Byrge					
13a. TYPE OF REPORT Technical Interim		13b. TIME COVERED FROM 9/82 TO 6/84		14. DATE OF REPORT (Yr., Mo., Day) August 1986	
15. PAGE COUNT 124					
16. SUPPLEMENTARY NOTATION					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB. GR.			
11	01	04	Phosphoric Acid, Anodize, Peel, Optimized, PPL Etch, Stress, Durability, Lap, Shear, Adhesive, (over)		
19. ABSTRACT (Continue on reverse if necessary and identify by block number)					
Ten different 350°F (177°C) curing adhesive/primer systems were used to bond phosphoric acid anodized aluminum test specimens. The objective of the program was to compare the compatibility of these adhesive/primer systems with phosphoric acid anodized and sulfuric/dichromate acid etched aluminum surfaces. All the specimens were prepared by Douglas Aircraft Company during the PABST program and tested at the University of Dayton. Lap shear, peel, and stress-durability tests were carried out. The test results indicated several general types of behavior. Firstly, the predominate failure mode for most of the adhesive/primer systems in all three types of tests was an interfacial failure between the primer and adhesive. Secondly, little to no difference is observed between the results for the anodized and acid/dichromate etched surface treatments, although a few of the specific adhesive/primer/alloy/test type combinations exhibited better or worse properties for one surface type than the other. <i>(Keywords:)</i>					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL Weldon Scardino			22b. TELEPHONE NUMBER (Include Area Code) (513) 255- 6981		22c. OFFICE SYMBOL AFWAL/ MLJ

11. TITLE

EVALUATION OF 350°F CURING ADHESIVE SYSTEMS ON PHOSPHORIC ACID
ANODIZED ALUMINUM SUBSTRATES

18. SUBJECT TERMS (Cont.)

Primer	Aluminum
Bonding	Compatibility

PREFACE

This report covers work performed during the period from June 1982 to June 1984 under Air Force Contract F33615-84-C-5130. The work was performed and evaluated by the University of Dayton Research Institute and administered under the direction of the Systems Support Division of the Air Force Wright Aeronautical Laboratories/Materials Laboratory, Wright-Patterson Air Force Base, Ohio. Mr. Weldon Scardino was the program Project Engineer.

This report was submitted by the authors for publication in August 1986.

Accession For	
NTIS GRA&I	☒
DTIC TAB	☒
Unannounced	☐
Justification	
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A1	



TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
1	BACKGROUND AND INTRODUCTION	1
2	MATERIALS AND TEST PROCEDURES	2
	2.1 Lap Shear Tests	3
	2.2 Peel Tests	7
	2.3 Stress-Durability Tests	7
3	DISCUSSION OF RESULTS	11
	3.1 Lap Shear Results	11
	3.2 Peel Results	22
	3.3 Stress-Durability Results	29
	3.4 Summary of Results	38
APPENDIX A		41
APPENDIX B		81
APPENDIX C		99

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Lap Shear Panel and Test Specimen.	4
2	Stress-Durability Panel and Test Specimen (RAAB Style).	5
3	Explanation of Failure Mode Notation.	6
4	Floating Roller ("Bell") Peel Specimen and Fixture (from ASTM D3167).	8
5	Stress-Durability Fixture (from ASTM D2919).	9
6	Lap Shear Strength of Adhesives.	16
7	Lap Shear Strength of Adhesives.	17
8	Lap Shear Strength of Adhesives.	18
9	Lap Shear Strength of Adhesives.	19
10	Lap Shear Strength of Adhesives.	20
11	Lap Shear Strength of Adhesives.	21
12	Peel Strength of Adhesives.	27
13	Peel Strength of Adhesives.	28

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Adhesive/Primer Systems	2
2	Lap Shear Test Results-2024-T81 Bare Aluminum Adherends-Phosphoric Acid Anodized Surface Preparation	12
3	Lap Shear Test Results-7075-T76 Bare Aluminum Adherends-Phosphoric Acid Anodized Surface Preparation	13
4	Lap Shear Test Results-2024-T81 Bare Aluminum Adherends-OFPL Etched Surface Preparation	14
5	Lap Shear Test Results-7075-T76 Bare Aluminum Adherends-OFPL Etched Surface Preparation	15
6	Peel Strength Results on 2024-T81 Bare Aluminum with PAA Etched Surface Preparation	23
7	Peel Strength Results on 7075-T76 Bare Aluminum with PAA Etched Surface Preparation	24
8	Peel Strength Results on 2024-T81 Bare Aluminum with OFPL Etched Surface Preparation	25
9	Peel Strength Results on 7075-T76 Bare Aluminum with OFPL Etched Surface Preparation	26
10	Hot-Humid Stress-Durability Test Results - 2024-T81 Bare Aluminum - PAA Surface Preparation	30
11	Hot-Humid Stress-Durability Test Results - 7075-T76 Bare Aluminum - PAA Surface Preparation	31
12	Hot-Humid Stress-Durability Test Results - 2024-T81 Bare Aluminum - OFPL Surface Preparation	32
13	Hot-Humid Stress-Durability Test Results - 7075-T76 Bare Aluminum - OFPL Surface Preparation	33
14	Salt-Spray Stress-Durability Test Results - 2024-T81 Bare Aluminum - PAA Surface Preparation	34

LIST OF TABLES (conc'd.)

<u>Table</u>		<u>Page</u>
15	Salt-Spray Stress-Durability Test Results - 7075-T76 Bare Aluminum - PAA Surface Preparation	35
16	Salt-Spray Stress-Durability Test Results - 2024-T81 Bare Aluminum - OFPL Surface Preparation	36
17	Salt-Spray Stress-Durability Test Results - 7075-T76 Bare Aluminum - OFPL Surface Preparation	37

SECTION 1

BACKGROUND AND INTRODUCTION

During the late seventies, a major research program entitled "Primary Adhesive Bonded Structure Technology" (PABST) was carried out by the Douglas Aircraft Company under USAF funding. The thrust of this program was to advance the state-of-the-art of adhesive bonding technology to a point where it could be confidently used in bonding primary aircraft structure without the use of mechanical fastening. A substantial portion of this work was concerned with establishing the compatibility of the phosphoric acid anodizing (PAA) surface preparation and 122°C (250°F) curing adhesives.

Test specimens for evaluating the compatibility of 177°C (350°F) curing adhesives with PAA were fabricated by Douglas Aircraft but not tested because contractual funds were exhausted. These specimens were turned over to the Air Force Materials Laboratory (AFML) who sent them to the University of Dayton Research Institute (UDRI) for testing.

Three types of mechanical tests were performed (lap shear, peel, and stress-rupture) at various temperatures and after various exposure conditions. No judgement of either the acceptability or unacceptability of any adhesive, primer, or surface preparation is made. General observations are made regarding the performance of the various adhesive/primer systems.

SECTION 2

MATERIALS AND TEST PROCEDURES

A total of nine different adhesives and ten different primers were used to prepare the specimens. Each adhesive was paired with one of the primers so that a total of ten adhesive/primer systems were in the program. Table 1 lists these adhesives and primers along with the respective suppliers.

TABLE 1
ADHESIVE/PRIMER SYSTEMS

Adhesive	Primer	Supplier
RB 398	RB 500	Reliable (Ciba Geigy)
MB 329	MB 6725-1	Narmco
FM 400	BR 400	American Cyanamid
EA 9649	EA 9205	Hysol
AF 130	EC 3917	3M
AF 31	EC 2174	3M
PL 729-3	PL 728	B.F. Goodrich
HT 424	HT 424F	American Cyanamid
FM 61	BR 227	American Cyanamid
FM 61	BR 227A	American Cyanamid

All of the specimens tested in this investigation consisted of bare aluminum alloy (2024-T81 and 7075-T76) adherends whose surfaces were prepared for bonding with either the PAA or the Optimized Forest Product Laboratory (OFPL) surface treatments. These two surface treatments were in accordance with Boeing Aircraft Company specifications BAC 5555 (for the PAA) and BAC 5514 (for the OFPL).

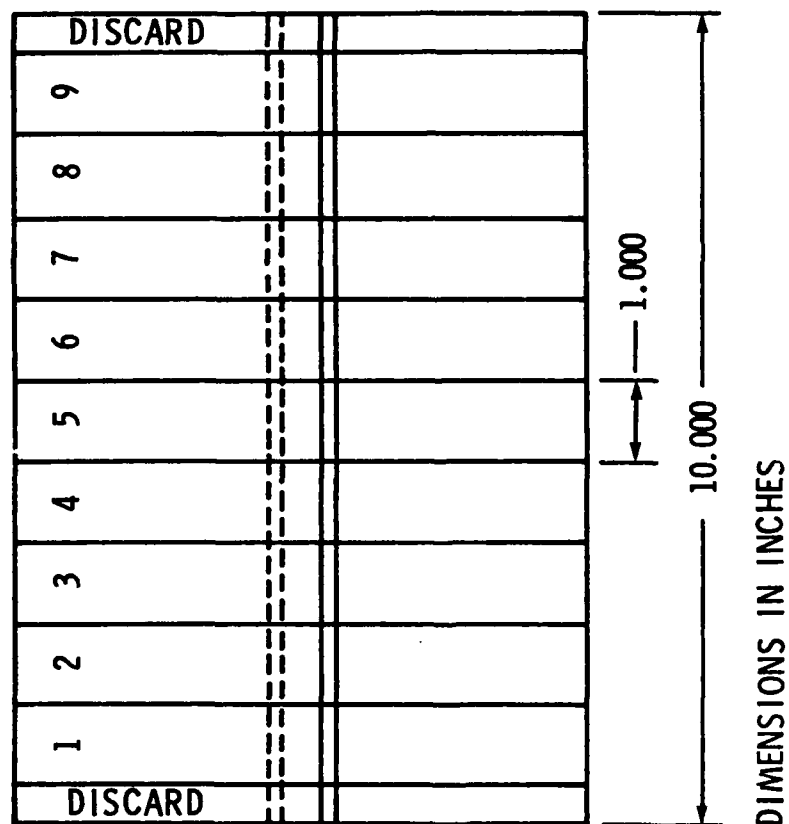
All of the panels from which specimens were cut were nondestructively inspected by an ultrasonic "C-scan" technique. Most of the panels exhibited high-quality void-free bond areas although a few exhibited bond area defects varying from minor to major. All of the c-scan printouts for the panels used in this program are presented in Appendices A through C.

2.1 LAP SHEAR TESTS

Lap shear specimens of the "blister detection" type were fabricated and tested to the requirements of ASTM D3165. This corresponds closely to Federal Specification MMM-A-132A. Figure 1 illustrates the type of panel which was received and from which lap shear specimens were machined. For some alloy/surface preparation/adhesive combinations the standard type lap shear panels were not available. Extra specimens of the type used for stress-durability testing were available however, and these specimens were used for generating lap shear data for those alloy/surface preparation/adhesive combinations for which the standard lap shear specimens illustrated in Figure 1 were not available. The stress-durability type specimen, also referred to as a RAAB type specimen, has four test joints and is illustrated in Figure 2. When these specimens were used for lap shear data, only one of the four joints was broken.

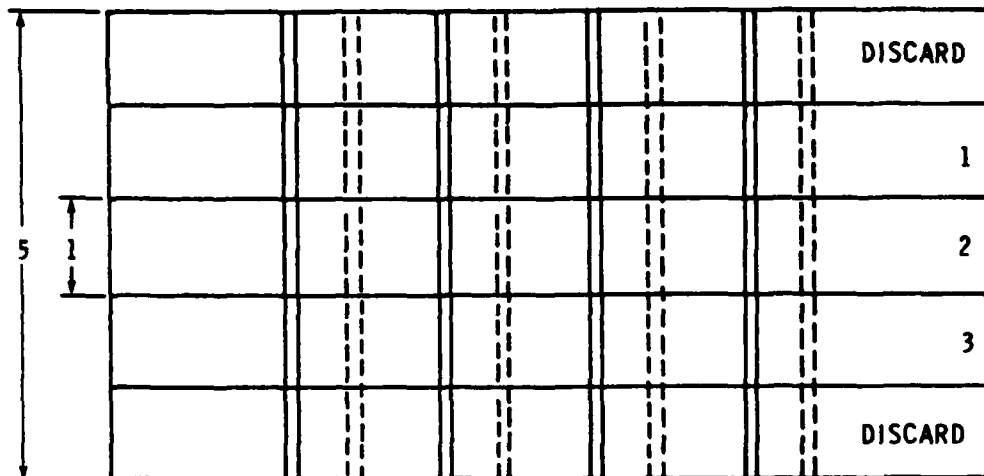
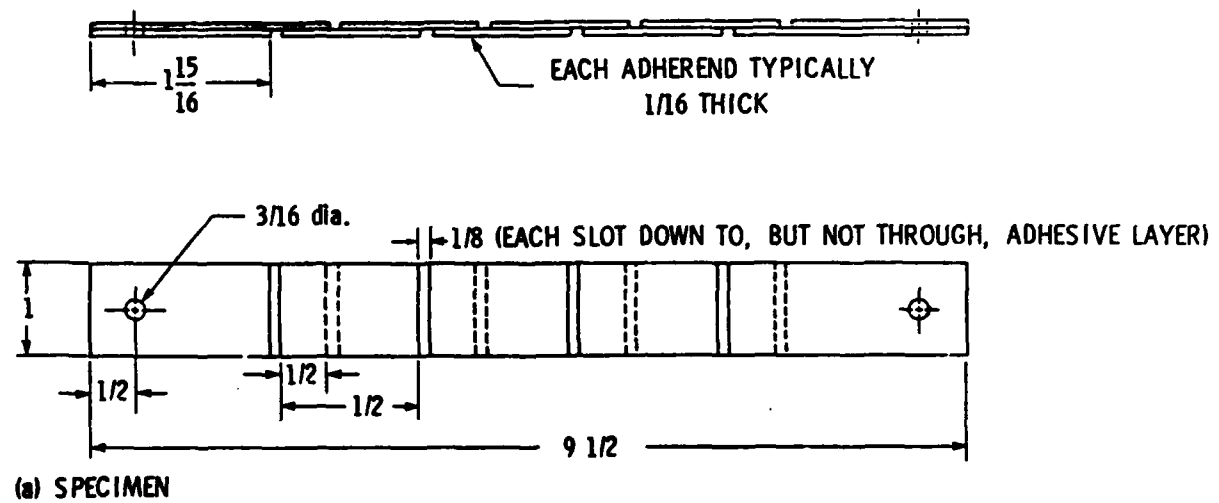
Traditionally, bonded joint failures have been reported as adhesive, cohesive, or some combination of the two. However, it was felt that this method of reporting failure modes was inadequate. Accordingly, a different format for reporting failure mode was utilized during this investigation. This format is illustrated and explained in Figure 3.

The interpretation of bonded joint failure modes is very subjective. It is difficult, with the naked eye, to ascertain the exact failure mode unless it is totally cohesive (within the adhesive layer). While interfacial failure modes may appear obvious, one cannot be sure, short of resorting to expensive surface instrumental analysis, that a very thin layer of primer or adhesive has not remained adhered to an otherwise clean appearing surface. Since the primer layer is so thin, the only evidence of its presence, to the eye, is generally color. In this investigation, the only discriminations made regarding failure mode were those detectable by eye. Thus, it is to be recognized that regardless of the different presentation format, the failure modes reported in this document are still subjective.



NOTE: SLOTS DOWN TO BUT NOT THROUGH ADHESIVE LAYER

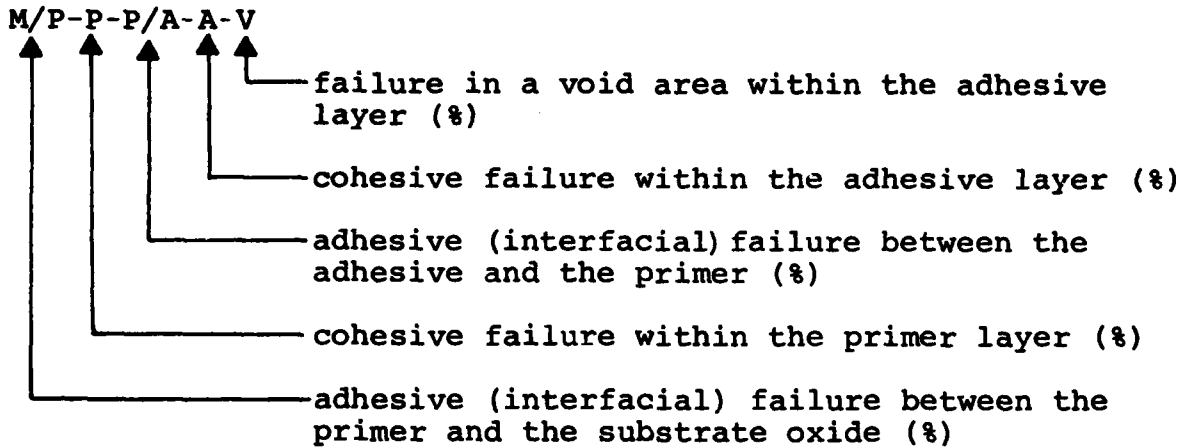
Figure 1. Lap Shear Panel and Test Specimen.



DIMENSIONS IN INCHES
(b) PANEL

Figure 2. Stress-Durability Panel and Test Specimen (RAAB Style).

For Bonds Made with a Primer on the Substrate Surface



Example: 5-0-30-65-0 indicates that, according to the observer's estimate, the failed joint exhibits the following failure mode.

The primer pulled cleanly off the metallic oxide on 5% of the bond area.

At no point along the bondline did the failure locus run cohesively within the primer layer.

The adhesive debonded cleanly from the primer on 30% of the bond area.

The failure locus ran cohesively within the adhesive layer on 65% of the bond area.

No part of the failure locus ran through a void area.

Figure 3. Explanation of Failure Mode Notation.

Lap shear tests were conducted at -54°C (-65°F), 22°C (72°F), and 177°C (350°F) on dry unaged specimens. Each specimen was held at the test temperature for ten minutes prior to loading to insure thermal equilibrium. Generally, three replicate tests were conducted for each material and test condition.

2.2 PEEL TESTS

Metal-to-metal peel specimens were prepared in accordance with the requirements of ASTM method D3167 except that the specimens were one inch wide rather than one-half inch. Figure 4 illustrates the specimen and test fixture. All peel tests were carried out at -54°C (-65°F) after a ten minute soak at the test temperature to insure thermal equilibrium. Three replicate tests were carried out for each adhesive/alloy/surface preparation combination available for testing.

2.3 STRESS-DURABILITY TESTS

Stress-durability specimens (RAAB type) were machined from full-area bonded panels measuring 4-inches wide by 9 1/2-inches long. Three samples, corresponding to the design illustrated in Figure 2, were machined from each panel.

Stress-durability tests were conducted in accordance with ASTM method D2919 and consisted of mounting the specimen in the fixture illustrated in Figure 5, imposing a predetermined shear stress (50% of the room temperature lap shear strength for each adhesive specimen) upon the specimen, and placing the specimen-fixture assembly in an elevated temperature, high humidity or salt spray environment until the specimen failed or the exposure period reached a preselected limit (2400 hours in this case). In the event that the exposure period reached the 2400 hour limit without specimen failure, the fixture was removed from the environmental cabinet, the specimen unloaded and removed from the fixture, and tested for residual strength. Since the specimens used for these tests contained four test

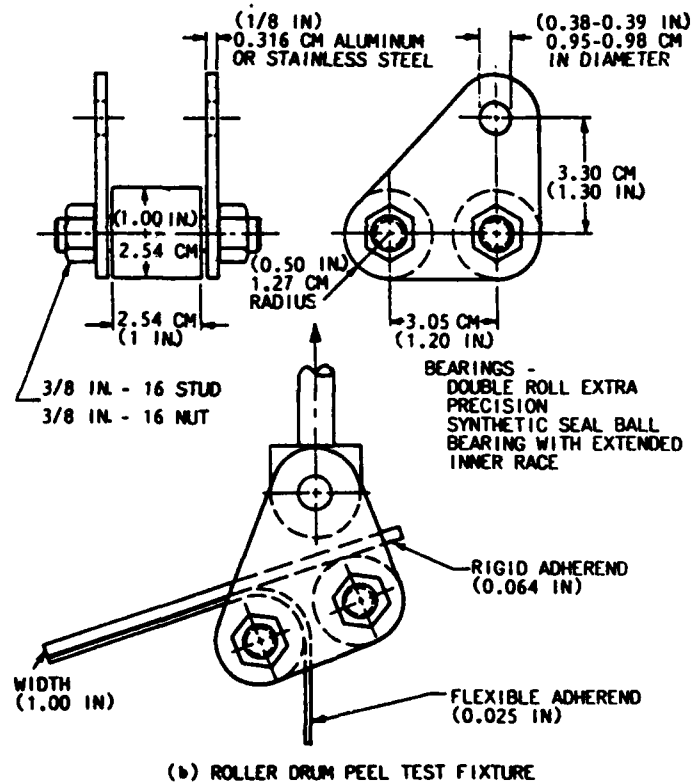
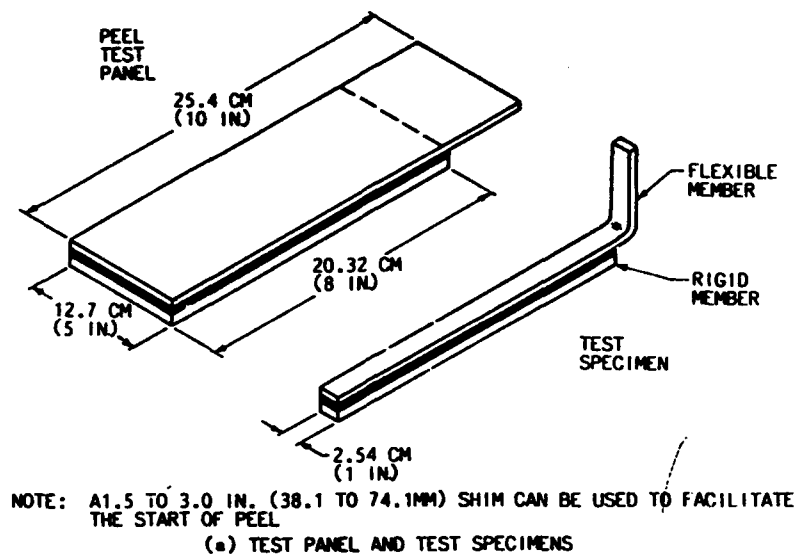


Figure 4. Floating Roller ("Bell") Peel Specimen and Fixture (from ASTM D 3167).

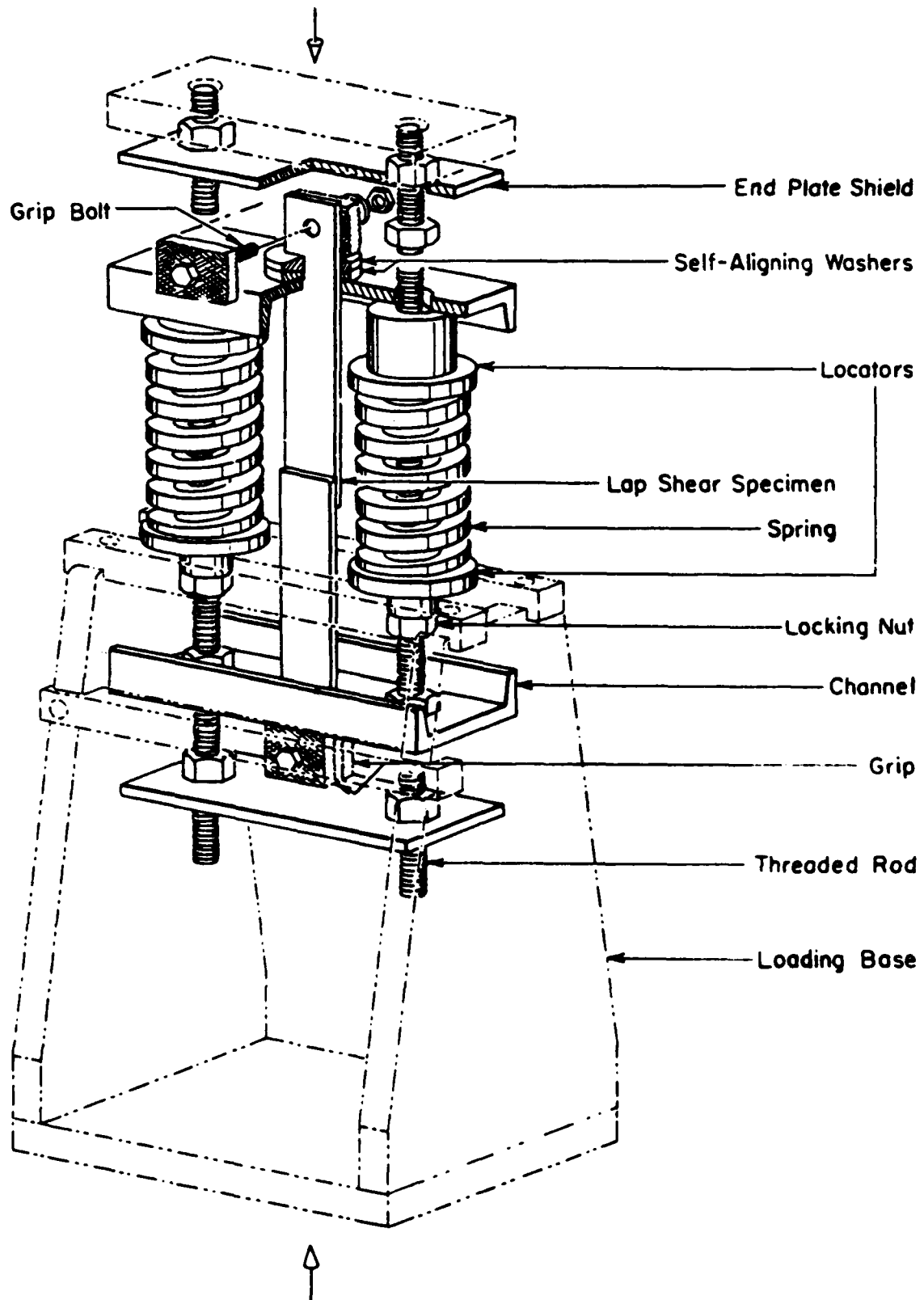


Figure 5. Stress-Durability Fixture. (from ASTM D2919).

joints (Figure 2), up to four time-to-failure data points could be obtained for each specimen. In the event that one of the four test joints failed during aging, the fixture was removed from the environmental cabinet, the specimen removed from the fixture, a hole drilled through the center of the failed lap joint, the failed joint bolted together, the specimen remounted and reloaded in the test fixture, and the assembly returned to the environmental cabinet. Each time a test joint failed, this procedure was repeated with the recorded time-to-failure for each joint being the cumulative time in the aging environment while under load. Residual strength testing was conducted at room temperature and involved breaking of only one of the surviving test joints. Thus, all residual strength values listed in the following tables represent only one value.

Stress-durability testing was carried out in two different environments;

- (a) a hot-humid environment of 140°F (60°C) and 95-100 percent relative humidity (RH), and
- (b) a salt-fog environment of 95°F (35°C) with a 5% salt spray solution.

SECTION 3

DISCUSSION OF RESULTS

All of the data generated during this test program are summarized and presented in this section in both tabular and graphical form. Observations derived from inspection of these data are also presented.

3.1 LAP SHEAR RESULTS

Tables 2-5 present the results of the lap shear tests and Figures 6-11 illustrate these data graphically.

Inspection of the data listed in these tables and presented in these figures leads to the following observations.

- Most of the failures in the lap shear tests occurred within the primer layer or along the primer/adhesive interface. As mentioned before, this was judged by visual inspection and was based on whether the primer could be visually observed (via color) on both or only one surface of the failed joint.
- Most of the failures judged to be within the adhesive layer (the traditional "cohesive" failure) occurred in the 177°C (350°F) tests.
- Three of the adhesive systems (HT-424/HT-424F, FM-61/BR227, and FM-61/BR227A) exhibited 177°C (350°F) strength levels significantly lower than the other seven adhesive systems tested.
- The HT-424/HT-424F system exhibited significantly lower room temperature strength levels than the other nine systems on the OFPL prepared surfaces. The failure mode for this adhesive however, was within the adhesive layer on both these low strength OFPL specimens and on the PAA specimens, which yielded reasonably high strength. The panels from which the HT-424/HT-424F specimens were obtained exhibited poor quality in the NDI c-scans for both the OFPL and PAA panels. Consequently, no plausible explanation is evident to explain the low OFPL results as opposed to the PAA results.

TABLE 2
LAP SHEAR TEST RESULTS
2024-T81 BARE ALUMINUM ADHERENDS
PHOSPHORIC ACID ANODIZED SURFACE PREPARATION

Adhesive System	Test Temp.		Ult. Strength ¹		Std. Dev.		Failure Mode (%)				
	(°F)	(°C)	(psi)	(MPa)	(psi)	(MPa)	M/P	P	P/A	A	V
RB 398/RB 500	72	22	2490	17.2	230	1.6	0	73	20	7	0
	350	177	1420	9.8	110	0.8	0	0	90	0	10
	-65	-54	2260	15.6	30	0.2	0	73	20	7	0
MB 329/ MB 6725-1	72	22	2310	15.9	150	1.0	0	97	0	3	0
	350	177	1940	13.4	100	0.7	0	17	0	83	0
	-65	-54	2010	13.9	110	0.8	0	97	0	0	3
FM400/BR400	72	22	2630	18.1	230	1.6	0	77	0	23	0
	350	177	2330	16.1	150	1.0	0	0	23	77	0
	-65	-54	2490	17.2	160	1.1	0	95	0	0	5
EA 9649/ EA 9205	72	22	2540	17.5	30	0.2	0	100	0	0	0
	350	177	2530	17.4	200	1.4	0	10	7	83	0
	-65	-54	2560	17.6	380	2.6	0	98	0	2	0
AF 130/ EC 3917	72	22	1550	10.7	210	1.5	0	100	0	0	0
	350	177	2000	13.8	180	1.2	0	50	3	44	3
	-65	-54	970	6.7	430	3.0	0	71	0	7	22
AF 31/ EC 2174	72	22	4000	27.6	30	0.2	0	95	0	5	0
	350	177	1670	11.5	30	0.2	0	97	0	3	0
	-65	-54	1370	9.4	120	0.8	0	93	0	7	0
PL 729-3/ PL 728	72	22	3570	24.6	180	1.2	0	53	0	47	0
	350	177	1510	10.4	300	2.1	0	0	0	100	0
	-65	-54	2250	15.5	270	1.9	0	97	0	3	0
HT 424/ HT 424F	72	22	2060	14.2	NOTE 2		0	0	25	75	0
	350	177	No Load	---	---	---	0	0	0	100	0
	-65	-54	530	3.7	NOTE 2		0	0	5	95	0
FM61/BR 227	72	22	2820	19.4	250	1.7	0	7	27	66	0
	350	177	530	3.7	70	0.5	0	73	0	27	0
	-65	-54	2250	15.5	210	1.5	0	30	47	23	0
FM61/BR227A	72	22	2750	18.9	70	0.5	0	100	0	0	0
	350	177	510	3.5	60	0.4	0	30	40	30	0
	-65	-54	1720	11.9	160	1.1	0	97	0	3	0

¹Average of three single lap shear specimens unless otherwise noted.

TABLE 3

LAP SHEAR TEST RESULTS
7075-T76 BARE ALUMINUM ADHERENDS
PHOSPHORIC ACID ANODIZED SURFACE PREPARATION

Adhesive System	Test Temp.		Ult. Strength ¹		Std. Dev.		Failure Mode (%)				
	(°F)	(°C)	(psi)	(MPa)	(psi)	(MPa)	M/P	P	P/A	A	V
RB 398/RB 500	72	22	2410	16.6	60	0.6	0	80	10	10	0
	350	177	1540	10.6	30	0.2	0	0	0	100	0
	-65	-54	2060	14.2	150	1.0	0	95	0	0	5
MB 329/ MB6725-1	72	22	2175	15.0	330	2.3	0	87	0	0	13
	350	177	1990	13.7	80	0.5	0	17	0	80	3
	-65	-54	1835	12.6	180	1.2	0	87	0	0	13
FM400/BR400	72	22	2460	17.0	240	1.7	0	67	0	33	0
	350	177	2190	15.1	40	0.3	0	0	17	83	0
	-65	-54	2210	15.2	220	1.5	0	93	0	0	7
EA 9649/ EA 9205	72	22	2620	18.1	385	2.7	0	97	0	3	0
	350	177	2515	17.3	15	0.1	0	13	20	67	0
	-65	-54	2360	16.3	45	0.3	0	100	0	0	0
AF/130/ EC 3917	72	22	1680	11.6	120	0.8	0	97	0	3	0
	350	177	2125	14.6	50	0.4	0	67	8	23	2
	-65	-54	1300	9.0	20	0.1	0	100	0	0	0
AF 31/ EC 2174	72	22	3725	25.7	260	1.8	0	93	0	7	0
	350	177	1690	11.6	50	0.4	0	98	0	2	0
	-65	-54	1320	9.1	30	0.2	0	100	0	0	0
PL 729-3/ PL 728	72	22	3435	23.7	135	0.9	0	0	0	100	0
	350	177	1870	12.9	150	1.0	0	0	0	100	0
	-65	-54	2300	15.8	290	2.0	0	97	0	3	0
HT 424/ HT 424F	72	22	1945	13.4	Note 2		0	0	40	60	0
	350	177	710	4.9	Note 2		0	0	10	90	0
	-65	-54	2990	20.6	Note 2		0	0	70	30	0
FM61/BR227	72	22	2765	19.1	120	0.8	0	10	23	67	0
	350	177	520	3.6	170	1.2	0	80	3	17	0
	-65	-54	2490	17.2	310	2.1	0	23	50	27	0
FM61/BR227A	72	22	2650	18.3	200	1.4	0	88	0	12	0
	350	177	665	4.6	40	0.3	0	57	33	10	0
	-65	-54	1600	11.0	130	0.9	0	93	0	7	0

¹Average of three single lap shear specimens unless otherwise noted.

TABLE 4

LAP SHEAR TEST RESULTS
2024-T81 BARE ALUMINUM ADHERENDS
OFPL ETCHED SURFACE PREPARATION

Adhesive System	Test Temp.		Ult. Strength ¹		Std. Dev.		Failure Mode (%)				
	(°F)	(°C)	(psi)	(MPa)	(psi)	(MPa)	M/P	P	P/A	A	V
RB 398/RB 500	72	22	2180	15.0	180	1.2	0	97	0	3	0
MB 329/ MB 6725-1	72	22	2200	15.2	210	1.5	0	10	87	3	0
FM400/BR400	72	22	2330	16.1	110	0.8	0	0	40	50	10
EA 9649/ EA 9205	72	22	2640 ²	18.2	300	2.1	0	95	0	0	0
AF 130/EC 3917	72	22	1690 ³	11.6	420	2.9	0	100	0	0	0
AF 31/EC 2174	72	22	3830	26.4	260	1.8	0	87	0	13	0
PL 729-3/PL 728	72	22	4040 ²	27.8	59	0.4	0	30	60	10	0
HT 424/HT 424F	72	22	1240	8.5	420	2.9	0	0	0	100	0
FM61/BR227	72	22	2690 ⁴	18.5	80	0.6	0	0	13	87	0
FM61/BR227A	72	22	2770 ⁴	19.1	30	0.2	0	73	0	27	0

¹Average of three RAAB type specimens unless otherwise noted.

²Average of two RAAB-type specimens.

³Two of the three specimens failed between the RAAB lap joints.

⁴Single lap shear specimens, average of three.

TABLE 5

LAP SHEAR TEST RESULTS
7075-T76 BARE ALUMINUM ADHERENDS
OFPL ETCHED SURFACE PREPARATION

Adhesive System	Test Temp.		Ult. Strength ¹		Std. Dev.		Failure Mode (%)				
	(°F)	(°C)	(psi)	(MPa)	(psi)	(MPa)	M/P	P	P/A	A	V
RB 398/RB 500	72	22	2240	15.4	280	1.9	0	70	0	30	0
MB 329/ MB 6725-1	72	22	1920 ²	13.2	210	1.5	0	10	70	15	5
FM400/BR400	72	22	2340	16.1	120	0.8	0	0	47	50	3
EA 9649/EA 9205	72	22	2510	17.3	250	1.7	0	97	0	3	0
AF 130/EC 3917	72	22	1680 ²	11.6	240	1.7	0	90	0	10	0
AF 31/EC 2174	72	22	3720	25.6	10	0.1	0	90	0	10	0
PL 729-3/PL 728	72	22	4080	28.1	80	0.1	0	30	60	10	0
HT 424/HT 424F	72	22	750	5.2	660	4.5	0	0	13	87	0
PM61/BR227	72	22	2750 ³	18.0	80	0.6	0	0	46	47	7
FM61/BR227A	72	22	2810	10.4	110	0.7	0	90	0	10	0

¹Average of three RAAB type specimens unless otherwise noted.

²One of the three specimens failed between the RAAB lap joints.

³Single lap shear specimens, average of three.

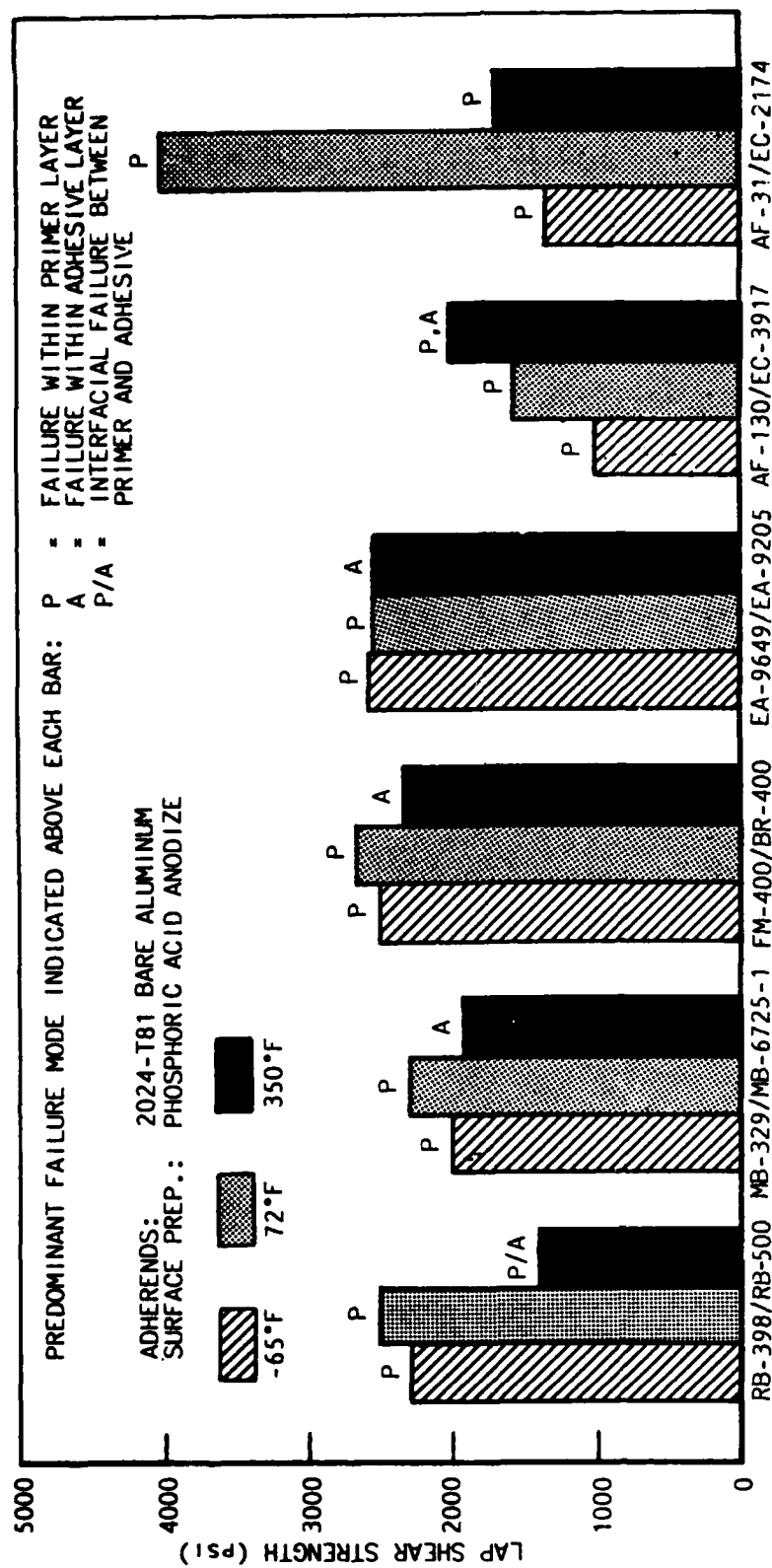


Figure 6. Lap Shear Strength of Adhesives.

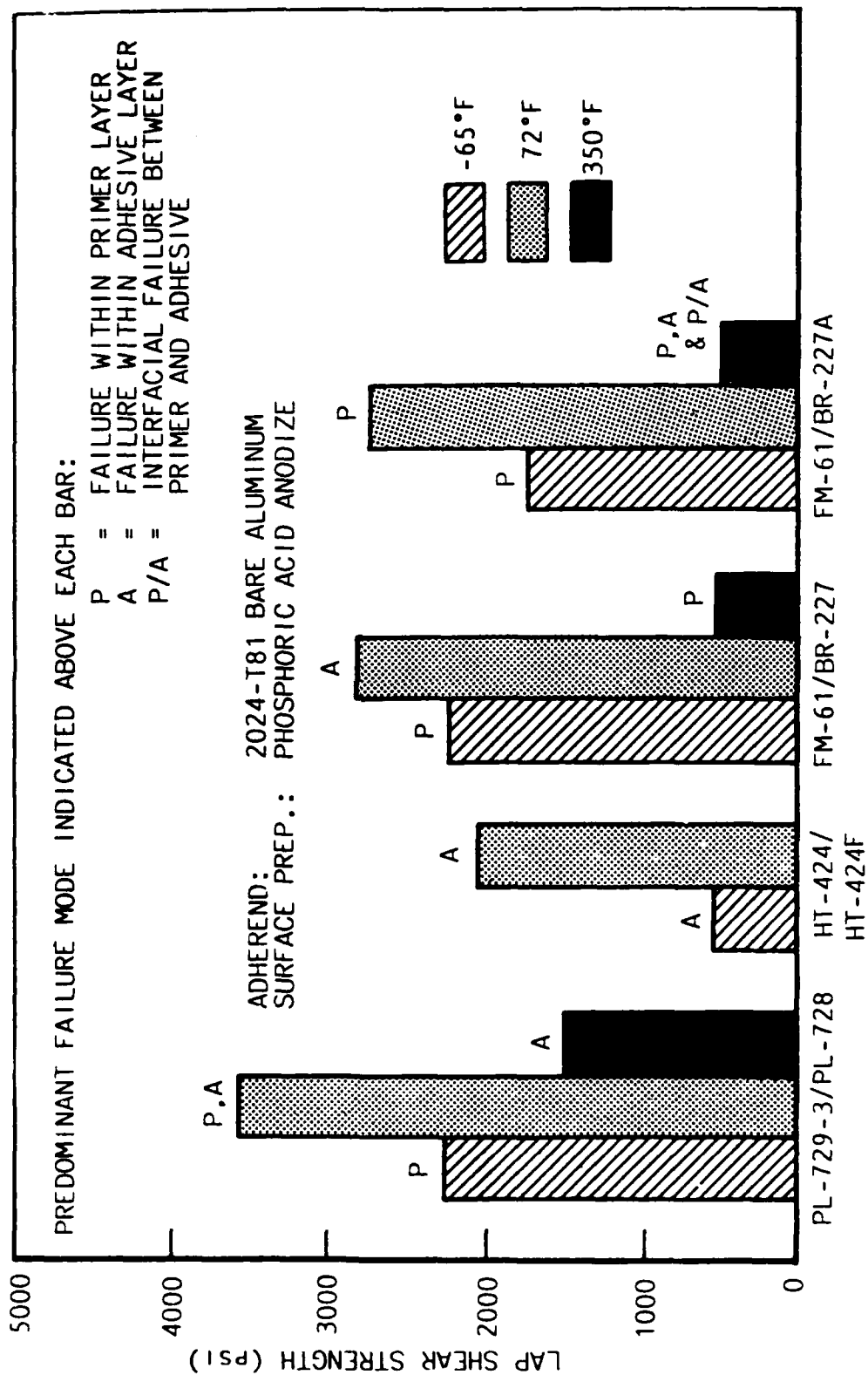


Figure 7. Lap Shear Strength of Adhesives.

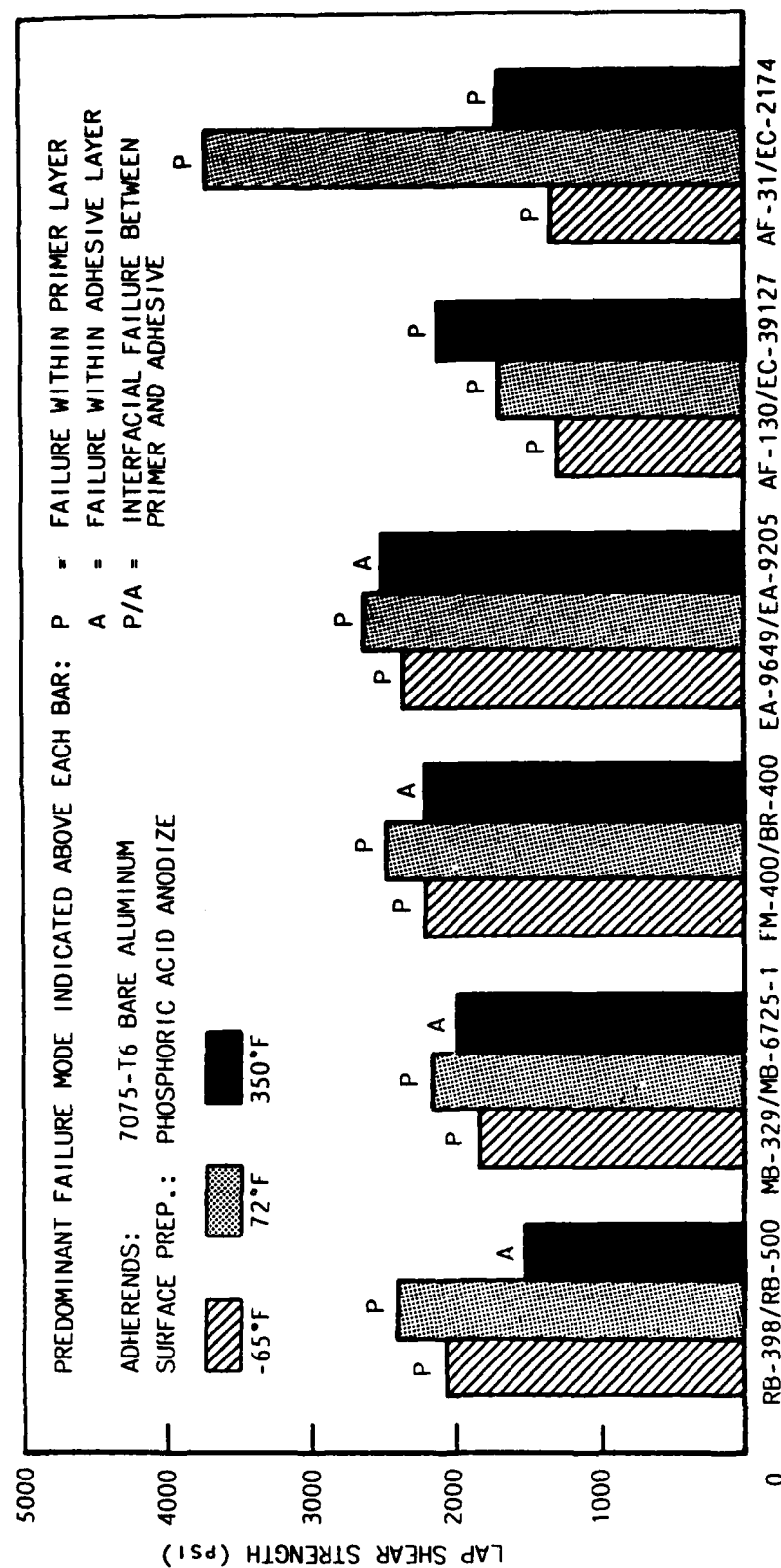


Figure 8. Lap Shear Strength of Adhesives.

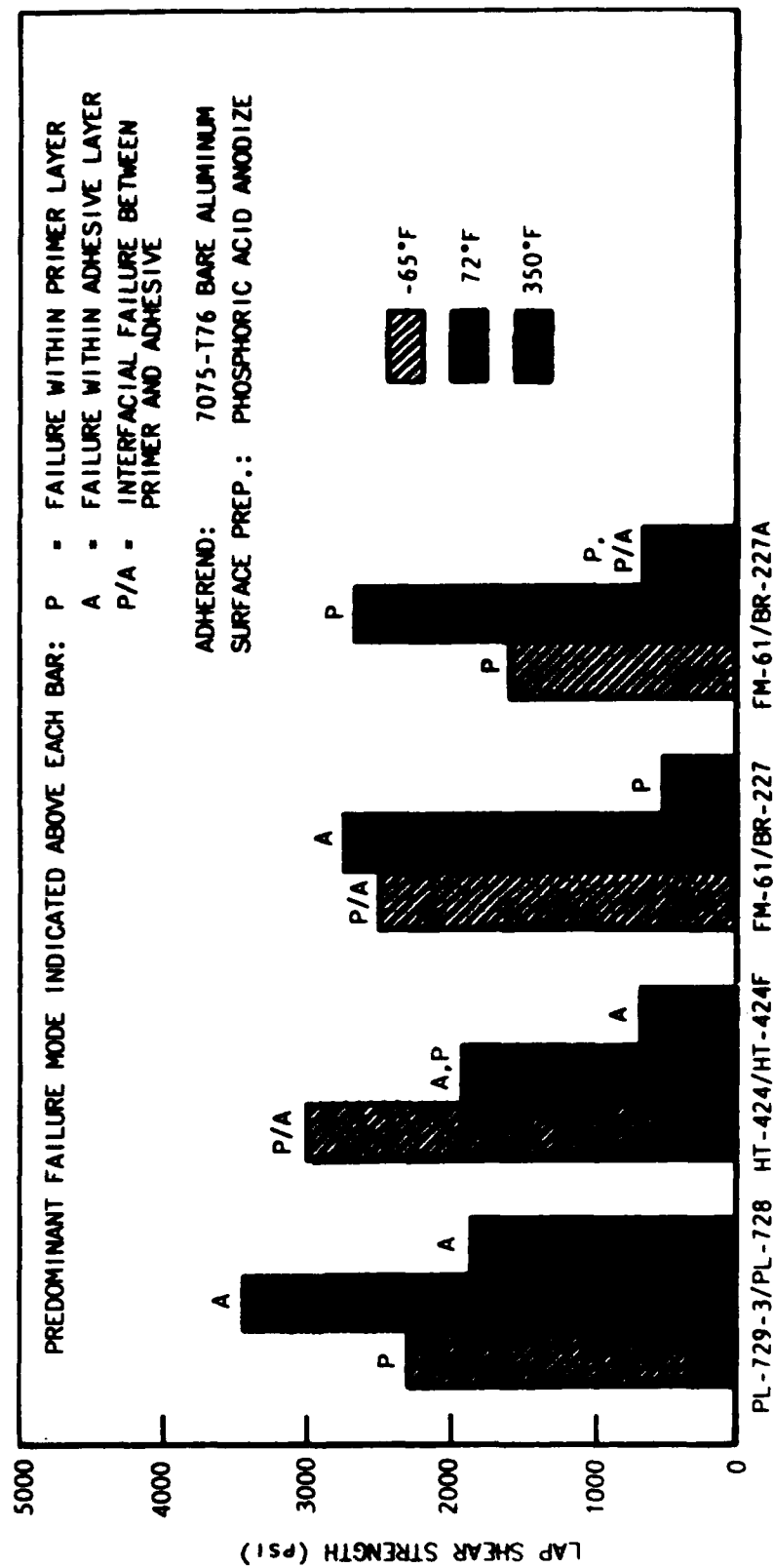


Figure 9. Lap Shear Strength of Adhesives.

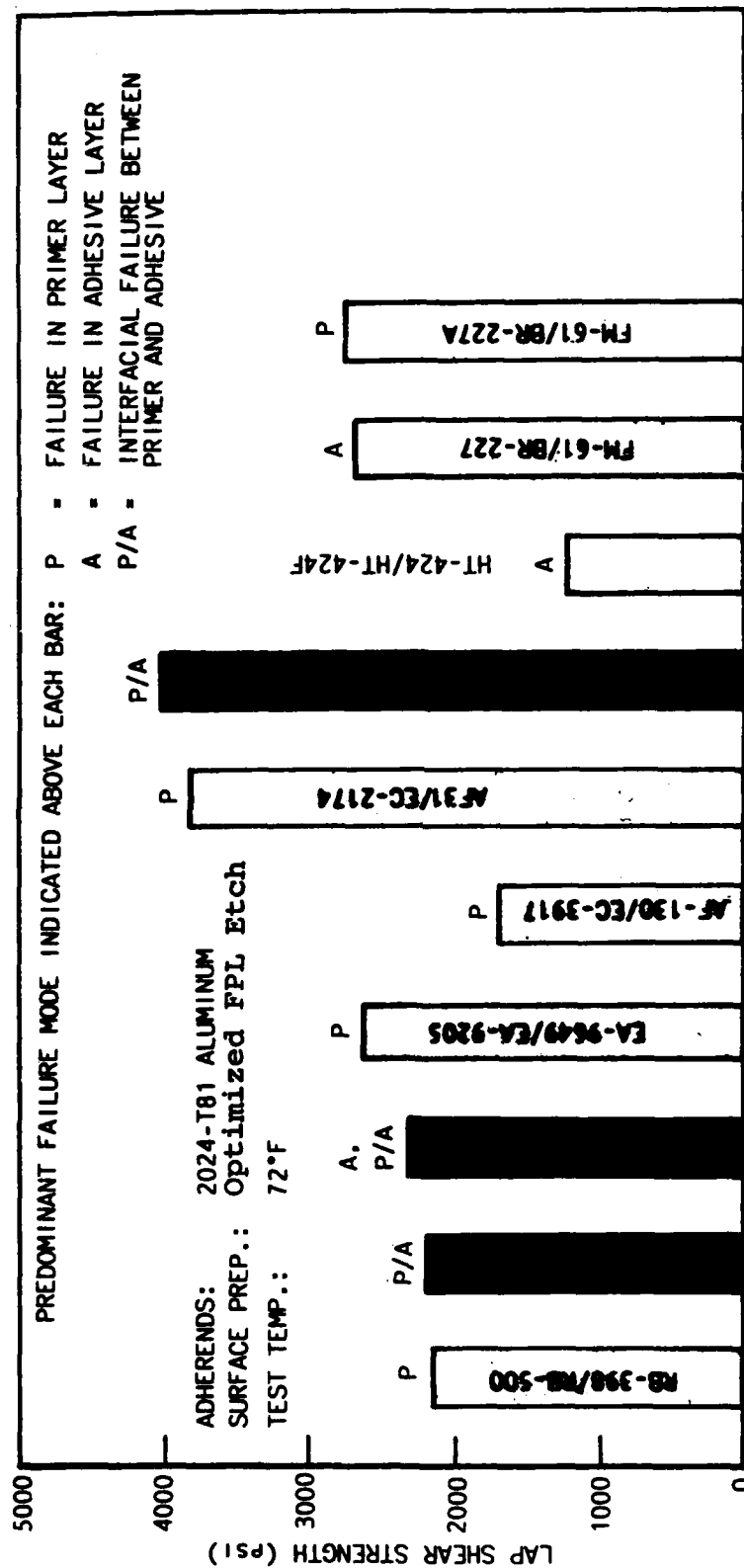


Figure 10. Lap Shear Strength of Adhesives.

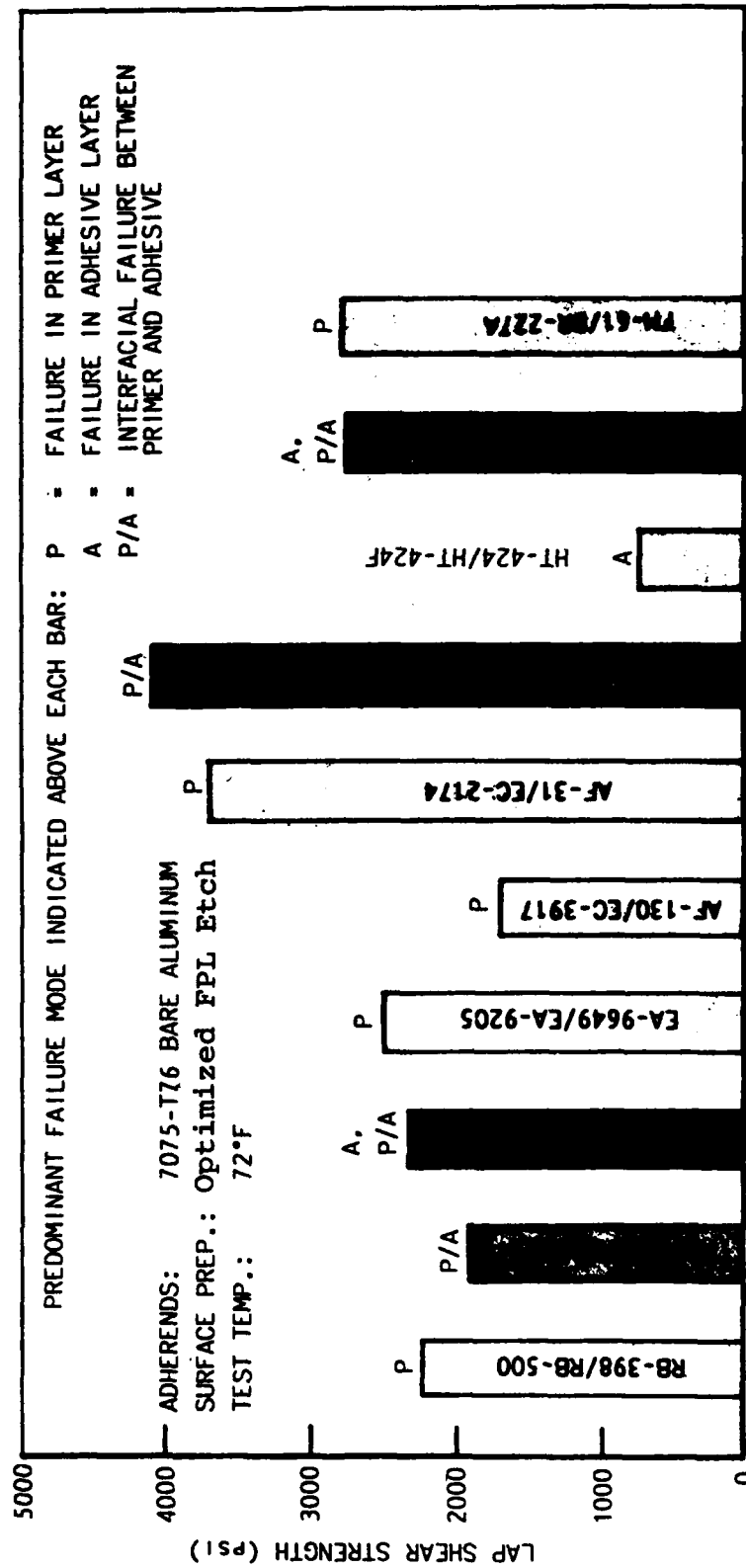


Figure 11. Lap Shear Strength of Adhesives.

- The only test condition for which lap shear behavior could be compared on the PAA and OFPL surface preparations was for the room temperature test condition with no environmental aging. For this condition, no significant overall differences in behavior were apparent between the two surface preparations. Six of the ten adhesive/primer systems (RB398/RB500, EA9649/EA9205, AF130/EC3917, AF31/EC2174, FM61/BR227, and FM61/BR227A) exhibited no difference in either strength or failure mode between the two surface preparations. Two of the ten adhesive/primer systems (MB329/MB6725-1 and FM400/BR400) exhibited no difference in strength, but a lesser degree of primer failure on the OFPL surface than on the PAA surface. One of the ten adhesive/primer systems (PL729-3/PL728) exhibited a higher strength on OFPL etched specimens than on PAA specimens, but with no difference in failure mode. One of the ten adhesive/primer systems (HT424/HT424F) exhibited a higher strength on PAA specimens than on OFPL etched specimens, but with no difference in failure mode.

3.2 PEEL RESULTS

Table 6-9 present the peel data and Figures 12 and 13 illustrate the data graphically. Inspection of these data and figures leads to the following observations:

- Nearly all of the failures were interfacial between the primer and adhesive. Only the HT-424/HT-424F and FM-61/BR227A systems exhibited much deviation from this failure mode and in these cases, the failures were within the adhesive layer (the traditionally designated cohesive failure).
- Most all of the peel strengths were in the 2.5 to 4.0 lb/in range. The only exceptions were in those cases where the failures occurred in the adhesive layer, the HT-424/HT-424F and FM-61/BR227A systems cited above. In these cases, the peel strengths reached 6-7 lb/in for the FM-61/BR227A and 13-15 lb/in for the HT-424/HT424F.
- Comparisons between the peel behavior of specimens prepared with PAA and OFPL etched surfaces can be made on only eight of the ten adhesive/primer systems in the program, and then only for the -65°F (-54°C) unaged test condition. On six of these systems (RB398/RB500, MB329/MB6725-1, FM400/BR400, EA9649/EA9205, AF31/EC2174, and

TABLE 6

PEEL STRENGTH RESULTS¹ ON 2024-T81
BARE ALUMINUM WITH PAA ETCHED SURFACE PREPARATION

Adhesive System	Test Temp. °F (°C)	Peel Strength		Standard Dev.		Failure Mode (%)				
		lbs/in of width	N/cm of width	lbs/in of width	N/cm of width	M/P	P	P/A	A	V
RB-398/RB-500	-65 (-54)	3.3	5.8	0.7	1.2	0	0	90	0	10
MB-329/MB-6725-1	-65 (-54)	2.7	4.7	0.4	0.7	0	0	95	0	5
FM-400/FM-400	-65 (-54)	2.6	4.5	0.2	0.3	0	0	95	0	5
EA-9649/EA-9205	-65 (-54)	3.6	6.2	0.1	0.1	0	0	100	0	0
AF-130/EC-3917	-65 (-54)	3.5	6.2	0.6	1.0	0	0	93	0	7
AF-31/EC-2174	-65 (-54)	2.7	4.7	0.1	0.2	0	0	100	0	0
PL-729-3/PL-728	-65 (-54)	2.8	4.9	0.1	0.2	0	0	100	0	0
HT-424/HT-424F ²	---	---	---	---	---	---	---	---	---	---
FM-61/BR-227	-65 (-54)	2.4	4.2	0.3	0.5	0	0	100	0	0
FM-61/BR-227A	-65 (-54)	3.3	5.8	0.3	0.6	0	0	53	47	0

¹Average of three peel specimens.

²Specimens not submitted for test.

TABLE 7

PEEL STRENGTH RESULTS¹ ON 7075-T76
BARE ALUMINUM WITH PAA ETCHED SURFACE PREPARATION

Adhesive System	Test Temp.	Peel Strength		Standard Dev.		Failure Mode (%)				
	°F (°C)	lbs/in of width	N/cm of width	lbs/in of width	N/cm of width	M/P	P	P/A	A	V
RB-398/RB-500	-65 (-54)	3.0	5.2	0.3	0.5	0	0	90	0	10
MB-329/MB-6725-1	-65 (-54)	2.7	4.8	0.4	0.7	0	0	95	0	5
FM-400/FM-400	-65 (-54)	3.7	6.4	0.5	0.9	0	0	92	0	8
EA-9649/EA-9205	-65 (-54)	3.5	6.2	0.2	0.3	0	0	100	0	0
AP-130/EC-3917	-65 (-54)	3.4	6.0	0.1	0.1	0	0	93	0	7
AF-31/EC-2174	-65 (-54)	2.2	3.8	0.2	0.3	0	0	100	0	0
PL-729-3/PL-728	-65 (-54)	4.2	7.4	0.4	0.6	0	0	100	0	0
HT-424/HT-424F ²	--- ---	---	---	---	---	---	---	---	---	---
FM-61/BR-227	-65 (-54)	4.1	7.2	0.3	0.5	0	0	100	0	0
FM-61/BR-227A	-65 (-54)	4.4	7.8	1.5	2.7	0	0	60	40	0

¹ Average of three peel specimens.

² Specimens not submitted for test.

TABLE 8

PEEL STRENGTH RESULTS¹ ON 2024-T81
BARE ALUMINUM WITH OPPL ETCHED SURFACE PREPARATION

Adhesive System	Test Temp.	Peel Strength		Standard Dev.		Failure Mode (%)				
	°F (°C)	lbs/in of width	N/cm of width	lbs/in of width	N/cm of width	M/P	P	P/A	A	V
RB-398/BR-500	-65 (-54)	3.5	6.1	0.5	1.0	0	0	100	0	0
MB-329/MB-6725-1	-65 (-54)	3.1	5.4	0.5	0.8	0	0	95	0	5
FM-400/FM-400	-65 (-54)	3.6	6.3	0.4	0.6	0	0	85	10	5
EA-9649/EA-9205	-65 (-54)	3.2	5.6	0.3	0.6	0	0	100	0	0
AF-130/EC-3917 ²	--- ---	---	---	---	---	---	---	---	---	---
AF-31/EC-2174	-65 (-54)	2.5	4.5	0.4	0.7	0	0	100	0	0
PL-729-3/PL-728	-65 (-54)	3.8	6.6	0.2	0.4	0	0	100	0	0
HT-424/HT-424F	-65 (-54)	15.2	26.6	3.5	6.1	0	0	30	70	0
FM-61/BR-227	-65 (-54)	6.3	11.0	1.3	2.3	0	0	63	37	0
FM-61/BR-227A	-65 (-54)	6.8	12.0	0.4	0.7	0	0	8	92	0

¹ Average of three peel specimens.

² Specimens not submitted for test.

TABLE 9

PEEL STRENGTH RESULTS¹ ON 7075-T76
BARE ALUMINUM WITH OFPL ETCHED SURFACE PREPARATION

Adhesive System	Test Temp. °F (°C)	Peel Strength		Standard Dev.		Failure Mode (%)				
		lbs/in of width	N/cm of width	lbs/in of width	N/cm of width	M/P	P	P/A	A	V
RB-398/RB-500	-65 (-54)	2.8	4.9	0.7	1.2	0	0	100	0	0
MB-329/MB-6725-1	-65 (-54)	3.8	6.7	1.4	2.5	0	0	90	0	10
FM-400/FM-400 ²	---	---	---	---	---	---	---	---	---	---
EA-9649/EA-9205	-65 (-54)	3.3	5.7	0.2	0.3	0	0	100	0	0
AF-130/EC-3917 ²	---	---	---	---	---	---	---	---	---	---
AF-31/EC-2174 ²	---	---	---	---	---	---	---	---	---	---
PL-729-3/PL-728 ²	---	---	---	---	---	---	---	---	---	---
HT-424/HT-424F	-65 (-54)	13.4	23.5	3.5	6.1	0	0	30	70	0
FM-61/BR-227	-65 (-54)	3.6	6.4	0.6	1.1	0	0	80	20	0
FM-61/BR-277A	-65 (-54)	7.2	12.6	0.4	0.7	0	0	33	67	0

¹ Average of three peel specimens.

² Specimens not submitted for test.

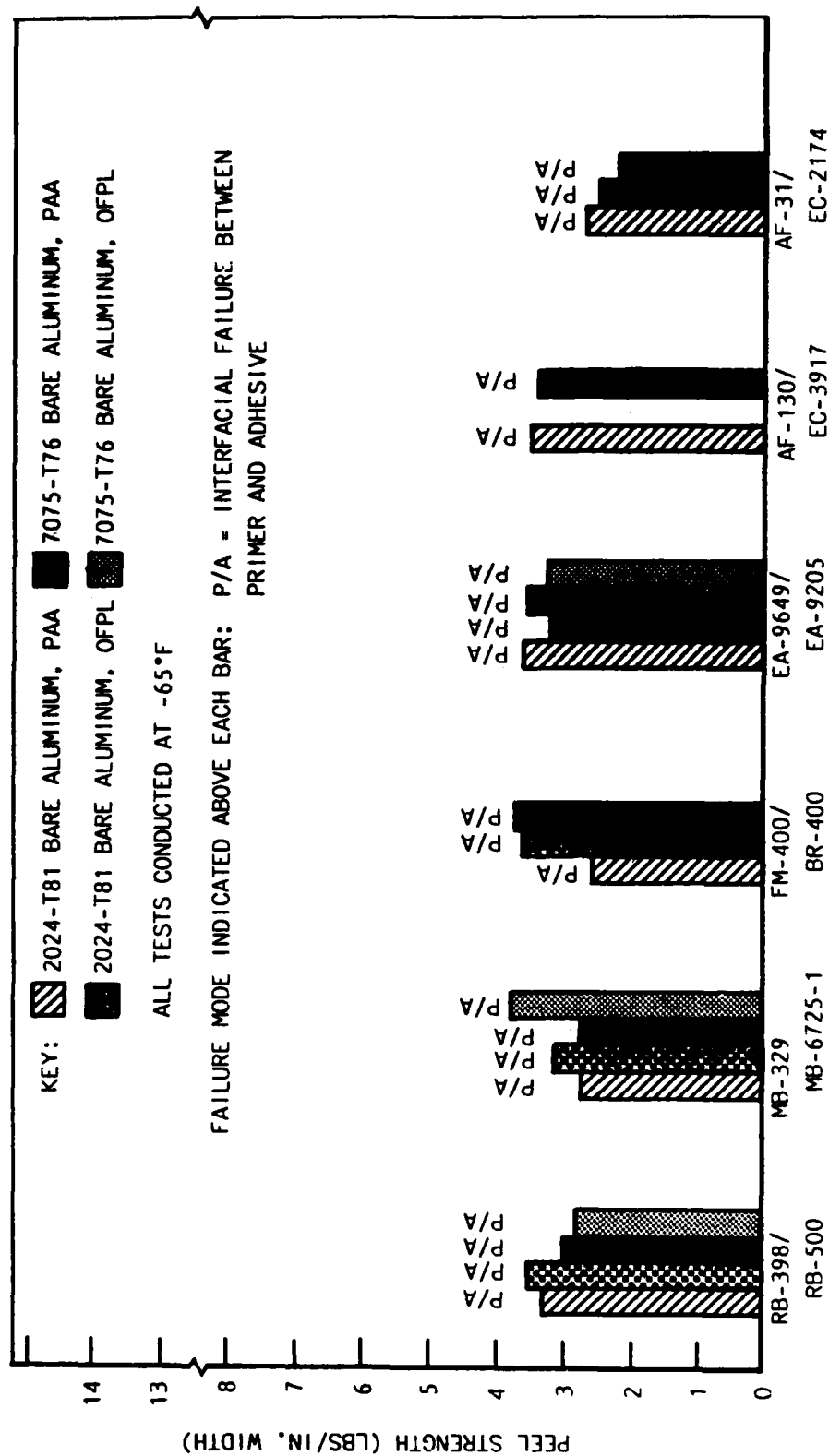


Figure 12 . Peel Strength of Adhesives.

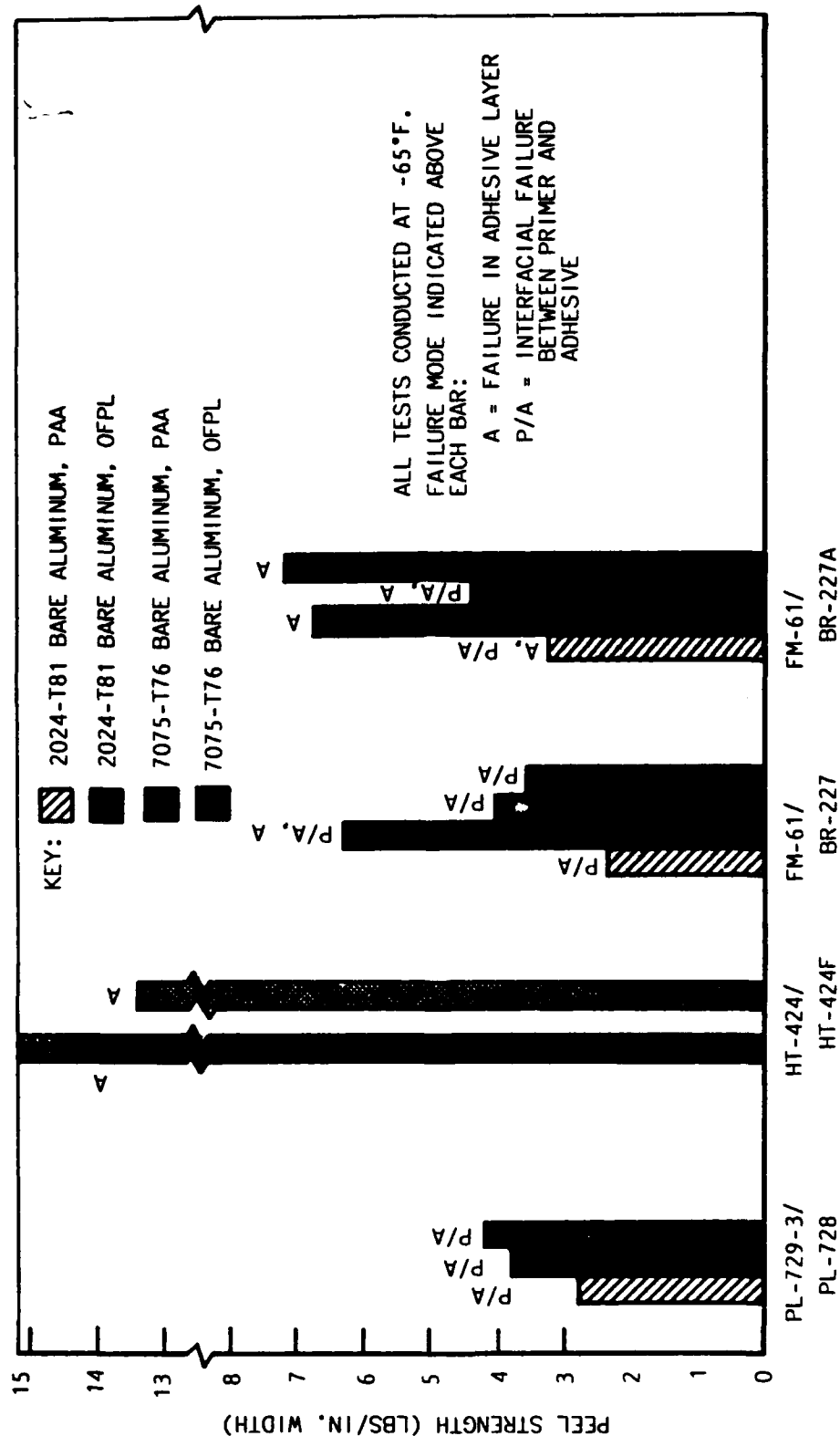


Figure 13. Peel Strength of Adhesives.

PL729-3/PL728) no difference in either strength or failure mode between the two surface preparations was evident. One of the systems (FM61/BR227) exhibited better strength with the OFPL etch surface preparation than with the PAA on the 2024 alloy, but with little difference in failure mode. Further, no difference between the two surface preparations was noted for the 7075 alloy with this adhesive/primer system. One of the systems (FM61/BR227A) exhibited both better strength and less primer related failure with the OFPL etch than with the PAA treatment on both alloys.

3.3 STRESS-DURABILITY RESULTS

Tables 10-13 present the results of the hot-humid stress-durability tests while Tables 14-17 present the results of the salt-spray stress-durability tests. Inspection of these data leads to the following observations:

- Nearly all systems survived the full 2400 hours without failure in both the hot-humid and salt-spray environments except for the FM-61/BR-227 and FM61/BR227A systems. In the hot-humid environment, neither of these systems survived for more than 1250 hours. In the salt-spray environment the FM-61/BR227 systems survived for the full 2400 hours while with the FM-61/BR227A system over half of the joints survived for the full 2400 hours.
- In most cases, the systems that did survive the full 2400 hours exhibited residual strengths that equaled or exceeded their original unaged room-temperature lap shear strength. In those cases where the residual strength was significantly less than the original room-temperature lap shear strength, the PL-729-3/PL728 and FM-61/BR-227A systems exhibited this strength degradation most frequently.
- The most common failure mode observed in the stress-durability tests was interfacial failure between the primer and adhesive layer or cohesive failure within the adhesive layer. Five systems (RB-398/RB-500, MB329/MB6725-1, AF-31/EC-2174, PL-729-3/PL-728, and FM-61/BR-227) exhibited a mixture of failure modes, including adhesive, primer-to-adhesive, and primer failures.

TABLE 10
HOT-HUMID STRESS-DURABILITY TEST RESULTS
2024-T81 BARE ALUMINUM
PAA SURFACE PREPARATION
EXPOSURE ENVIRONMENT: 140°F (60°C) and 95-100% R.H.

Adhesive/Primer System	Stress Level During Exposure ¹		Time to Failure (hrs)	Number of Bonded Joints Represented (4 joints per specimen)	Residual Lap Shear Strength ²		Failure Mode (%)					
	(psi)	(MPa)			(psi)	(MPa)	N/P	P	P/A	A	V	V
RB-398/RB-500	1240	8.6	2400 ²	8	2380	16.4	0	0	80	20	0	0
MB-329/MB-6725-1	1160	8.0	2400 ²	8	2820	19.4	0	0	60	40	0	0
FM-400/BR-400	1320	9.1	2400 ²	8	2680	18.5	0	0	0	95	5	5
EA-9649/EA-9205	1270	8.8	2400 ²	8	2900	20.0	0	60	0	40	0	0
AF-130/EC-3917	770	5.3	2400 ²	8	1670	11.5	0	100	0	0	0	0
AF-31/EC-2174	2000	13.8	2400 ²	8	3570	24.6	0	0	85	15	0	0
PL-729-3/PL-728	1790	12.3	2400 ²	8	3380	23.3	0	0	85	15	0	0
HT-424/HT-424F	1030	7.1	2400 ²	8	1980	13.6	0	0	15	85	0	0
FM-61/BR-227	1410	9.7	696 ³	1	-----	-----	0	0	0	100	0	0
			768 ³	1	-----	-----	0	0	0	100	0	0
			792 ³	1	-----	-----	0	0	0	100	0	0
			672 ³	1	-----	-----	0	0	0	100	0	0
			744 ³	1	-----	-----	0	0	0	100	0	0
			840 ³	1	-----	-----	0	0	0	100	0	0
			696 ³	1	-----	-----	0	0	0	100	0	0
			768 ³	1	-----	-----	0	0	0	100	0	0
			744 ³	1	-----	-----	0	0	0	100	0	0
			624 ³	1	-----	-----	0	0	0	100	0	0
			1224 ³	1	-----	-----	0	0	0	100	0	0
			1248 ³	1	-----	-----	0	0	0	100	0	0
FM-61/BR-227A	1370	9.4										

¹ Indicated stress level represents 50% of the average room temperature lap shear strength.

² Specimen did not fail within 2400-hour exposure period and was removed for residual strength testing.

³ All residual strengths were obtained at 72°F (22°C). Value represents one joint of (4 joint) specimen.

⁴ Time at which one joint of specimen failed. This joint was bolted and specimen was returned to environmental chamber. Residual strength tests were not conducted as all joints failed within the 2400-hour exposure period. Fourth joint of each specimen was not returned to aging chamber after third joint failed. First three numbers for this adhesive were from one specimen, second three from a second specimen.

TABLE 11

HOT-HUMID STRESS-DURABILITY TEST RESULTS

7075-T76 BARE ALUMINUM

PAA SURFACE PREPARATION

EXPOSURE ENVIRONMENT: 140°F (60°C) and 95-100% R.H.

Adhesive/Primer System	Stress Level During Exposure ¹ (psi) (MPa)	Time to Failure (hrs)	Number of Bonded Joints Represented (4 joints per specimen)	Residual Shear Strength ²		Failure Mode (%)				
				(psi)	(MPa)	M/P	P	P/A	A	V
RB-398/RB-500	1200 8.3	2400 ²	8	2650	18.2	0	0	0	70	30
NB-329/NB-6725-1	1090 7.5	2400 ²	8	2630	18.1	0	0	0	45	55
FM-400/RR-400	1230 8.5	2400 ²	8	2110	14.5	0	0	0	25	75
EA-9549/EA-9205	1310 9.0	2400 ²	8	2990	20.6	0	30	35	35	30
AF-130/EC-3917	840 5.8	2400 ²	8	1590	11.0	0	90	0	5	5
AF-31/EC-2174	1860 12.8	2400 ²	8	3570	24.6	0	0	0	80	20
PL-729-3/PL-728	1720 11.9	2400 ²	8	3240	22.3	0	0	0	90	10
IT-424/IT-424F	970 6.7	2400 ²	8	2140	14.7	0	0	0	15	85
FM-61/BR-227	1380 9.5	624 ³	1	-----	-----	0	0	0	100	0
		672 ³	1	-----	-----	0	0	0	100	0
		696 ³	1	-----	-----	0	0	0	100	0
		600 ³	1	-----	-----	0	0	0	100	0
		0 ³	1	-----	-----	0	0	0	15	85
		555 ³	1	-----	-----	0	0	0	15	85
		360 ³	1	-----	-----	0	0	0	100	0
FM-61/BR-227A	1330 9.2	360 ³	1	-----	-----	0	0	0	100	0
		216 ³	1	-----	-----	0	0	0	100	0
		888 ³	1	-----	-----	0	0	0	100	0
		696 ³	1	-----	-----	0	0	0	100	0
		864 ³	1	-----	-----	0	0	0	100	0

¹ Indicated stress level represents 50% of the average room temperature lap shear strength.² Specimen did not fail within 2400-hour exposure period and was removed for residual strength testing.³ All residual strengths were obtained at 72°F (22°C). Value represents one joint of (4 joint) specimen.⁴ Time at which one joint of specimen failed. This joint was bolted and specimen was returned to environmental chamber. Residual strength tests were not conducted as all joints failed within the 2400-hour exposure period. Fourth joint of each specimen was not returned to aging chamber after third joint failed. First three numbers for this adhesive were from one specimen, second three from a second specimen.

TABLE 12

HOT-HUMID STRESS-DURABILITY TEST RESULTS

2024-T81 BARE ALUMINUM

OFPL SURFACE PREPARATION

EXPOSURE ENVIRONMENT: 140°F (60°C) and 95-100% R.H.

Adhesive/Primer System	Stress Level During Exposure ¹		Time to Failure (hrs)	Number of Bonded Joints Represented (4 joints per specimen)	Residual Lap Shear Strength ²		Failure Mode (%)				
	(psi)	(MPa)			(psi)	(MPa)	M/P	P	P/A	A	V
RB-398/RB-500	1090	7.5	2400 ²	8	2510	17.3	0	40	10	50	0
MB-239/MB-6725-1	1100	7.6	2400 ²	8	2580	17.8	0	0	25	70	5
FM-400/BR-400	1170	8.1	2400 ²	8	2270	15.7	0	0	0	95	5
EA-9649/EA-9205	1320	9.1	2400 ²	8	2950	20.3	0	0	0	50	0
AF-130/EC-3917	850	5.9	2400 ²	8	2380	16.4	0	0	30	70	0
AF-31/EC-2174	1910	13.2	2400 ²	8	3230	22.2	0	0	100	0	0
PL-729-3/PL-728	2020	13.9	2400 ²	8	3400	23.4	0	0	0	10	0
HT-424/HT-424F	620	4.3	2400 ²	4	700	4.8	0	0	0	100	0
			48 ³	1	----	----	0	0	0	10	0
			48 ³	1	----	----	0	0	20	80	0
			48 ³	1	----	----	0	0	15	85	0
FM-61/BR-227	1350	9.3	696 ³	1	----	----	0	0	0	100	0
			720 ³	1	----	----	0	0	0	100	0
			792 ³	1	----	----	0	0	10	90	0
			912 ³	1	----	----	0	0	0	100	0
			888 ³	1	----	----	0	0	10	90	0
			912 ³	1	----	----	0	0	0	100	0
			696 ³	1	----	----	0	0	85	15	0
FM-61/BR-227A	1390	9.6	840 ³	1	----	----	0	0	0	100	0
			1104 ³	1	----	----	0	0	60	40	0
			696 ³	1	----	----	0	0	20	80	0
			960 ³	1	----	----	0	0	15	85	0
			960 ³	1	----	----	0	0	85	15	0

¹ Indicated stress level represents 50% of the average room temperature lap shear strength.² Specimen did not fail within 2400-hour exposure period and was removed for residual strength testing.³ All residual strengths were obtained at 72°F (22°C). Value represents one joint of (4 joint) specimen.⁴ Time at which one joint of specimen failed. This joint was bolted and specimen was returned to environmental chamber. Residual strength tests were not conducted as all joints failed within the 2400-hour exposure period. Fourth joint of each specimen was not returned to aging chamber after third joint failed. First three numbers for this adhesive were from one specimen, second three from a second specimen.

TABLE 13

HOT-HUMID STRESS-DURABILITY TEST RESULTS

7075-T76 BARE ALUMINUM

OPPL SURFACE PREPARATION

EXPOSURE ENVIRONMENT: 140°F (60°C) and 95-100% R.H.

Adhesive/Primer System	Stress Level During Exposure ¹		Time to Failure (hrs)	Number of Bonded Joints Represented (4 joints per specimen)	Residual Lap ³ Shear Strength		Failure Mode (%)				
	(psi)	(MPa)			(psi)	(MPa)	M/P	P	P/A	A	V
RB-398/RB-500	1120	7.7	2400 ²	8	2430	16.7	0	0	0	70	30
MB-329/MB-6725-1	960	6.6	2400 ²	8	2440	16.8	0	0	0	70	25
FM-400/BR-400	1170	8.1	2400 ²	8	2310	15.9	0	0	0	40	60
EA-9649/EA-9205	1260	8.7	2400 ²	8	2930	20.2	0	55	0	45	0
AF-130/EC-3917	840	5.8	2400 ²	8	2220	15.3	0	0	0	50	50
AF-31/EC-2174	1860	12.8	2400 ²	8	3320	22.9	0	0	0	100	0
PL-729-3/PL-728	2040	14.1	2400 ²	8	3320	22.2	0	0	0	90	10
HT-424/HT-424F	370	2.5	2400 ²	8	1770	12.2	0	0	0	50	50
FM-61/BR-227	1370	9.4	696 ⁴	1	-----	-----	0	0	0	20	80
			864 ⁴	1	-----	-----	0	0	0	0	100
			840 ⁴	1	-----	-----	0	0	0	0	100
			864 ⁴	1	-----	-----	0	0	0	25	75
			720 ⁴	1	-----	-----	0	0	0	30	70
			864 ⁴	1	-----	-----	0	0	0	5	95
			864 ⁴	1	-----	-----	0	0	0	100	0
			960 ⁴	1	-----	-----	0	0	0	100	0
			960 ⁴	1	-----	-----	0	0	0	100	0
			720 ⁴	1	-----	-----	0	0	0	100	0
			768 ⁴	1	-----	-----	0	0	0	85	15
			744 ⁴	1	-----	-----	0	0	0	85	15
FM-61/BR-227A											

¹ Indicated stress level represents 50% of the average room temperature lap shear strength.² Specimen did not fail within 2400-hour exposure period and was removed for residual strength testing.³ All residual strengths were obtained at 72°F (22°C). Value represents one joint of (4 joint) specimen.⁴ Time at which one joint of specimen failed. This joint was bolted and specimen was returned to environmental chamber. Residual strength tests were not conducted as all joints failed within the 2400-hour exposure period. Fourth joint of each specimen was not returned to aging chamber after third joint failed. First three numbers for this adhesive were from one specimen, second three from a second specimen.

TABLE 14

SALT-SPRAY STRESS-DURABILITY TEST RESULTS

2024-T81 BARE ALUMINUM

PAA SURFACE PREPARATION

EXPOSURE ENVIRONMENT: 95°F (35°C), 5% SALT SOLUTION

Adhesive/Primer System	Stress Level During Exposure ¹		Time to Failure (hrs)	Number of Bonded Joints Represented (4 joints per specimen)	Residual Lap Shear Strength ³		Failure Mode (%)				
	(psi)	(MPa)			(psi)	(MPa)	M/P	P	P/A	A	V
RB-398/RB-500	1240	8.5	2400 ²	4	2570	17.7	0	10	80	10	0
MB-329/MB-6725/1	1160	8.0	2400 ²	4	2470	17.0	0	0	65	35	0
FM-400/BR-400	1320	9.1	2400 ²	4	2810	19.4	0	0	80	20	0
EA-9649/EA-9205	1270	8.8	2400 ²	4	2600	17.9	0	0	95	0	5
AF-130/EC-3917	770	5.3	2400 ²	4	2930	20.2	0	0	50	0	50
AF-31/EC-2174	2000	13.8	2400 ²	4	4120	28.4	0	0	75	25	0
PL-729-3/PL-728	1790	12.3	2400 ²	4	1920	13.2	0	0	80	20	0
HT-424/HT-424-F	1030	7.1	2400 ²	4	1330	9.2	0	0	0	85	15
FM-61/BR-227	1410	9.7	2400 ²	4	2190	15.1	0	0	90	10	0
FM-61/BR-227A	1370	9.4	720 ⁴	1	----	----	0	0	90	10	0
			2400 ²	3	1420	9.8	0	0	100	0	0

¹Indicated stress level represents 50% of the average room temperature lap shear strength.²Specimen did not fail within 2400-hour exposure period and was removed for residual strength testing.³All residual strengths were obtained at 72°F (22°C). Value represents one joint of (4 joint) specimen.⁴Time at which one joint of specimen failed. This joint was bolted and specimen was returned to environmental chamber.

TABLE 15

SALT-SPRAY STRESS-DURABILITY TEST RESULTS

7075-T76 BARE ALUMINUM

PAA SURFACE PREPARATION

EXPOSURE ENVIRONMENT: 95°F (35°C), 5% SALT SOLUTION

Adhesive/Primer System	Stress Level During Exposure ¹		Time to Failure	Number of Bonded Joints Represented (4 joints per specimen)	Residual Lap Shear Strength ³		Failure Mode (%)					
	(psi)	(MPa)			(psi)	(MPa)	M/P	P	P/A	A	V	
RB-398/RB-500	1200	8.3	2400 ²	4	2560	17.6	0	0	90	10	0	0
MB-329/MB-6725-1	1090	7.5	2400 ²	4	2520	17.4	0	0	70	10	20	20
FM-400/BR-400	1230	8.5	2400 ²	4	2320	16.0	0	0	40	40	20	20
EA-9649/EA-9205	1310	9.0	2400 ²	4	2580	17.8	0	0	100	0	0	0
AF-130/EA-3917	840	5.8	2400 ²	4	1520	10.5	0	10	75	0	15	15
AF-31/EC-2174	1860	12.8	2400 ²	4	3720	25.6	0	0	75	25	0	0
PL-279-3/PL-728	1720	11.9	2400 ²	4	3210	22.1	0	0	85	15	0	0
HT-424/HT-424-F	970	6.7	2400 ²	4	2030	14.0	0	0	25	65	10	10
FM-61/BR-227	1380	9.5	2400 ²	4	2400	16.8	0	0	100	0	0	0
FM-61/BR-227A	1330	9.2	2400 ²	4	1610	11.1	0	0	100	0	0	0

¹ Indicated stress level represents 50% of the average room temperature lap shear strength.² Specimen did not fail within 2400-hour exposure period and was removed for residual strength testing.³ All residual strengths were obtained at 72°F (22°C). Value represents one joint of (4 joint) specimen.

TABLE 16

SALT-SPRAY STRESS-DURABILITY TEST RESULTS

2024-T81 BARE ALUMINUM

OFPL SURFACE PREPARATION

EXPOSURE ENVIRONMENT: 95°F (35°C), 5% SALT SOLUTION

Adhesive/Primer System	Stress Level During Exposure ¹		Time to Failure (hrs)	Number of Bonded Joints Represented (4 joints per specimen)	Residual Lap Shear Strength ³		Failure Mode (%)				
	(psi)	(MPa)			(psi)	(MPa)	M/P	P	P/A	A	V
RB-398/RB-500	1090	7.5	2400 ²	4	2540	17.5	0	0	50	50	0
MB-329/MB-6725-1	1100	7.6	2400 ²	4	2490	17.2	0	0	75	25	0
FM-400/BR-400	1170	8.1	2400 ²	4	2420	16.6	0	0	40	50	10
EA-9649/EA-9205	1320	9.1	2400 ²	4	2770	19.1	0	0	85	15	0
AF-130/EC-3917	850	5.9	2400 ²	4	960	6.6	0	0	0	100	0
AF-31/EC-2174	1910	13.2	2400 ²	4	3790	26.1	0	0	95	5	0
PL-729-3/PL728	2020	13.9	2400 ²	4	3140	21.6	0	0	80	20	0
HT-424/HT-424-F	620	4.3	----- ⁴	4	-----	-----	0	0	20	40	40
FM-61/BR-227	1350	9.3	2400 ²	4	2210	15.3	0	0	60	40	0
FM-61/BR-227A	1390	9.6	648 ⁵	1	-----	-----	0	0	90	10	0
			2400 ²	3	2230	15.4	0	0	40	60	0

¹Indicated stress level represents 50% of the average room temperature lap shear strength.²Specimen did not fail within 2400-hour exposure period and was removed for residual strength testing.³All residual strengths were obtained at 72°F (22°C). Value represents one joint of (4 joint) specimen.⁴Specimen failed in loading. Large void area in bonds.⁵Time at which one joint of specimen failed. This joint was bolted and specimen was returned to environmental chamber.

TABLE 17

SALT-SPRAY STRESS-DURABILITY TEST RESULTS

7075-T76 BARE ALUMINUM

OFPL SURFACE PREPARATION

EXPOSURE ENVIRONMENT: 95°F (25°C), 5% SALT SOLUTION

Adhesive/Primer System	Stress Level ¹ During Exposure ¹		Time to Failure (hrs)	Number of Bonded Joints Represented (4 joints per specimen)	Residual Lap ³ Shear Strength ³		Failure Mode (%)				
	(psi)	(MPa)			(psi)	(MPa)	M/P	P	P/A	A	V
RB-398/RB-500 MB-329/MB-6725-1	1120	7.7	2400 ²	4	2630	18.1	0	0	60	40	0
	960	6.6	1309 ⁴	1	-----	-----	0	0	50	50	0
FM-400/BR-400 EA-9649/EA-9205 AF-130/EC-3917 AF-31/EC-2174 PL-729-3/PL728			1989 ⁴	1	-----	-----	0	0	85	15	0
			2203 ⁵	1	-----	-----	0	0	85	15	0
	1170	8.1	2400 ²	4	2140	14.8	0	0	35	50	15
	1260	8.7	2400 ²	4	2530	17.4	0	0	85	10	5
	840	5.8	2400 ²	4	1460	10.1	0	0	95	0	5
	1860	12.8	2400 ²	4	1870	12.9	0	0	85	15	0
HT-424/HT424F FM-61/BR-227 FM-61/BR-227A	2040	14.1	456 ⁴	1	-----	-----	0	0	85	15	0
			912 ⁴	1	-----	-----	0	0	90	10	0
			2400 ²	2	3390	24.4	0	0	70	30	0
	370	2.5	2400 ²	4	1350	9.3	0	0	0	90	10
	1370	9.2	2400 ²	4	2450	16.9	0	0	100	0	0
	1410	9.7	648	4 ⁶	260	1.8	0	0	85	15	0

¹Indicated stress level represents 50% of the average room temperature lap shear strength.²Specimen did not fail within 2400-hour exposure period and was removed for residual strength testing.³All residual strengths were obtained at 72°F (22°C). Value represents one joint of (4 joint) specimen.⁴Joint failed during exposure period. Joint was bolted and specimen returned to salty-spray chamber.⁵Test terminated after this joint failed because of excessive adherend corrosion.⁶Three joints failed after 648 hours. Remaining joint tested for residual strength without further aging.

- In the hot-humid durability tests, no difference in durability, residual strength, or failure mode was observed for nine of the ten adhesive/primer systems. The one exception (AF-130/EC-3917) exhibited higher residual strength and less primer failure on OFPL surfaces than on PAA surfaces. For the hot-humid durability tests, cohesive failure within the adhesive layer and interfacial failure between the primer and adhesive were the two predominate failure modes.
- In the salt-spray durability tests, the difference (or similarity) between the behavior of the OFPL and PAA prepared surfaces is not clear cut. Three of the adhesive/primer systems (RB-398/RB-500, EA-9649/EA-9205, and FM-61/BR-227) exhibit no difference between the two surface preparations. One system (FM-400/BR-400) exhibits higher residual strength on both alloys with the PAA surface than with the OFPL surface. Six systems (MB-329/MB-6725-1, AF-130/EC3917, AF-31/EC-2174, PL-729-3/PL-728, HT-424/HT-424F, and FM-61/BR-227A) exhibited higher residual strength with one of the alloys (generally the 7075) for the PAA surface preparation than for the OFPL preparation. In these six cases the other alloy showed no differences between the two surface preparations. Only two adhesive/primer systems (PL729-3/PL-728 and FM-61/BR-227A) exhibited higher residual strengths for OFPL etched surfaces than for PAA surfaces and in both cases this was for the 2024 alloy. In nearly all cases, the predominate failure mode for the salt-spray durability test specimens was interfacial between the primer and adhesive. This was true for both alloys, both surface preparations, nearly all of the adhesive/primer systems, and for both residual strength specimens as well as for those few specimens which failed during exposure.

3.4 SUMMARY OF RESULTS

No consistent differences were observed between the performance of the various adhesive/primer, alloy, surface preparation combinations tested in this program. The goal of the testing was to evaluate the compatibility of 177°C (350°F). curing adhesive/primer systems with the PAA surface treatment.

Most of the adhesive/primer systems exhibited equivalent performance with both the PAA and OFPL etch surface treatments for all types of tests and exposure conditions. Some of the adhesive/primer systems performed better with the OFPL etch surface treatment than with the PAA surface treatment, but in those instances where such a difference appeared, it was only for one of the three types of tests conducted.

In lap-shear, for example, the MB329/MB6725-1 and FM400/BR400 systems exhibited less primer failure on OFPL surfaces than on PAA surfaces but with no difference in strength. In peel and stress-durability these two systems exhibited equivalent behavior, both in strength and failure mode, for the two surface preparations.

In peel, the FM61/BR227A system exhibited better strength and less primer related failure with the OFPL etch than with the PAA but in lap-shear and stress-durability no difference in performance between the two surface preparations was noted for this system.

In stress-durability, the AF-130/EC-3917 system yielded higher residual strengths and less primer failure with the OFPL etch than with the PAA for the case of a humidity environment but no difference between the two surface preparations was observed for this system in lap-shear, peel, or in salt-spray stress-durability.

The results of the tests carried out in this program serve to indicate that, in general, there was no glaring incompatibility between any of the materials tested and the PAA surface preparation.

APPENDIX A

INDIVIDUAL SPECIMEN LAP SHEAR TEST RESULTS AND ULTRASONIC C-SCAN INSPECTION RESULTS OF PANELS USED FOR LAP SHEAR SPECIMENS

Tables A1 through A4 present the results obtained for each individual lap shear specimen tested during this program. These data are summarized in both tabular and graphical form in Section 3.1. In addition to the lap shear test data, the ultrasonically generated c-scans for each panel are presented in Figures A1 through A24. Figures A1 through A20 were generated at AFWAL/MLSE while Figures A21 through A24 were supplied with the panels by Douglas Aircraft. These figures are arranged so that they correspond to the data in the preceding table (Figures A1 through A10 correspond to Table A1 for example).

It will be noted that there appears to be a rather good correlation between disbond areas appearing in the c-scans and the corresponding specimen strengths and failure modes. The numbers from 1-9 appearing along the edges of the panels in Figures A1-A-20 represent the position from which specimen numbers 1-9 were machined.

TABLE A1

INDIVIDUAL LAP SHEAR STATIC TEST RESULTS ON 7075-T76 BARE
ALUMINUM WITH PHOSPHORIC ACID ANODIZED SURFACE PREPARATION

Adhesive/Primer System	Test Temperature (°F) (°C)	Specimen Number	Ult. Strength		Failure Mode (%)				
			(psi)	(MPa)	M/P	P	P/A	A	V
RB398/RB500	(72) (22)	1A601-1	2469	17.02	0	80	10	10	0
		1A601-4	2402	16.56	0	90	0	10	0
		1A601-7	2347	16.18	0	90	0	10	0
		Avg.	2406	16.59	0	87	3	10	0
		Std Dev	61	0.42					
RB398/RB500	(350) (177)	1A601-2	1520	10.48	0	0	0	100	0
		1A601-5	1571	10.83	0	0	0	100	0
		1A601-8	1528	10.54	0	0	0	100	0
		Avg.	1540	10.62	0	0	0	100	0
		Std Dev	27	0.19					
RB398/RB500	(-65) (-54)	1A601-3	2102	14.49	0	95	0	0	5
		1A601-6	2176	15.00	0	95	0	0	5
		1A601-9	1891	13.04	0	95	0	0	5
		Avg	2056	14.18	0	95	0	0	5
		Std Dev	148	1.02					
MB329/MB6725-1	(72) (22)	1B601-1	2556	17.6	0	80	0	20	0
		1B601-4	1935	13.3	0	80	0	0	20
		1B601-7	2035	14.0	0	90	0	0	10
		Avg	2175	15.0	0	83	0	7	10
		Std Dev	333	2.3					
MB329/MB6725-1	(350) (177)	1B601-2	1920	13.2	0	20	0	80	0
		1B601-5	1962	13.5	0	10	0	80	10
		1B601-8	2070	14.3	0	20	0	80	0
		Avg	1984	13.7	0	17	0	8	3
		Std Dev	77	0.5					
MB329/MB6725-1	(-65) (-54)	1B601-3	1862	12.8	0	90	0	0	10
		1B601-6	1643	11.3	0	70	0	0	30
		1B601-9	2000	13.8	0	100	0	0	0
		Avg	1835	12.6	0	87	0	0	13
		Std Dev	180	1.2					

FM400/BR400	(72)(22)	1C601-1	2731	18.8	0	20	0	80	0
		1C601-4	2272	15.7	0	80	0	10	0
		1C601-7	2382	16.4	0	90	0	10	0
		Avg	2462	17.0	0	67	0	33	0
		Std Dev	240	1.6					
FM400/BR400	(350)(177)	1C601-2	2146	14.8	0	0	10	90	0
		1C601-5	2224	15.3	0	0	10	90	0
		1C601-8	2205	15.2	0	0	30	70	0
		Avg	2192	15.1	0	0	17	83	0
		Std Dev	41	0.3					
FM400/BR400	(-65)(-54)	1C601-3	2024	14.0	0	95	0	0	5
		1C601-6	2154	14.9	0	95	0	0	5
		1C601-9	2458	17.0	0	90	0	0	10
		Avg	2212	15.2	0	93	0	0	7
		Std Dev	223	1.5					
EA9649/EA9205	(72)(22)	1D601-1	3065	21.1	0	90	0	10	0
		1D601-4	2379	16.4	0	100	0	0	0
		1D601-7	2421	16.7	0	100	0	0	0
		Avg	2622	18.1	0	97	0	3	0
		Std Dev	385	2.63					
EA9649/EA9205	(350)(177)	1D601-2	2510	17.3	0	20	10	70	0
		1D601-5	2502	17.3	0	10	30	60	0
		1D601-8	2529	17.4	0	10	20	70	0
		Avg	2514	17.3	0	13	20	67	0
		Std Dev	13.8	0.06					
EA9649/EA9205	(-65)(-54)	1D601-3	2343	16.2	0	100	0	0	0
		1D601-6	2330	16.1	0	100	0	0	0
		1D601-9	2413	16.6	0	100	0	0	0
		Avg	2362	16.3	0	100	0	0	0
		Std Dev	45	0.27					
AF130/EC3917	(72)(22)	1E601-1	1806	12.45	0	90	0	10	0
		1E601-4	1658	11.43	0	100	0	0	0
		1E601-7	1568	10.81	0	100	0	0	0
		Avg	1677	11.56	0	97	0	3	0
		Std Dev	120	0.83					

AF 130/EC39 17	(350) (177)	1E60 1-2	2062	14.22	0	70	10	20	0
		1E60 1-5	2156	14.87	0	80	10	10	0
		1E60 1-8	2156	14.87	0	50	5	40	5
		Avg	2125	14.65	0	67	8	23	2
		Std Dev	54	0.38					
AF 130/EC39 17	(-65) (-54)	1E60 1-3	1287	8.87	0	100	0	0	0
		1E60 1-6	1302	8.98	0	100	0	0	0
		1E60 1-9	1320	9.10	0	100	0	0	0
		Avg	1303	8.98	0	100	0	0	0
		Std Dev	16.5	0.12					
AF 3 1/EC2 174	(72) (22)	1F60 1-1	3461	23.86	0	95	0	5	0
		1F60 1-4	3735	25.75	0	95	0	5	0
		1F60 1-7	3976	27.41	0	90	0	10	0
		Avg	3724	25.67	0	93	0	7	0
		Std Dev	258	1.78					
AF 3 1/EC2 174	(350) (177)	1F60 1-2	1670	11.51	0	100	0	0	0
		1F60 1-5	1654	11.40	0	100	0	0	0
		1F60 1-8	1753	12.09	0	95	0	5	0
		Avg	1692	11.67	0	98	0	2	0
		Std Dev	53	0.37					
AF 3 1/EC2 174	(-65) (-54)	1F60 1-3	1321	9.11	0	100	0	0	0
		1F60 1-6	1287	8.87	0	100	0	0	0
		1F60 1-9	1349	9.30	0	100	0	0	0
		Avg	1319	9.09	0	100	0	0	0
		Std Dev	31	0.22					
PL729-3/PL728	(72) (22)	1G60 1-1	3588	24.74	0	0	0	100	0
		1G60 1-4	3333	22.98	0	0	0	100	0
		1G60 1-7	3383	23.33	0	0	0	100	0
		Avg	3435	23.68	0	0	0	100	0
		Std Dev	135	0.98					
PL729-3/PL728	(350) (177)	1G60 1-2	2048	14.12	0	0	0	100	0
		1G60 1-5	1766	12.18	0	0	0	100	0
		1G60 1-8	1805	12.45	0	0	0	100	0
		Avg	1873	12.92	0	0	0	100	0
		Std Dev	153	1.05					

PL729-3/PL728	(-65)(-54)	1G601-3	2447	16.87	0	100	0	0	0
		1G601-6	1961	13.52	0	100	0	0	0
		1G601-9	2486	17.14	0	90	0	10	0
		Avg	2298	15.84	0	97	0	3	0
		Std Dev	293	2.02	0	97	0	3	0
HT424/HT424F	(72)(22)	1H601-1-2 ¹	1945	13.41	0	0	40	60	0
HT424/HT424F	(350)(177)	1H601-3-2 ¹	710	4.90	0	0	10	90	0
HT424/HT424F	(-65)(-54)	1H601-4-2 ¹	2990	20.62	0	0	70	30	0
FM6 1/BR227	(72)(22)	1I601-1	2902	20.00	0	0	10	90	0
		1I601-4	2699	18.61	0	10	40	50	0
		1I601-7	2695	18.58	0	20	20	60	0
		Avg	2765	19.06	0	10	23	67	0
		Std Dev	118	0.81					
FM6 1/BR227	(350)(177)	1I601-2	694	4.79	0	90	0	10	0
		1I601-5	511	3.52	0	80	0	20	0
		1I601-8	348	2.40	0	70	10	20	0
		Avg	518	3.57	0	80	3	17	0
		Std Dev	173	1.20					
FM6 1/BR227	(-65)(-54)	1I601-3	2212	15.25	0	10	70	20	0
		1I601-6	2822	19.46	0	50	10	40	0
		1I601-9	2443	16.84	0	10	70	20	0
		Avg	2492	17.18	0	23	50	27	0
		Std Dev	308	2.13					
FM6 1/BR227A	(72)(22)	1J601-1	2426	16.73	0	80	0	20	0
		1J601-4	2786	19.21	0	90	0	10	0
		1J601-7	2746	18.93	0	95	0	5	0
		Avg	2653	18.29	0	88	0	12	0
		Std Dev	197	1.36					
FM6 1/BR227A	(350)(177)	1J601-2	705	4.86	0	60	30	10	0
		1J601-5	636	4.39	0	50	40	10	0
		1J601-8	654	4.51	0	60	30	10	0
		Avg	665	4.59	0	57	33	10	0
		Std Dev	36	0.24					

FM6 1/BR227A	(-65)(-54)	1J601-3	1452	10.01	0	90	0	10	0
		1J601-6	1689	11.65	0	95	0	5	0
		1J601-9	1657	11.43	0	95	0	5	0
		Avg	1599	11.03	0	93	0	7	0
		Std Dev	129	0.89					

(1) RAAB specimen used, only one joint tested.

Panel No. 1A601
Alloy 7075T76 Bare
Surface Prep PAA
Primer RB500
Adhesive RB398

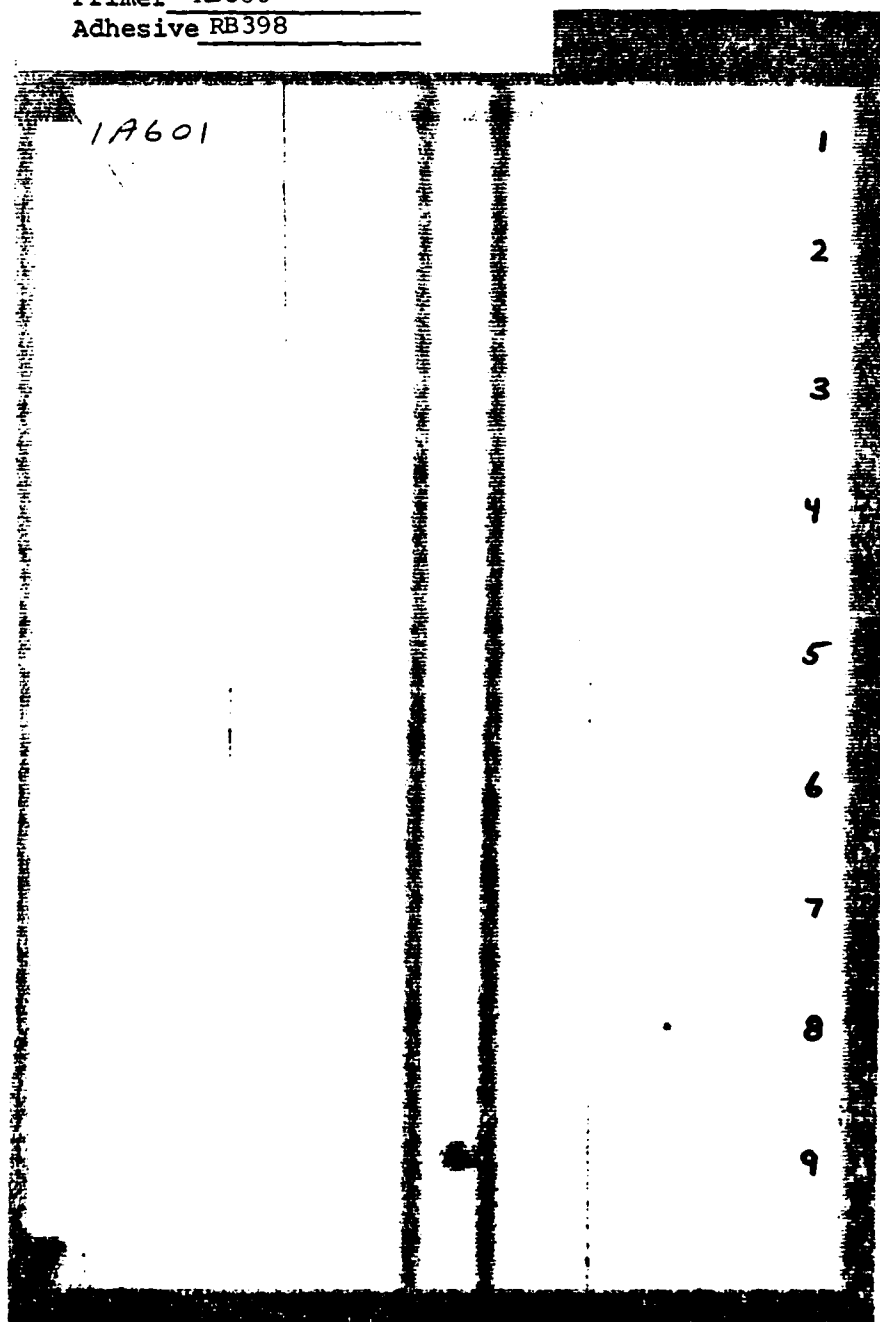


Figure A1. Ultrasonic C-Scan of Lap Shear Panel.

Panel No. 1B601
Alloy 7075T76 Bare
Surface Prep PAA
Primer MB6725-I
Adhesive MB329

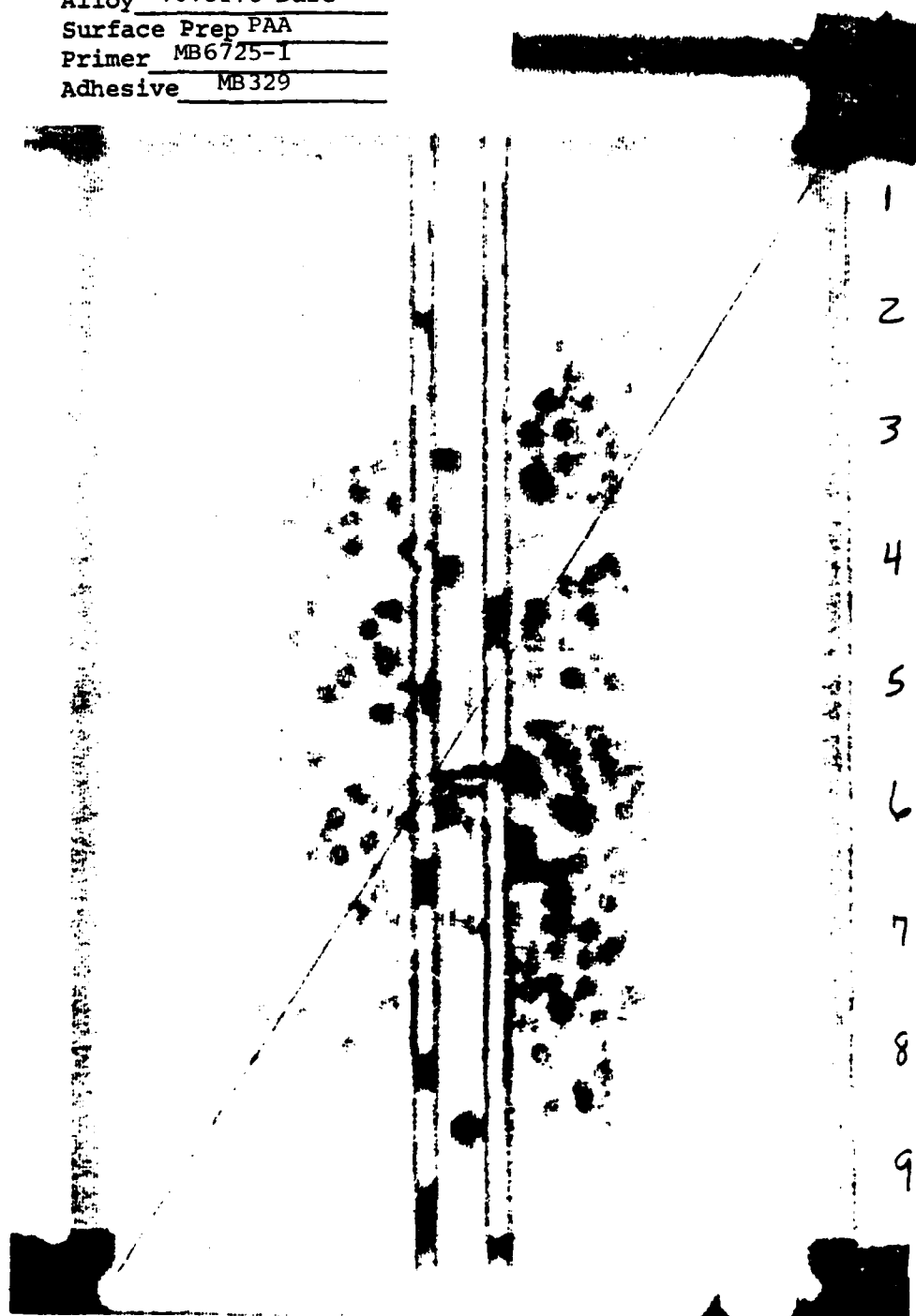


Figure A2. Ultrasonic C-Scan of Lap Shear Panel.

Panel No. 1C601
Alloy 7075T76 Bare
Surface Prep PAA
Primer BR400
Adhesive FM400

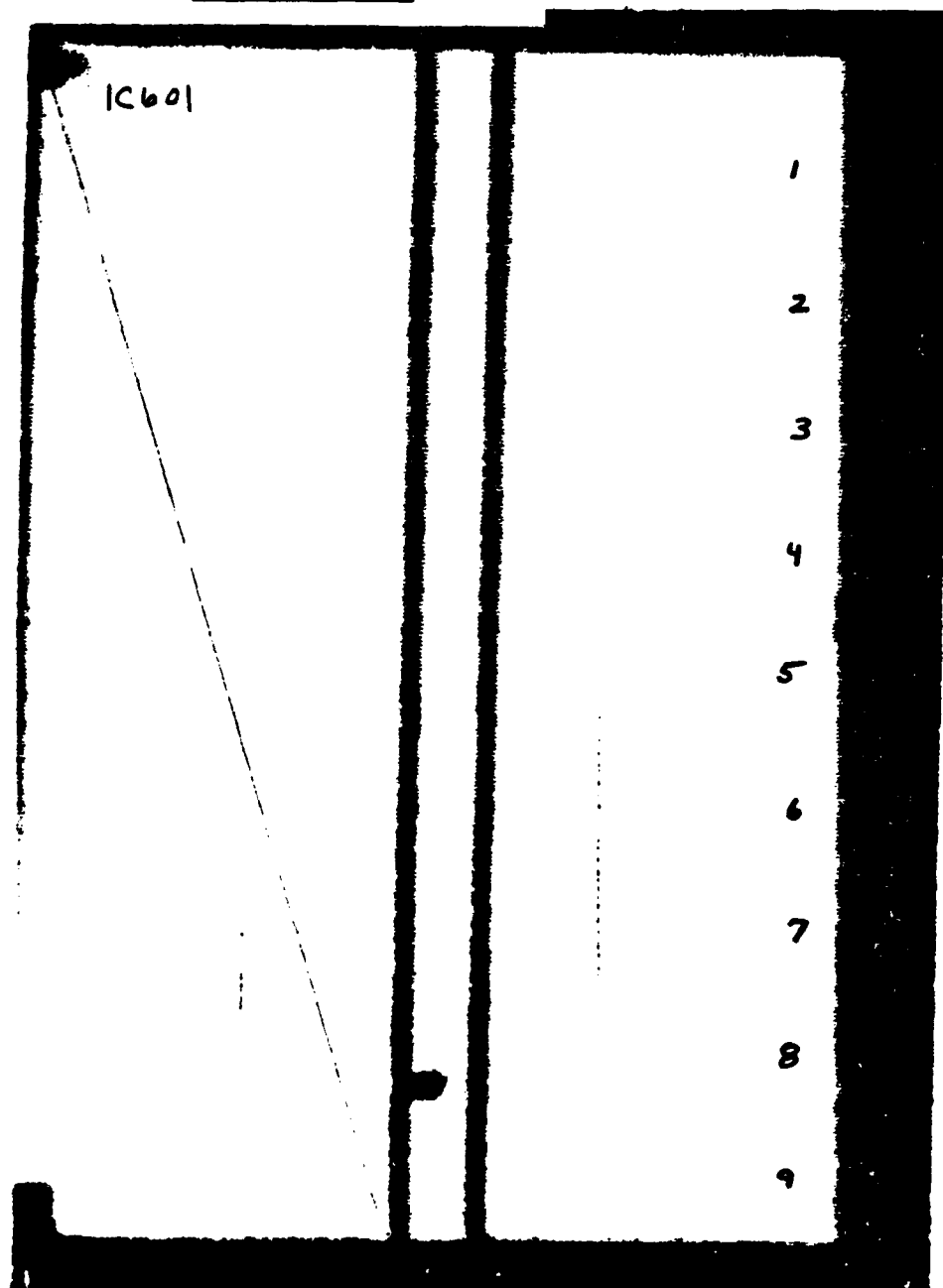


Figure A3. Ultrasonic C-Scan of Lap Shear Panel.

Panel No. 1D601
Alloy 7075T76 Bare
Surface Prep PAA
Primer EA9205
Adhesive EA9649

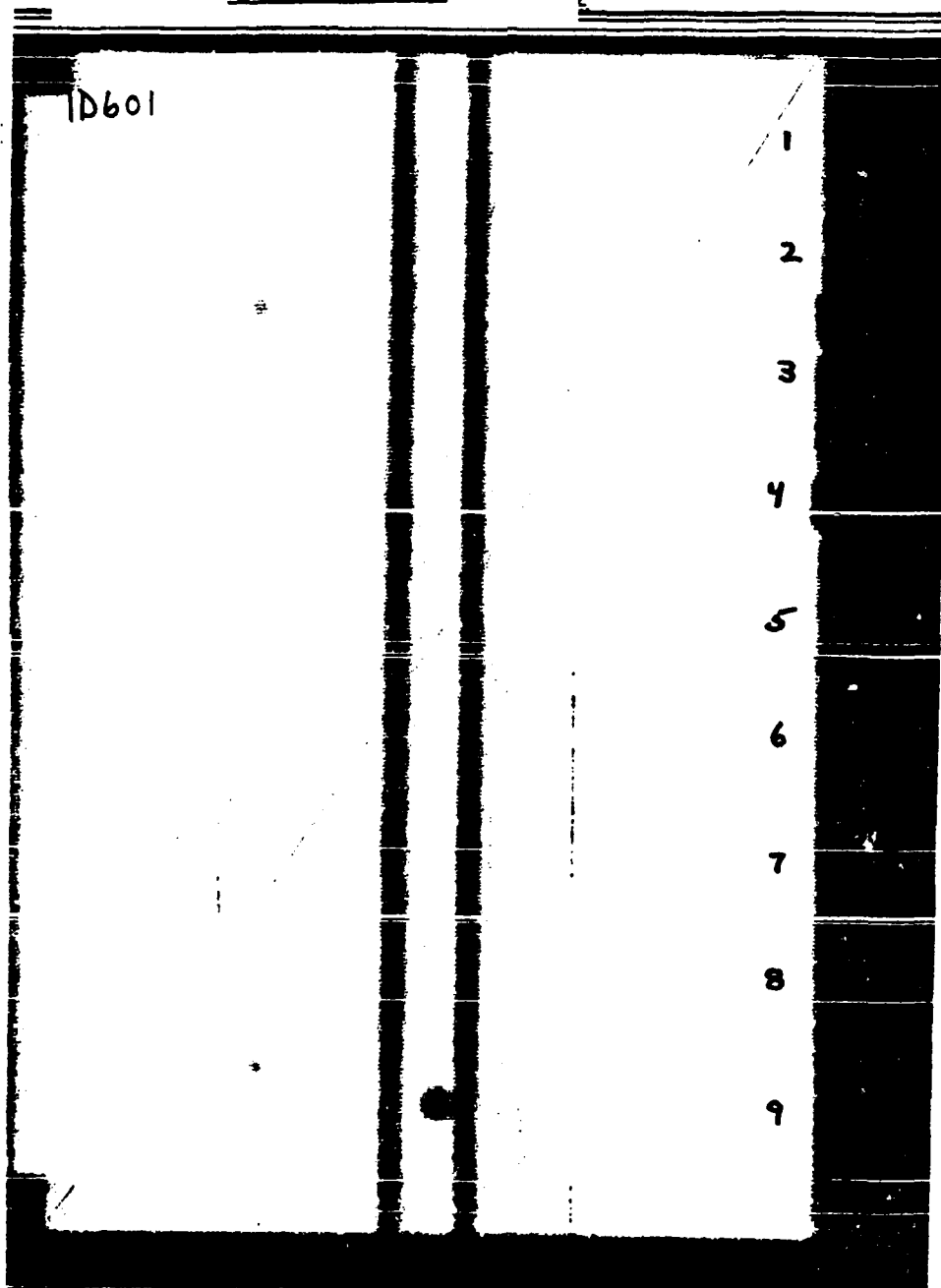


Figure A4. Ultrasonic C-Scan of Lap Shear Panel.

Panel No. 1E601
Alloy 7075T76 Bare
Surface Prep PAA
Primer EC3917
Adhesive AF130

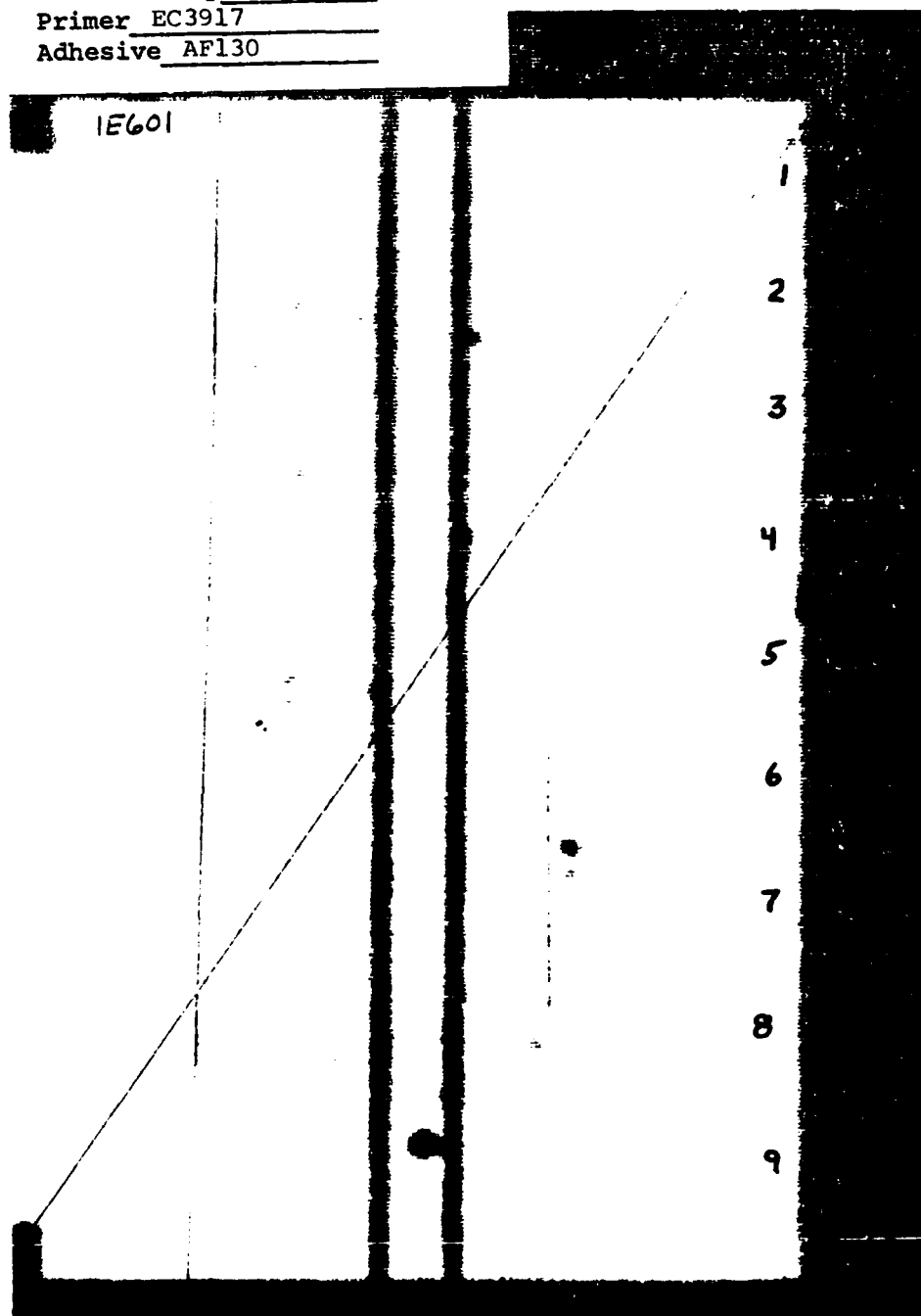


Figure A5. Ultrasonic C-Scan of Lap Shear Panel.

Panel No. 1F601
Alloy 7075T76 Bare
Surface Prep PAA
Primer EC2174
Adhesive AF31

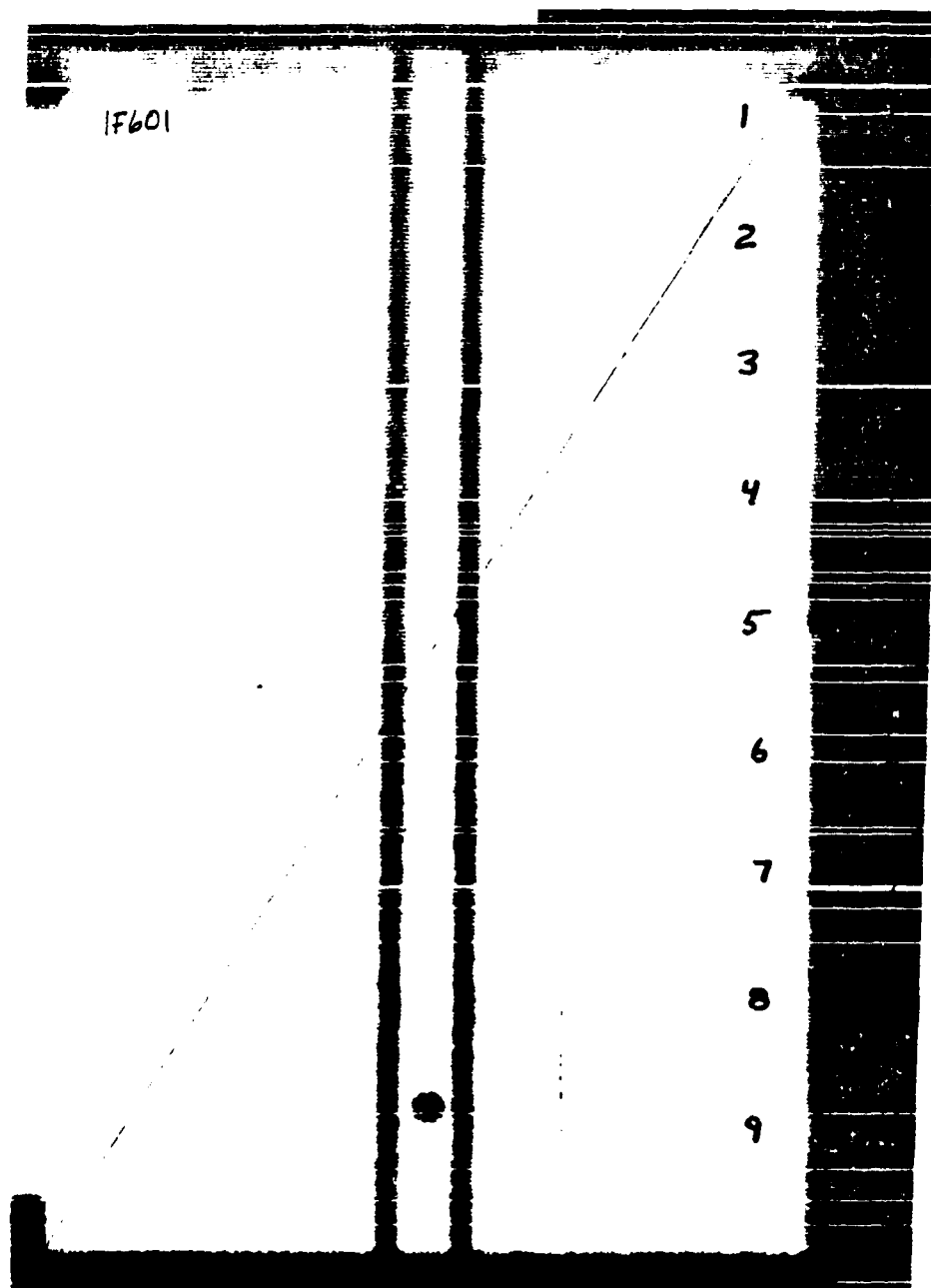


Figure A6. Ultrasonic C-Scan of Lap Shear Panel.

Panel No. 1G601
Alloy 7075T76 Bare
Surface Prep PAA
Primer PL728
Adhesive PL-729-3

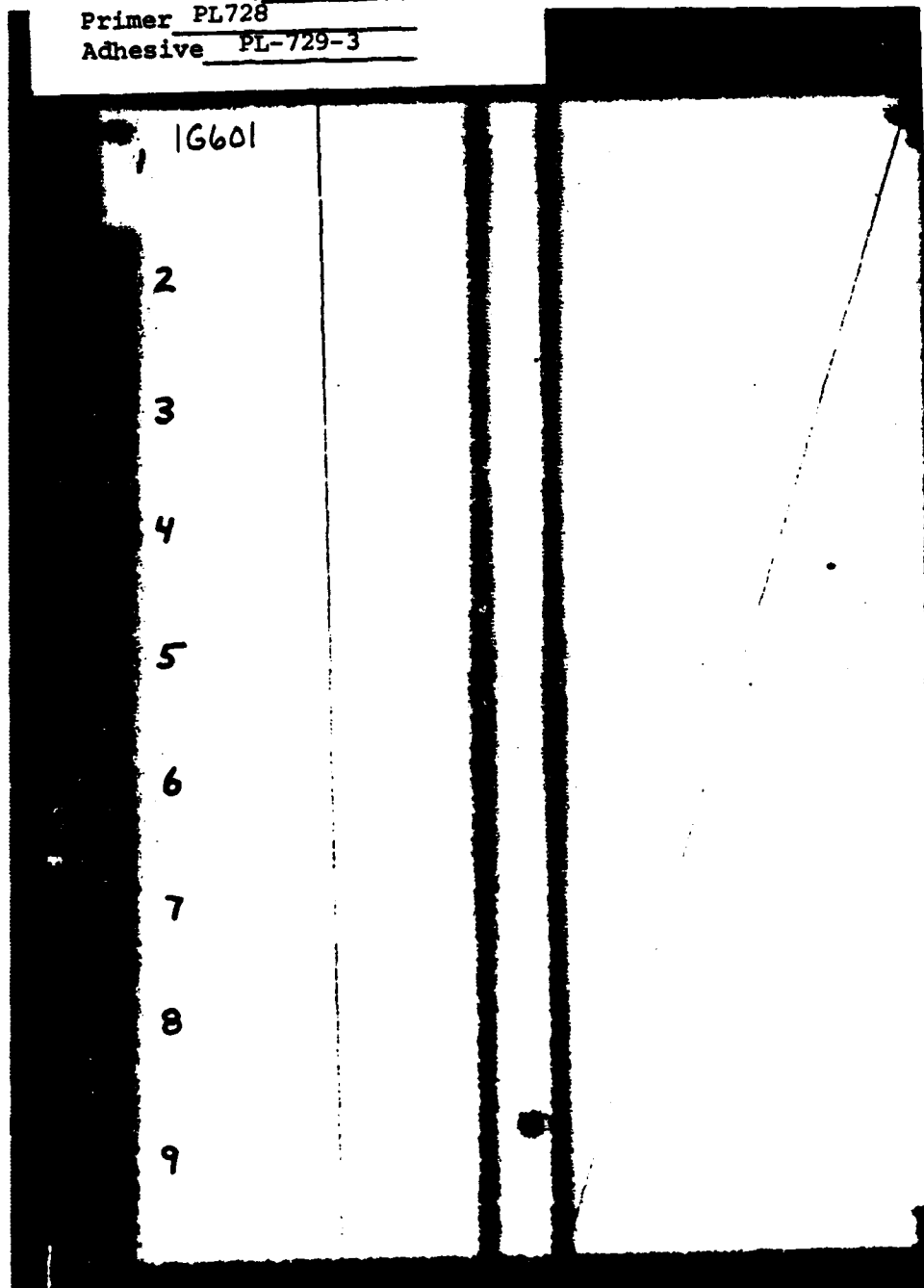


Figure A7. Ultrasonic C-Scan of Lap Shear Panel.

Panel No. 1H601
Alloy 7075T76 Bare
Surface Prep PAA
Primer HT424F
Adhesive HT424

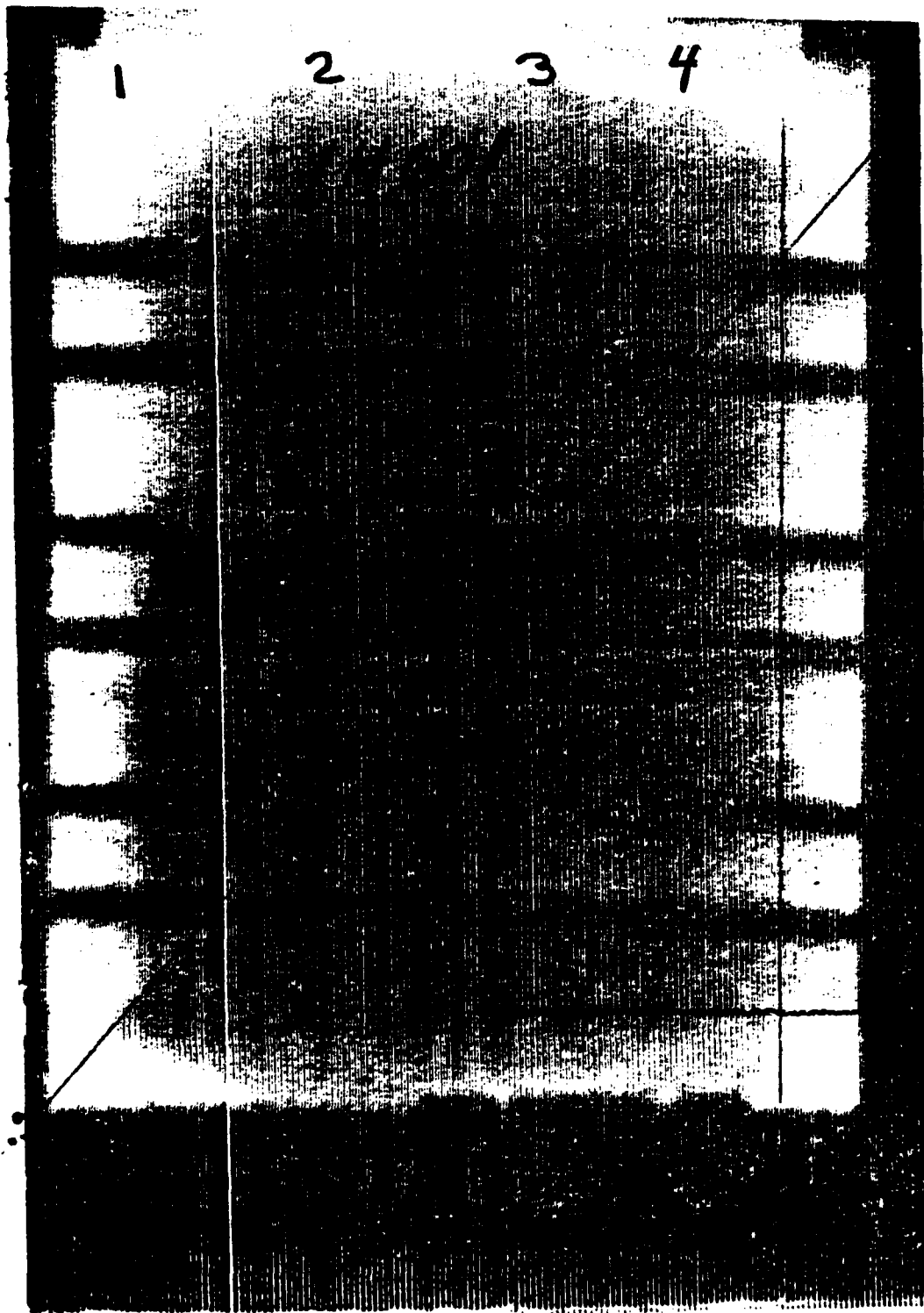


Figure A8. Ultrasonic C-Scan of RAAB type panel used for Lap Shear Specimens.

Panel No. 11601
Alloy 7075T76 Bare
Surface Prep PAA
Primer BR227
Adhesive FM61

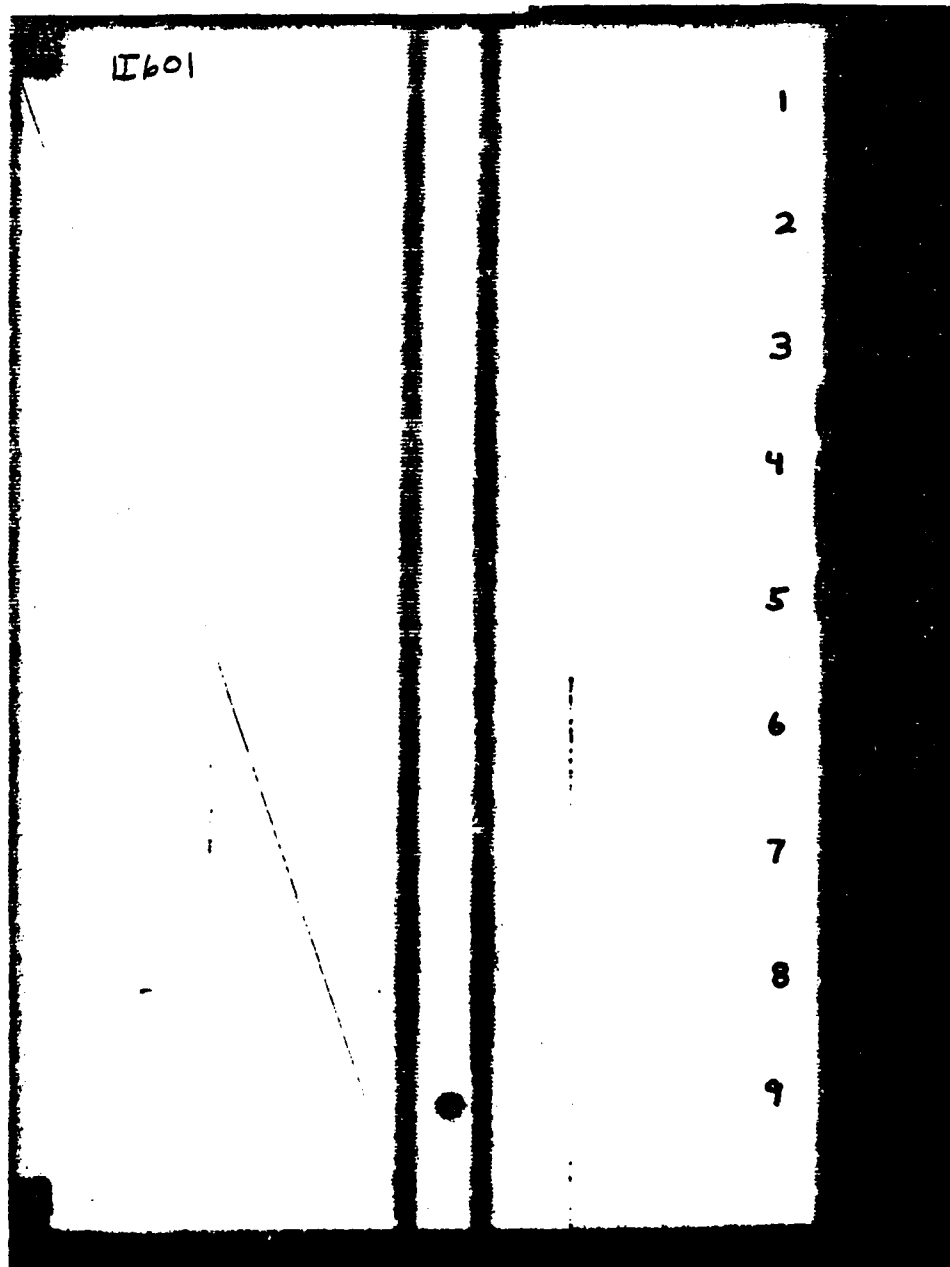


Figure A9. Ultrasonic C-Scan of Lap Shear Panel.

Panel No. 15601
Alloy 7075T76
Surface Prep PAA
Primer BR227A
Adhesive FM61

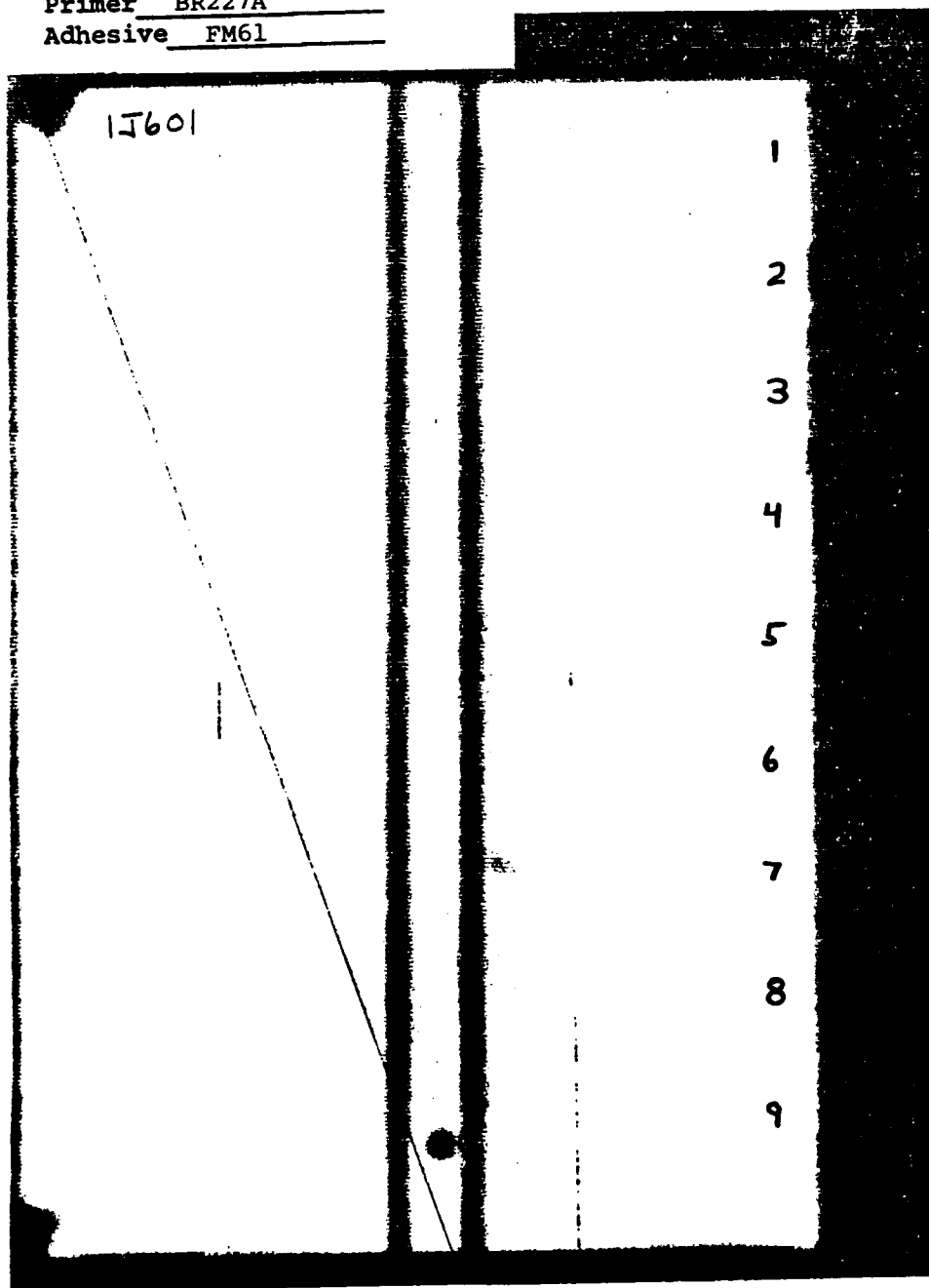


Figure A10. Ultrasonic C-Scan of Lap Shear Panel.

TABLE A2

INDIVIDUAL LAP SHEAR STATIC TEST RESULTS ON 2024-T81 BARE
ALUMINUM WITH PHOSPHORIC ACID ANODIZED SURFACE PREPARATION

Adhesive/Primer System	Test Temperature (°F) (°C)	Specimen Number	Ult. Strength		Failure Mode (%)				
			(psi)	(MPa)	M/P	P	P/A	A	V
RB398/RB500	(72) (22)	1A101-1	2747	18.9	0	40	50	10	0
		1A101-4	2311	15.9	0	90	10	0	0
		1A101-7	2402	16.6	0	90	0	10	0
		Avg	2487	17.2	0	73	30	7	0
		Std Dev	230	1.6					
RB398/RB500	(350) (177)	1A101-2	1529	10.5	0	0	90	0	10
		1A101-5	1413	9.7	0	0	90	0	10
		1A101-8	1302	9.0	0	0	90	0	10
		Avg	1415	9.8	0	0	90	0	10
		Std Dev	114	0.8					
RB398/RB500	(-65) (-54)	1A101-3	2281	15.7	0	90	0	0	10
		1A101-6	2222	15.3	0	100	0	0	0
		1A101-9	2264	15.6	0	90	0	0	10
		Avg	2256	15.6	0	93	0	0	7
		Std Dev	30	0.2					
MB329/MB6725-1	(72) (22)	1B101-1	2481	17.1	0	90	0	10	0
		1B101-4	2255	15.6	0	100	0	0	0
		1B101-7	2206	15.2	0	100	0	0	0
		Avg	2314	15.9	0	97	0	3	0
		Std Dev	147	1.0					
MB329/MB6725-1	(350) (177)	1B101-2	1841	12.7	0	20	0	80	0
		1B101-5	2035	14.0	0	20	0	80	0
		1B101-8	1957	13.5	0	10	0	90	0
		Avg	1944	13.4	0	17	0	83	0
		Std Dev	98	0.7					
MB329/MB6725-1	(-65) (-54)	1B101-3	2082	14.4	0	100	0	0	0
		1B101-6	1891	13.0	0	90	0	0	10
		1B101-9	2063	14.2	0	100	0	0	0
		Avg	2012	13.9	0	97	0	0	3
		Std Dev	105	0.8					

FM400/BR400	(72)(22)	1C101-1	2876	19.8	0	50	0	50	0
		1C101-4	2413	16.6	0	90	0	10	0
		1C101-7	2601	17.9	0	90	0	10	0
		Avg	2630	18.1	0	77	0	23	0
		Std Dev	230	1.6					
FM400/BR400	(350)(177)	1C101-2	2175	15.0	0	0	20	80	0
		1C101-5	2333	16.1	0	0	30	70	0
		1C101-8	2475	17.1	0	0	20	80	0
		Avg	2328	16.1	0	0	23	77	0
		Std Dev	150	1.0					
FM400/BR400	(-65)(-54)	1C101-3	2480	17.1	0	95	0	0	5
		1C101-6	2327	16.1	0	95	0	0	5
		1C101-9	2654	18.3	0	95	0	0	5
		Avg	2487	17.2	0	95	0	0	5
		Std Dev	164	1.1					
EA9649/EA9205	(72)(22)	1D101-1	2518	17.4	0	100	0	0	0
		1D101-4	2539	17.5	0	100	0	0	0
		1D101-7	2573	17.7	0	100	0	0	0
		Avg.	2543	17.5	0	100	0	0	0
		Std Dev	28	0.15					
EA9649/EA9205	(350)(177)	1D101-2	2422	16.7	0	10	10	80	0
		1D101-5	2418	16.7	0	10	10	80	0
		1D101-8	2761	19.0	0	10	0	90	0
		Avg	2534	17.4	0	10	7	83	0
		Std Dev	197	1.4					
EA9649/EA9205	(-65)(-54)	1D101-3	2336	16.1	0	100	0	0	0
		1D101-6	2344	16.2	0	100	0	0	0
		1D101-9	3004	20.7	0	95	0	5	0
		Avg	2561	17.6	0	98	0	2	0
		Std Dev	383	2.6					
AF130/EC3917	(72)(22)	1E101-1	1319	9.09	0	100	0	0	0
		1E101-4	1715	11.8	0	100	0	0	0
		1E101-7	1606	11.1	0	100	0	0	0
		Avg	1547	10.66	0	100	0	0	0
		Std Dev	205	1.41					

AF130/EC3917	(350)(177)	1E101-2	2124	14.65	0	80	0	10	10
		1E101-5	2075	14.30	0	70	0	0	0
		1E101-8	1795	12.40	0	0	10	90	0
		Avg	1998	13.78	0	50	3	44	3
		Std Dev	178	1.21					

AF130/EC3917	(-65)(-54)	1E101-3	1293	8.92	0	90	0	5	5
		1E101-6	479 *	3.30	0	40	0	5	55
		1E101-9	1129	7.79	0	85	0	10	5
		Avg	967	6.67	0	71	0	7	22
		Std Dev	431	2.97					

AF31/EC2174	(72)(22)	1F101-1	4035	27.82	0	95	0	5	0
		1F101-4	3979	27.44	0	95	0	5	0
		1F101-7	3996	27.55	0	95	0	5	0
		Avg	4003	27.6	0	95	0	5	0
		Std Dev	29	0.2					

AF31/EC2174	(350)(177)	1F101-2	1638	11.29	0	95	0	5	0
		1F101-5	1679	11.58	0	100	0	0	0
		1F101-8	1683	11.60	0	95	0	5	0
		Avg	1667	11.49	0	97	0	3	0
		Std Dev	25	0.17					

AF31/EC2174	(-65)(-54)	1F101-3	1284	8.85	0	90	0	10	0
		1F101-6	1310	9.03	0	100	0	0	0
		1F101-9	1504	10.37	0	90	0	10	0
		Avg	1366	9.42	0	93	0	7	0
		Std Dev	120	0.83					

PL729-3/PL728	(72)(22)	1G101-1	3765	25.96	0	0	0	100	0
		1G101-4	3516	24.24	0	80	0	20	0
		1G101-7	3426	23.62	0	80	0	20	0
		Avg	3569	24.61	0	53	0	47	0
		Std Dev	176	1.21					

PL729-3/PL728	(350)(177)	1G101-2	1178	8.12	0	0	0	100	0
		1G101-5	1622	11.18	0	0	0	100	0
		1G101-8	1740	12.00	0	0	0	100	0
		Avg	1513	10.43	0	0	0	100	0
		Std Dev	296	2.05					

*Poor C-scan indication.

PL729-3/PL728	(-65)(-54)	1G101-3	2483	17.12	0	100	0	0	0
		1G101-6	1954	13.47	0	100	0	0	0
		1G101-9	2298	15.84	0	90	0	10	0
		Avg	2245	15.48	0	97	0	3	0
		Std Dev	268	1.85					
HT424/HT424F	(72)(22)	1H101-1-1 ¹	2055	14.17	0	0	25	75	0
HT424/HT424F	(350)(177)	1H101-3-1 ¹	(No load re- corded) speci- men failed in handling		0	0	0	100	0
HT424/HT424F	(-65)(-54)	1H101-4-2 ¹	534	3.68	0	0	5	95	0
FM6/BF227	(72)(22)	1I101-1	3110	21.44	0	0	10	90	0
		1I101-4	2679	18.47	0	0	20	80	0
		1I101-7	2678	18.46	0	20	50	30	0
		Avg	2822	19.46	0	7	27	66	0
		Std Dev	249	1.72					
FM6 1/BR227	(350)(177)	1I101-2	459	3.17	0	90	0	10	0
		1I101-5	531	3.66	0	50	0	50	0
		1I101-8	597	4.12	0	80	0	20	0
		Avg	529	3.65	0	73	0	27	0
		Std Dev	69	0.48					
FM6 1/BR227	(-65)(-54)	1I101-3	2483	17.12	0	20	60	20	0
		1I101-6	2066	14.25	0	30	40	30	0
		1I101-9	2210	15.24	0	40	40	20	0
		Avg	2253	15.54	0	30	40	30	0
		Std Dev	212	1.46					
FM6 1/BR227A	(72)(22)	1J101-1	2698	18.60	0	100	0	0	0
		1J101-4	2829	19.51	0	100	0	0	0
		1J101-7	2711	18.69	0	100	0	0	0
		Avg	2746	18.93	0	100	0	0	0
		Std Dev	72	0.50					

FM6 1/BR227A	(350)(177)	1J101-2	451	3.11	0	20	40	40	0
		1J101-5	521	3.59	0	40	40	20	0
		1J101-8	570	3.93	0	30	40	30	0
		Avg	514	3.54	0	30	40	30	0
		Std Dev	60	0.41					

FM6 1/BR227A	(-65)(-54)	1J101-3	1634	11.27	0	100	0	0	0
		1J101-6	1631	11.25	0	100	0	0	0
		1J101-9	1902	13.11	0	90	0	10	0
		Avg	1722	11.88	0	97	0	3	0
		Std Dev	156	1.07					

(1) RAAB specimen used, only one joint tested.

Panel No.: 1A101
Alloy: 2024T81 Bare
Surface Prep: PAA
Primer: RB500
Adhesive: RB398

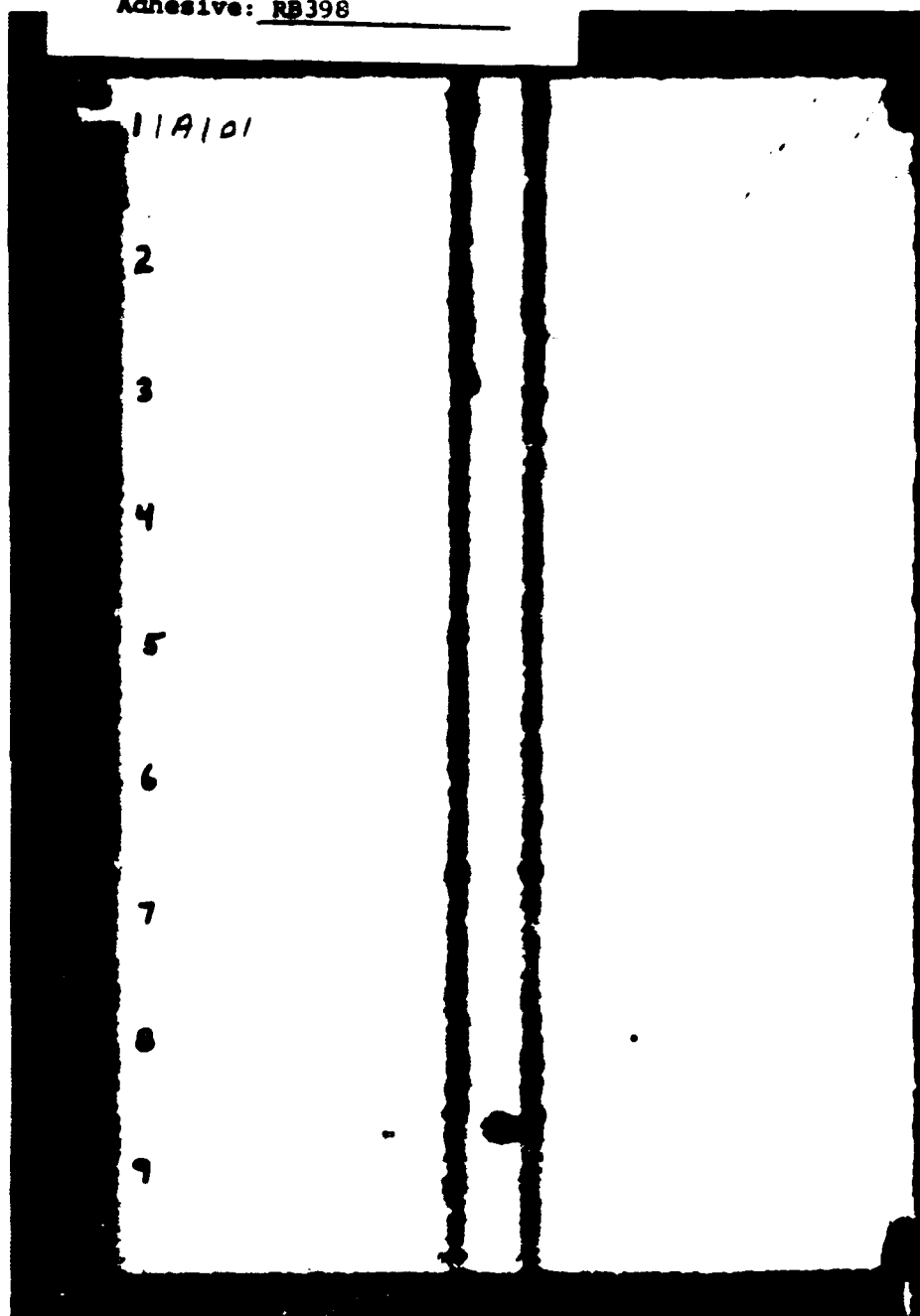


Figure All. Ultrasonic C-Scan of Lap Shear Panel.

Panel No. 1B101
Alloy 2024T81 Bare
Surface Prep PAA
Primer MB6725-1
Adhesive MB329

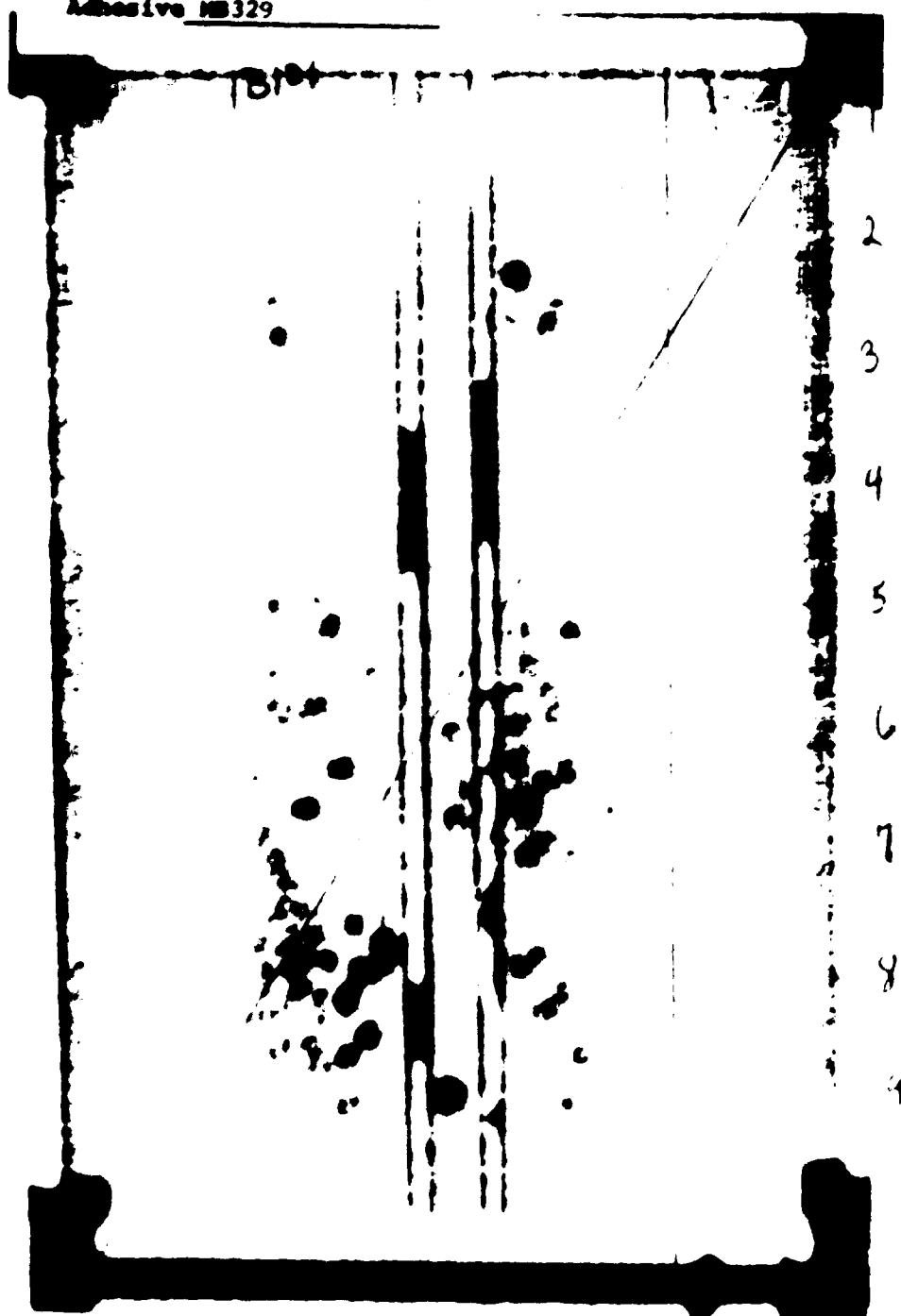


Figure A12. Ultrasonic C-Scan of Lap Shear Panel.

Panel No. 1C101
Alloy 2024T81 Bare
Surface Prep PAA
Primer BR400
Adhesive FM400

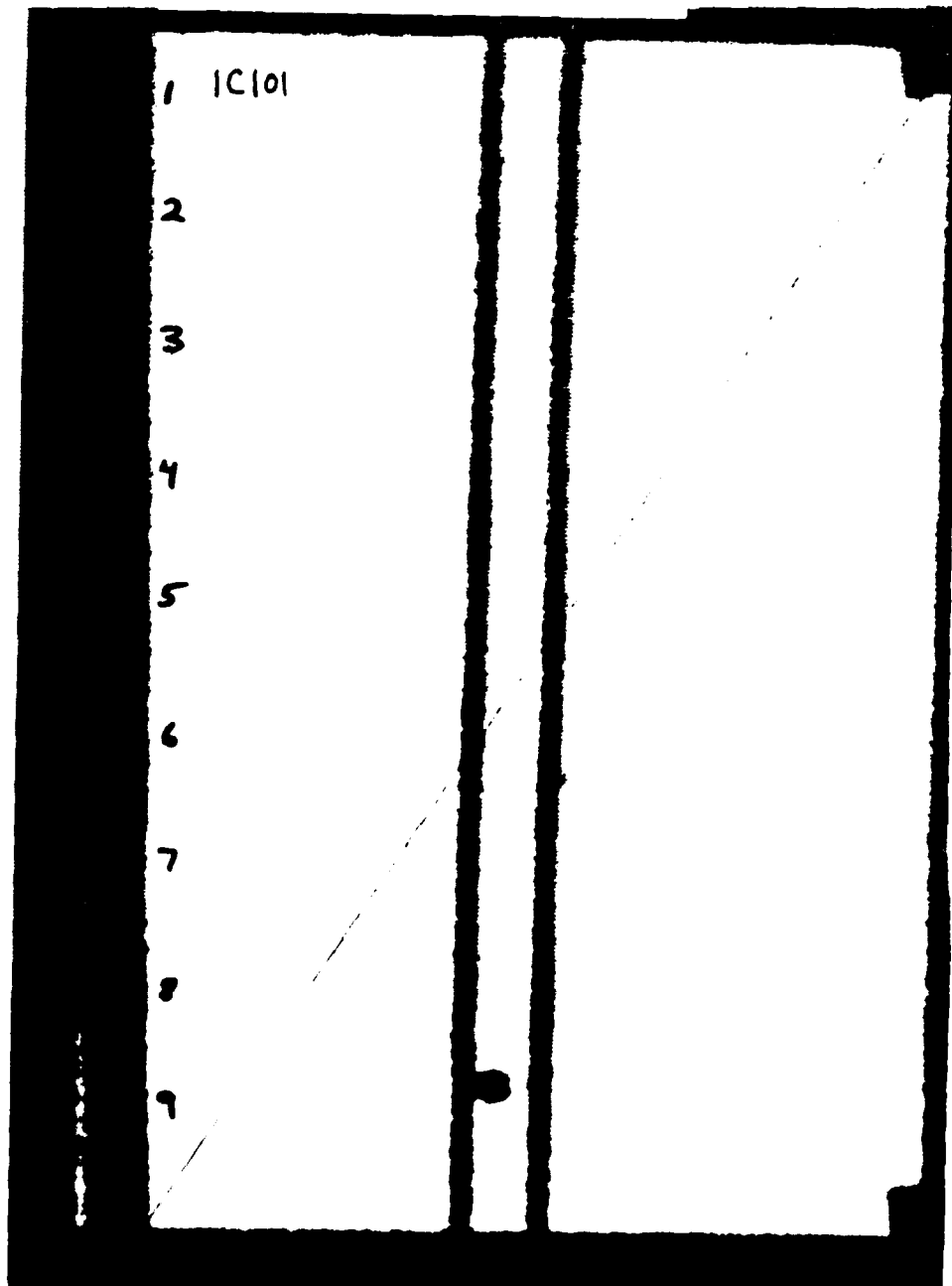


Figure A13. Ultrasonic C-Scan of Lap Shear Panel.

Panel No. 1D101
Alloy 2024T81 Bare
Surface Prep PAA
Primer EA9205
Adhesive EA9649

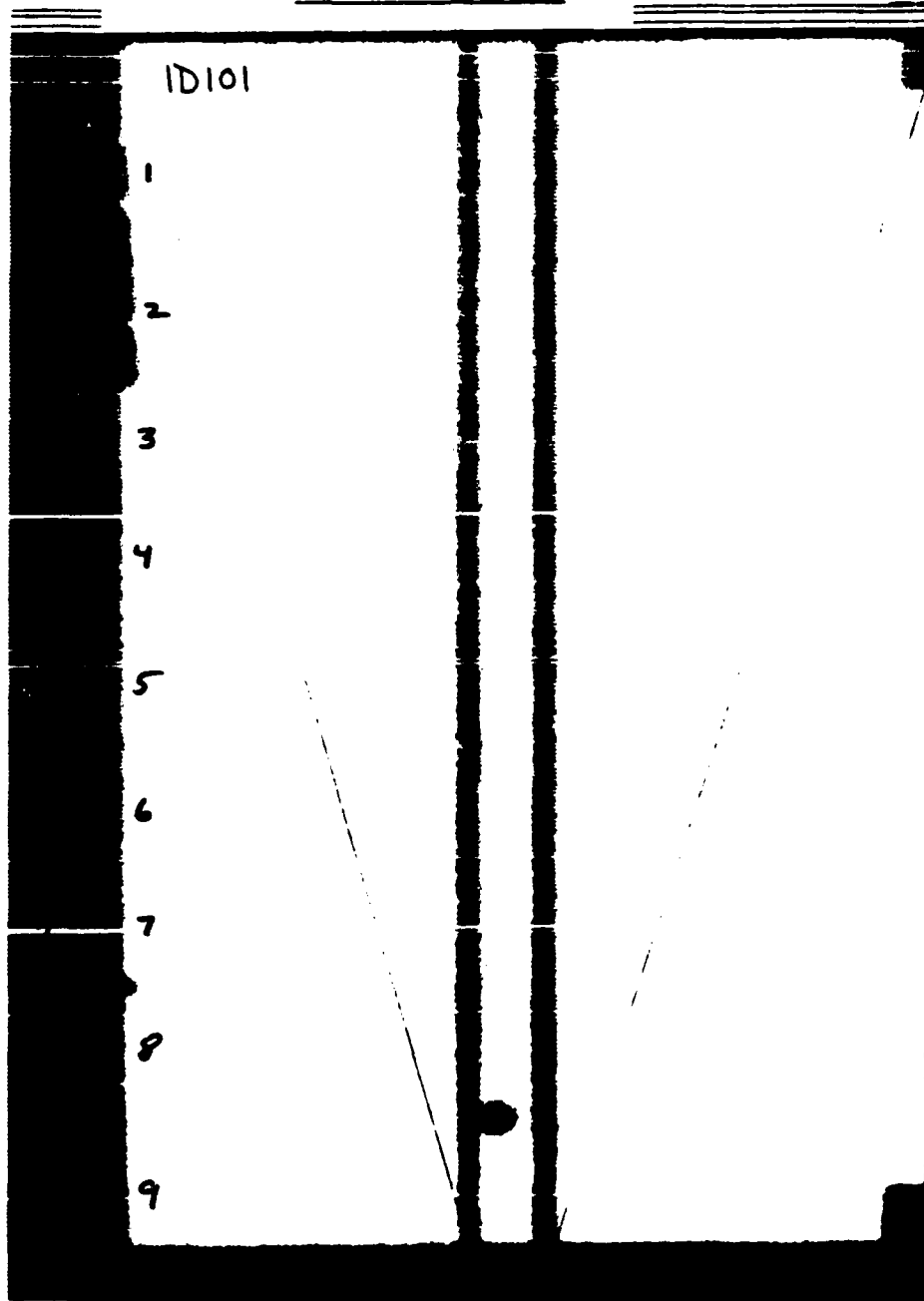


Figure A14. Ultrasonic C-Scan of Lap Shear Panel.

Panel No. 1E101
Alloy 2024T81 Bare
Surface Prep PAA
Primer EC3917
Adhesive AF-130

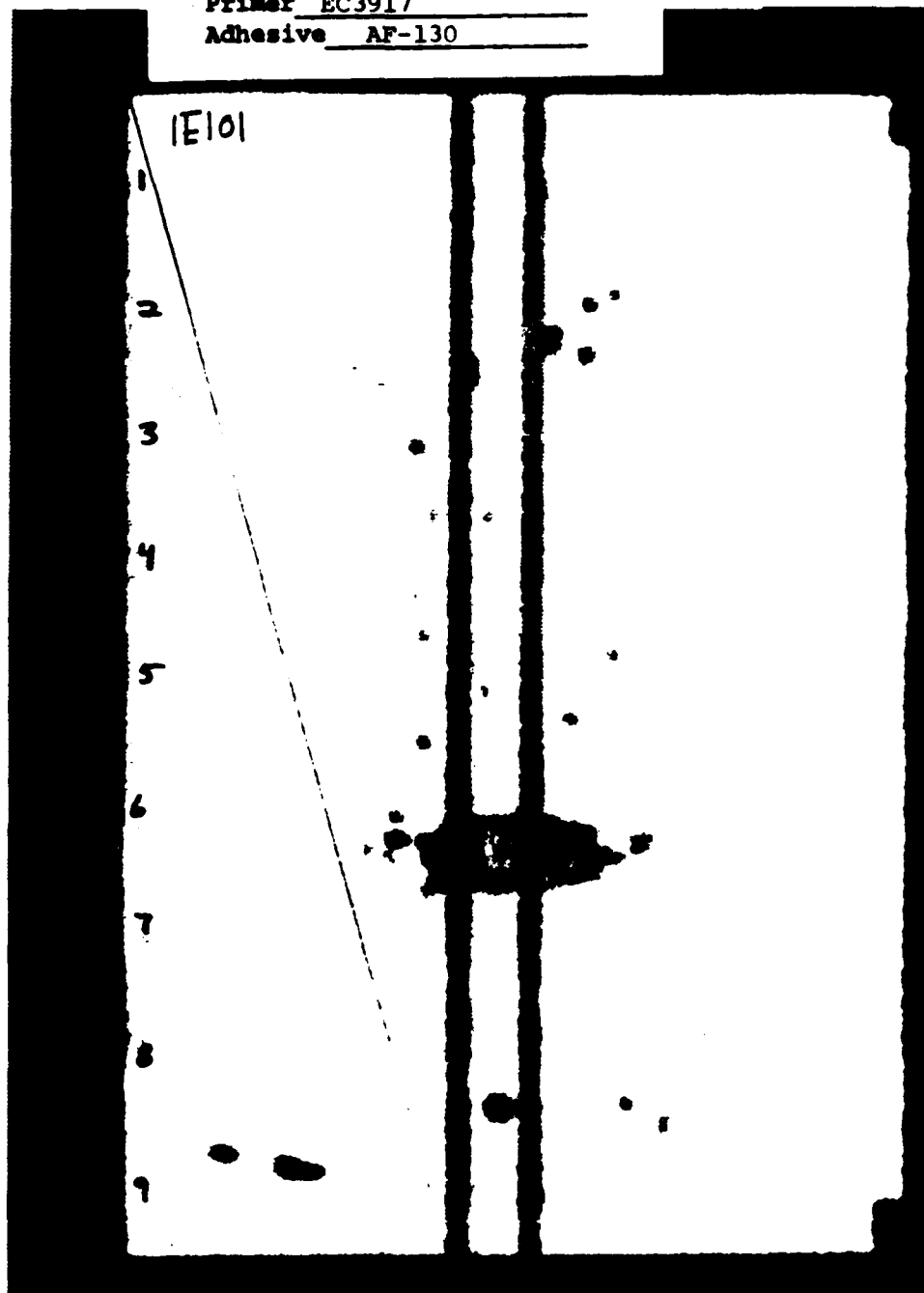


Figure A15. Ultrasonic C-Scan of Lap Shear Panel.

Panel No. 1F101
Alloy 2024T81 Bare
Surface Prep PAA
Primer EA2174
Adhesive AF31

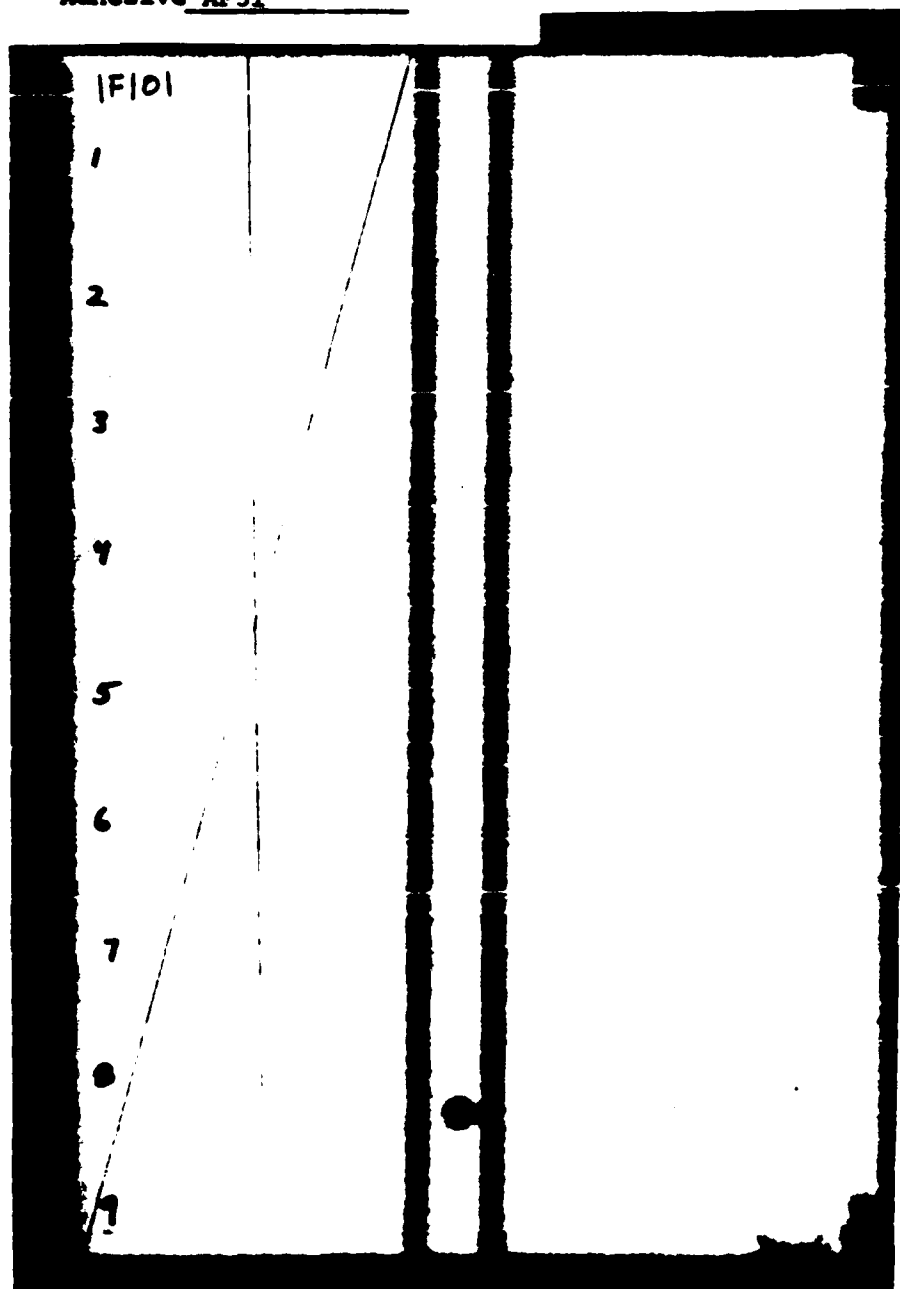


Figure A16. Ultrasonic C-Scan of Lap Shear Panel.

Panel No. 1G101
Alloy 2024T81 Bare
Surface Prep PAA
Primer PL728
Adhesive PL-729-3

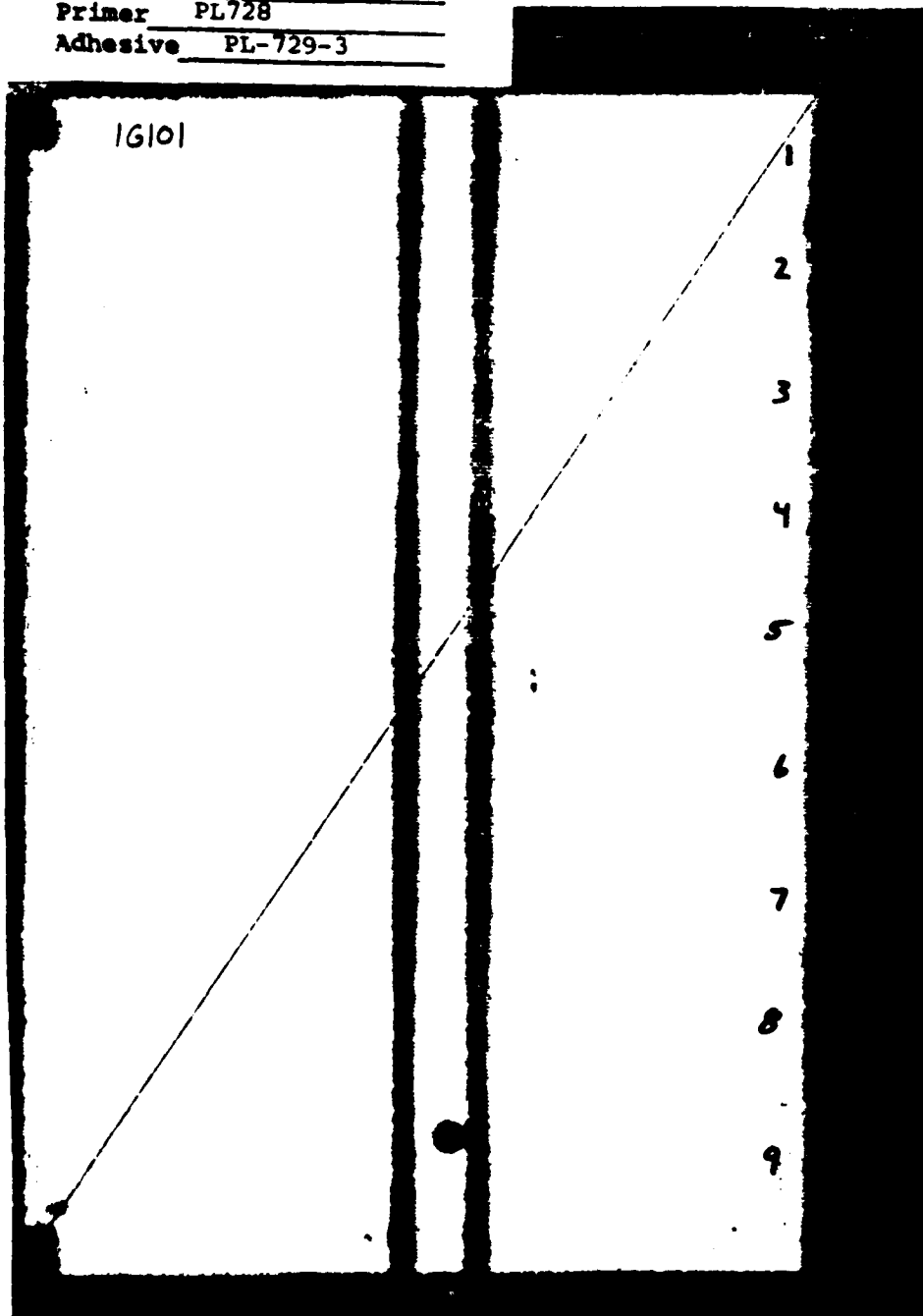


Figure A17. Ultrasonic C-Scan of Lap Shear Panel.

Panel No. 1H101
Alloy 2024T81 Bare
Surface Prep PAA
Primer HT424F
Adhesive HT424



Figure A18. Ultrasonic C-Scan of RAAB Type Panel
Used for Lap Shear Specimens.

Panel No. 11101
Alloy 2024T81 Bare
Surface Prep PAA
Primer BR227
Adhesive FM61

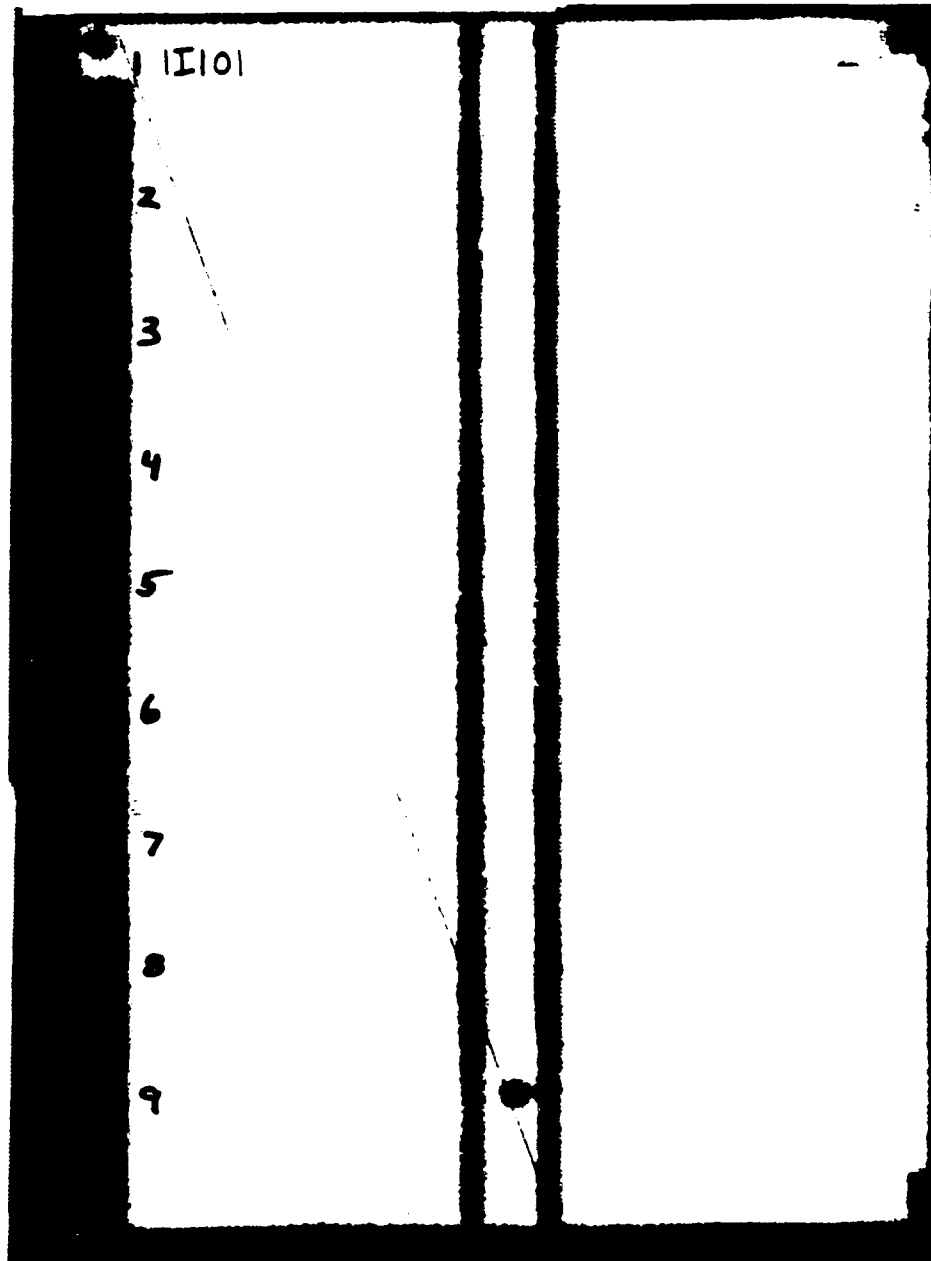


Figure A19. Ultrasonic C-Scan of Lap Shear Panel.

Panel No. 1J101
Alloy 2024T81 Bare
Surface Prep PAA
Primer BR227A
Adhesive FM61

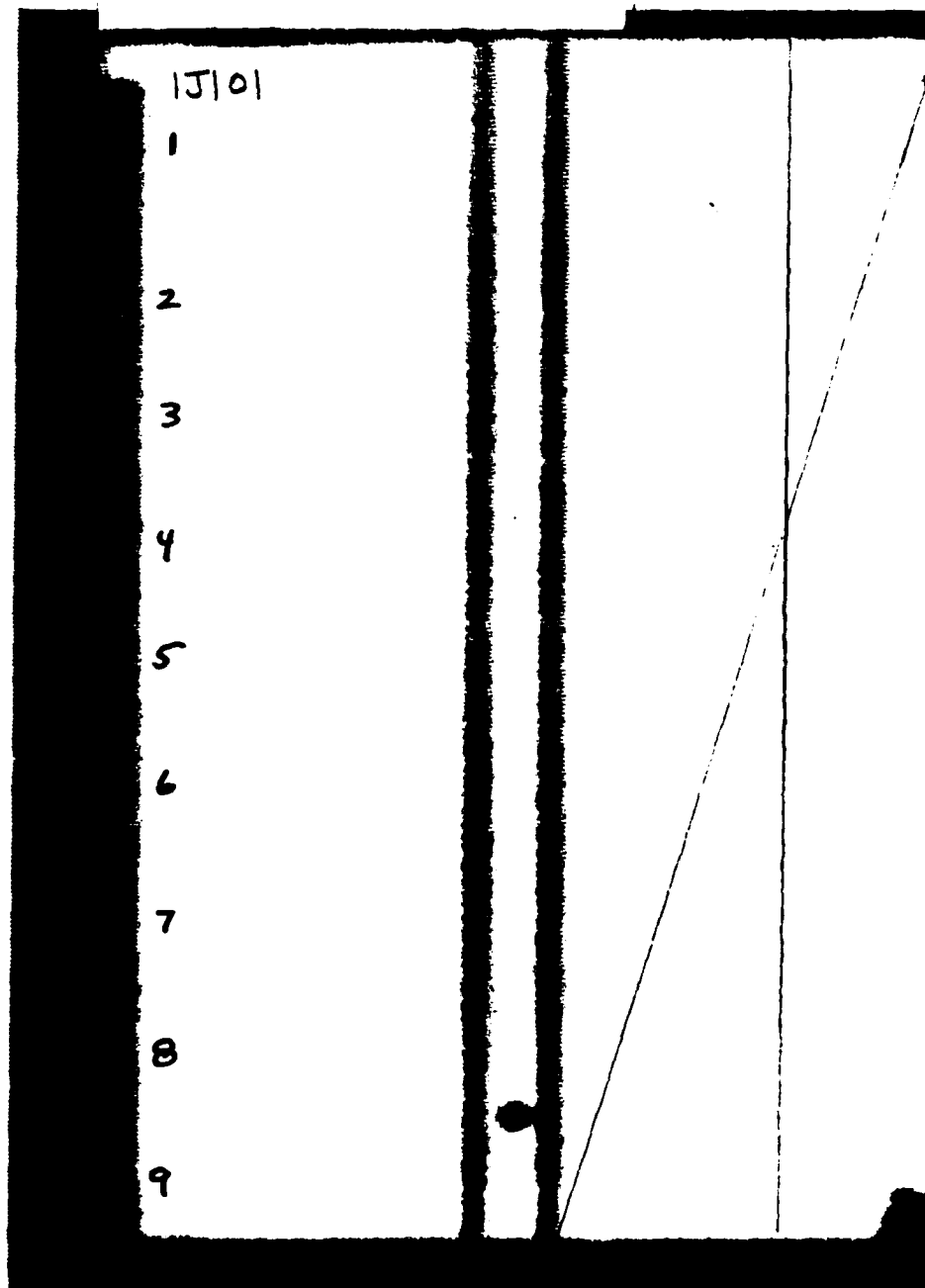


Figure A20. Ultrasonic C-Scan of Lap Shear Panel.

TABLE A3

INDIVIDUAL LAP SHEAR STATIC TEST RESULTS ON 2024-T81 BARE
ALUMINUM WITH OFPL ETCHED SURFACE PREPARATION "RAAB LAP JOINTS"

Adhesive/Primer System	Test Temperature (°F)(°C)	Specimen Number	Ult. Strength		Failure Mode (%)				
			(psi)	(MPa)	M/P	P	P/A	A	V
RB398/RB500	(72)(22)	2A104-1-2	2384	16.44	0	90	0	10	0
		2A104-2-2	2047	14.11	0	100	0	0	0
		2A104-3-2	2095	14.45	0	100	0	0	0
		Avg	2175	15.0	0	97	0	3	0
		Std Dev	182	1.2					
MB329/MB6725-1	(72)(22)	2B104-1-3	2113	14.57	0	10	90	0	0
		2B104-2-3	2044	14.10	0	10	90	0	0
		2B104-3-3	2440	16.82	0	10	80	10	0
		Avg	2199	15.16	0	10	87	3	0
		Std Dev	212	1.45					
FM400/BR400	(72)(22)	2C104-1-3	2276	15.69	0	0	40	50	10
		2C104-2-3	2252	15.52	0	0	40	50	10
		2C104-3-3	2460	16.96	0	0	40	50	10
		Avg	2329	16.06	0	0	40	50	10
		Std Dev	114	0.79					
EA9649/EA9205	(72)(22)	2D104-1-2	2849	19.64	0	90	0	10	0
		2D104-2-1	2422	16.70	0	100	0	0	0
		Avg	2636	18.17	0	95	0	5	0
		Std Dev	302	2.08					
AF130/EC3917	(72)(22)	2E104-1-1	2159	14.89	0	100	0	0	0
		2E104-2-1	1562	10.80	0	100	0	0	0
		2E104-3-2	1362	9.39	0	100	0	0	0
		Avg	1694	11.69	0	100	0	0	0
		Std Dev	415	2.86					
AF21/EC2174	(72)(22)	2F104-1-2	3527	24.32	0	80	0	20	0
		2F104-2-2	3968	27.36	0	90	0	10	0
		2F104-3-3	3988	27.50	0	90	0	10	0
		Avg	3828	26.39	0	87	0	13	0
		Std Dev	261	1.80					

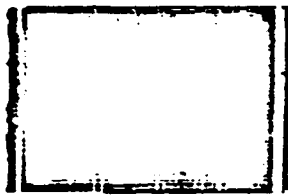
PL729-3/PL728	(72)(22)	2G104-1-2	4008	27.64	0	30	60	10	0
		2G104-2-2	4076	28.10	0	30	60	10	0
		Avg	4042	27.87	0	30	60	10	0
		Std Dev	48	0.33					

HT424/Ht424F	(72)(22)	2H104-1-2	1331	9.18	0	0	0	100	0
		2H104-2-2	778	5.36	0	0	0	100	0
		2H104-3-2	1598	11.02	0	0	0	100	0
		Avg	1236	8.52	0	0	0	100	0
		Std Dev	418	2.89					

FM6 1/BR227	(72)(22)	2I104-1	2781	19.81	0	0	20	80	0
		2I104-2	2682	18.49	0	0	10	90	0
		2I104-3	2620	18.06	0	0	10	90	0
		Avg	2694	18.79	0	0	13	87	0
		Std Dev	81	0.91					

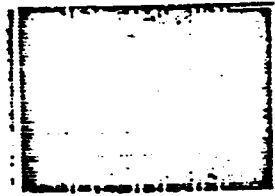
FM6 1/BR227A	(72)(22)	2J104-1	2798	19.29	0	80	0	20	0
		2J104-2	2735	18.86	0	80	0	20	0
		2J104-3	2781	19.18	0	60	0	40	0
		Avg	2771	19.11	0	73	0	27	0
		Std Dev	33	0.22					

(1) Specimen failed between the RAAB lap joint.



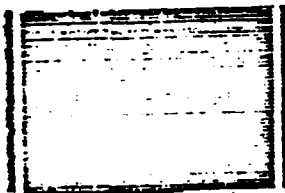
T81B
300
FPL

Panel No. 2A104
Alloy 2024T81 Bare
Surface Prep OFPL
Primer RB500
Adhesive RB398



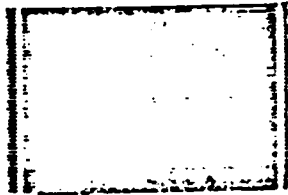
T81B
6725-1
FPL

Panel No. 2B104
Alloy 2024T81 Bare
Surface Prep OFPL
Primer MB6725-1
Adhesive MB329



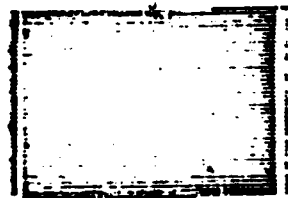
T81B
400
FPL

Panel No. 2C104
Alloy 2024T81
Surface Prep OFPL
Primer BR400
Adhesive FM400



T81B
9205
FPL

Panel No. 2D104
Alloy 2024T81 Bare
Surface Prep OFPL
Primer EA9205
Adhesive EA9649

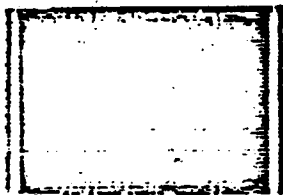


T81B
300
FPL

Panel No. 2E104
Alloy 2024T81 Bare
Surface Prep OFPL
Primer EC3917
Adhesive AF130

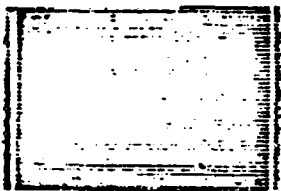
Figure A21. Ultrasonic C-Scans of Lap Shear Panels.

T818
2174
FPL



Panel No. 2F104
Alloy 2024T81 Bare
Surface Prep OFPL
Primer EC2174
Adhesive AF31

T81 S
728
FPL



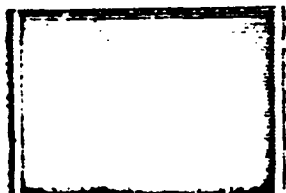
Panel No. 2G104
Alloy 2024T81 Bare
Surface Prep OFPL
Primer PL728
Adhesive PL729-3

T818
421 F
FPL



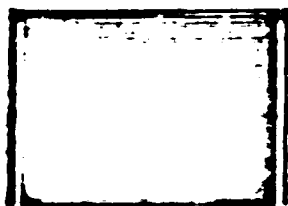
Panel No. 2H104
Alloy 2024T81 Bare
Surface Prep OFPL
Primer HT424F
Adhesive HT424

T818
217
FPL



Panel No. 2I104
Alloy 2024T81 Bare
Surface Prep OFPL
Primer BR227
Adhesive FM61

T818
2174
FPL



Panel No. 2J104
Alloy 2024T81 Bare
Surface Prep OFPL
Primer BR227A
Adhesive RM61

Figure 2.2. Ultrasonic C-Scans of Lap Shear Panels
Panel 2H104 is RAAB Type Used for Lap
Specimens.

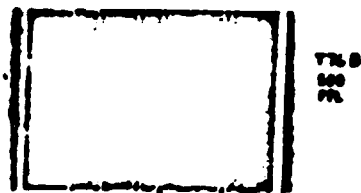
TABLE A4

INDIVIDUAL LAP SHEAR STATIC TEST RESULTS ON 7075-T76 BARE
ALUMINUM WITH OFPL ETCHED SURFACE PREPARATION "RAAB LAP JOINTS"

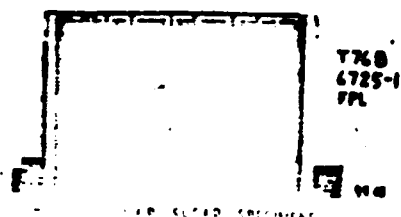
Adhesive/Primer System	Test Temperature (*F)(*C)	Specimen Number	Ult. Strength		Failure Mode (%)				
			(psi)	(MPa)	M/P	P	P/A	A	V
RB398/RB500	(72)(22)	2A604-1-2	2535	17.48	0	30	0	70	0
		2A604-2-2	2209	15.23	0	80	0	20	0
		2A604-3-2	1977	13.63	0	100	0	0	0
		Avg	2240	15.45	0	70	0	30	0
		Std Dev	280	1.9					
MB329/MB6725-1	(72)(22)	2B604-1-3	2147	14.80	0	10	60	30	0
		2B604-2-2	1882	12.98	0	100	0	0	0
		2B604-3-3	1728	11.91	0	10	80	0	10
		Avg	1919	13.23	0	40	47	10	3
		Std Dev	212	1.46					
FM400/BR400	(72)(22)	2C604-1-3	2448	16.88	0	0	20	80	0
		2C604-2-1	2375	16.38	0	0	25	70	5
		2C604-3-2	2204	15.20	0	0	95	0	5
		Avg	2342	16.15	0	0	47	50	3
		Std Dev	125	0.86					
EA9649/EA9205	(72)(22)	2D604-1-1	2801	19.31	0	90	0	10	0
		2D604-2-2	2359	16.27	0	100	0	0	0
		2D604-3-2	2379	16.40	0	100	0	0	0
		Avg	2513	17.33	0	97	0	3	0
		Std Dev	250	1.72					
AF130/EC3917	(72)(22)	2E604-1-1	1932	13.32	0	80	0	20	0
		2E604-2-2	1466	10.11	0	90	0	10	0
		2E604-3-2	1647	11.36	0	100	0	0	0
		Avg	1682	11.60	0	90	0	10	0
		Std Dev	235	1.62					
AF31/EC2174	(72)(22)	2F604-1-3	3725	25.68	0	90	0	10	0
		2F604-2-3	3717	25.63	0	90	0	10	0
		2F604-3-2	3704	25.54	0	90	0	10	0
		Avg	3715	25.62	0	90	0	10	0
		Std Dev	10.4	.07					

PL729-3/PL728	(72)(22)	2G604-1-2	4022	27.73	0	30	60	10	0
		2G604-2-2	4042	27.87	0	30	60	10	0
		2G604-3-2	4167	27.73	0	30	60	10	0
		Avg	4077	27.78	0	30	60	10	0
		Std Dev	79	0.08					
HT424/HT424F	(72)(22)	2H604-1-2	1505	10.38	0	0	30	70	0
		2H604-2-2	439	3.03	0	0	10	90	0
		2H604-3-2	295	2.03	0	0	0	100	0
		Avg	746	5.15	0	0	13	87	0
		Std Dev	661	4.56					
FM61/BR227	(72)(22)	2I604-1	2820	19.44	0	0	10	90	0
		2I604-2	2668	18.40	0	0	80	20	0
		2I604-3	2754	18.99	0	0	50	30	20
		Avg	2747	18.94	0	0	46	47	7
		Std Dev	76	0.52					
FM61/BR227A	(72)(22)	2J604-1	2764	19.06	0	90	0	10	0
		2J604-2	2737	18.87	0	90	0	10	0
		2J604-3	2933	20.22	0	90	0	10	0
		Avg	2811	19.38	0	90	0	10	0
		Std Dev	106	0.73					

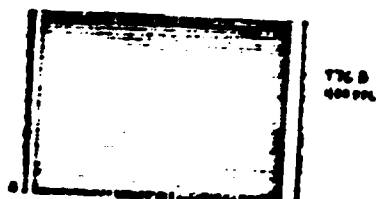
(1) Specimen failed between the RAAB lap joints.



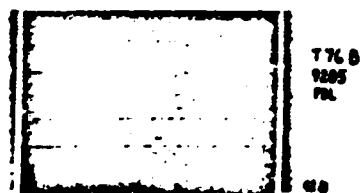
Panel No. 2A604
 Alloy 7075T76 Bare
 Surface Prep OFPL
 Primer RB500
 Adhesive RB398



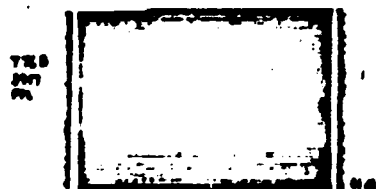
Panel No. 2B604
 Alloy 7075T76 Bare
 Surface Prep OFPL
 Primer MB6725-1
 Adhesive MB329



Panel No. 2C604
 Alloy 7075T76 Bare
 Surface Prep OFPL
 Primer BR400
 Adhesive FM400

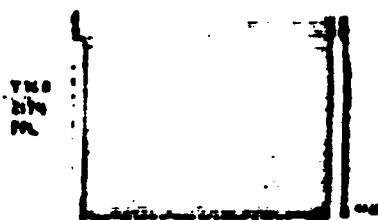


Panel No. 2D604
 Alloy 7075T76 Bare
 Surface Prep OFPL
 Primer EA9205
 Adhesive EA9649

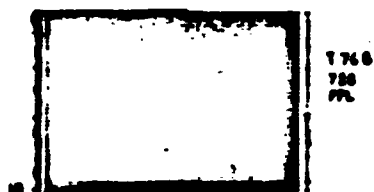


Panel No. 2E604
 Alloy 7075T76 Bare
 Surface Prep OFPL
 Primer EC3917
 Adhesive AF130

Figure A23. Ultrasonic C-Scans of Lap Shear Panels.



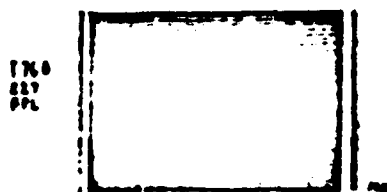
Panel No. 2F604
 Alloy 7075T76 Bare
 Surface Prep OFPL
 Primer EC2174
 Adhesive AF31



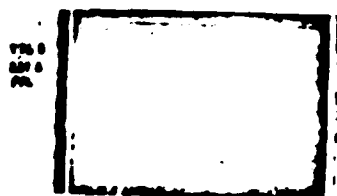
Panel No. 2G604
 Alloy 7075T76 Bare
 Surface Prep OFPL
 Primer PL728
 Adhesive PL729-3



Panel No. 2H604
 Alloy 7075T76 Bare
 Surface Prep OFPL
 Primer HT424F
 Adhesive HT424



Panel No. 2I604
 Alloy 7075T76 Bare
 Surface Prep OFPL
 Primer BR227
 Adhesive FM61



Panel No. 2J604
 Alloy 7075T76
 Surface Prep OFPL
 Primer BR227A
 Adhesive FM61

Figure A24. Ultrasonic C-Scans of Lap Shear Panels
 (Panel 2H104 a RAAR Type Used for Lap
 Shear Specimens).

APPENDIX B

INDIVIDUAL SPECIMEN PEEL TEST RESULTS AND ULTRASONIC C-SCAN INSPECTION RESULTS OF PANELS USED FOR PEEL SPECIMENS

Tables B1 through B4 present the results obtained for each individual peel specimen tested during this program. These data are summarized in both tabular and graphical form in Section 3.2. In addition to the peel test data, the ultrasonically generated c-scans for each panel are presented in Figures B1 through B8 . All of these c-scans were supplied with the panels by Douglas Aircraft. These figures are arranged so that they correspond to the data in the preceding table (Figures B1 and B2 correspond to Table B1 for example).

TABLE B1

**INDIVIDUAL PEEL STRENGTH RESULTS ON 2024-T81 BARE
ALUMINUM WITH PAA ETCHED SURFACE PREPARATION**

Adhesive/Primer System	Test Temperature °F (°C)	Specimen Number	Peel Strength		Failure Mode (%)				
			lbs/in width	N/cm of width	M/P	P	P/A	A	V
RB390/RB500	-65(-54)	1A103-2	4.1	7.2	0	90	0	0	10
		1A103-3	3.1	5.4	0	90	0	0	10
		1A103-4	2.8	4.9	0	90	0	0	10
		Avg	3.3	5.8	0	90	0	0	10
		Std Dev	0.7	1.2					
MB329/MB6725-1	-65(-54)	1B103-2	2.3	4.0	0	100	0	0	0
		1B103-3	3.1	5.4	0	95	0	0	5
		1B103-4	2.6	4.6	0	90	0	0	10
		Avg	2.7	4.7	0	95	0	0	5
		Std Dev	0.4	0.7					
FM400/BM400	-65(-54)	1C103-2	2.7	4.7	0	95	0	0	5
		1C103-3	2.6	4.6	0	95	0	0	5
		1C103-4	2.4	4.2	0	95	0	0	5
		Avg	2.6	4.5	0	95	0	0	5
		Std Dev	0.2	0.3					
EA9649/EA9205	-65(-54)	1D103-2	3.6	6.3	0	100	0	0	0
		1D103-3	3.5	6.1	0	100	0	0	0
		1D103-4	3.6	6.3	0	100	0	0	0
		Avg	3.6	6.2	0	100	0	0	0
		Std Dev	0.1	0.1					
AF130/EC3917	-65(-54)	1E103-2	3.7	6.5	0	95	0	0	5
		1E103-3	3.9	6.8	0	95	0	0	5
		1E103-4	2.9	5.1	0	90	0	0	10
		Avg	3.5	6.2	0	93	0	0	7
		Std Dev	0.6	1.0					
AF311/EC2174	-65(-54)	1F103-2	2.8	4.9	0	100	0	0	0
		1F103-3	2.6	4.6	0	100	0	0	0
		1F103-4	2.7	4.7	0	100	0	0	0
		Avg	2.7	4.7	0	100	0	0	0
		Std Dev	0.1	0.2	0	100	0	0	0

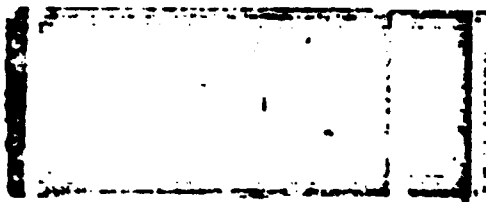
PL729-3/PL728	-65(-54)	1G103-2	2.8	4.9	0	100	0	0	0
		1G103-3	2.9	5.1	0	100	0	0	0
		1G103-4	2.7	4.7	0	100	0	0	0
		Avg	2.8	4.9	0	100	0	0	0
		Std Dev	0.1	0.2					

HT424/HT424F	---	---	---	---	---	---	---	---	---
--------------	-----	-----	-----	-----	-----	-----	-----	-----	-----

PM6 1/BR227	-65(-54)	1I103-2	2.7	4.7	0	100	0	0	0
		1I103-3	2.2	3.9	0	100	0	0	0
		1I103-4	2.2	3.9	0	100	0	0	0
		Avg	2.4	4.2	0	100	0	0	0
		Std Dev	0.3	0.5					

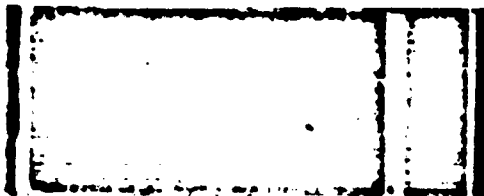
PM6 1/BR227A	-65(-54)	1J103-2	3.2	5.6	0	50	50	0	0
		1J103-3	3.1	5.4	0	60	40	0	0
		1J103-4	3.7	6.5	0	50	50	0	0
		Avg	3.3	5.8	0	53	47	0	0
		Std Dev	0.3	0.6					

(1) Specimens not submitted for test



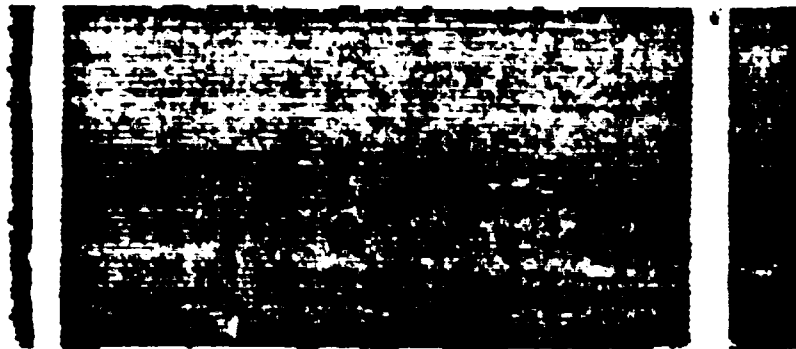
T81 B
MB398
PAA

Panel No. 1A103
Alloy 2024T81 Bare
Surface Prep PAA
Primer RB500
Adhesive RB398



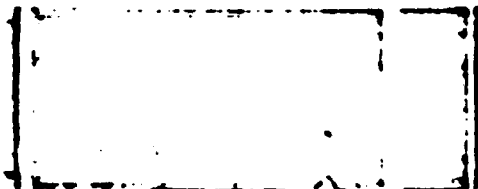
T81 B
MB6725-1
PAA

Panel No. 1B103
Alloy 2024T81 Bare
Surface Prep PAA
Primer MB6725-1
Adhesive MB329



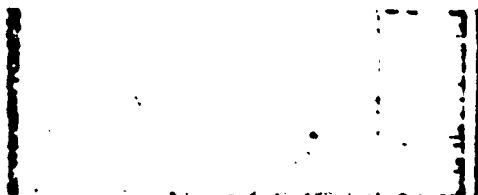
T81 B
BR400
B.P.
PAA

Panel No. 1C103
Alloy 2024T81 Bare
Surface Prep PAA
Primer BR400
Adhesive FM400



T81 B
EA9205
PAA

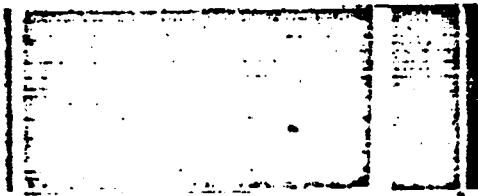
Panel No. 1D103
Alloy 2024T81 Bare
Surface Prep PAA
Primer EA9205
Adhesive EA9649



T81 B
EC3917
PAA

Panel No. 1E103
Alloy 2024T81 Bare
Surface Prep PAA
Primer EC3917
Adhesive AF130

Figure B1. Ultrasonic C-Scans of Peel Panels.



TB 8
EC 2174
PAA

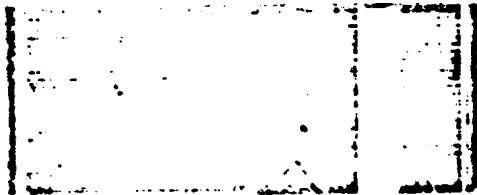
Panel No. 1F103

Alloy 2024T81 Bare

Surface Prep PAA

Primer EC2174

Adhesive AF31



TB 8
PL 728
PAA

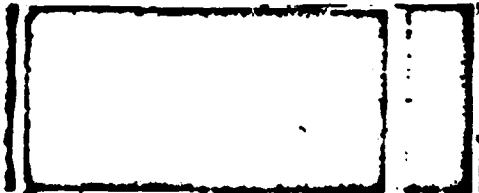
Panel No. 1G103

Alloy 2024T81 Bare

Surface Prep PAA

Primer PL728

Adhesive PL729-3



TB 8
BR 227
PAA

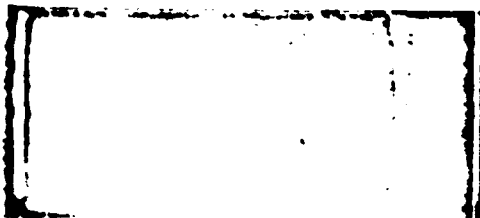
Panel No. 1I103

Alloy 2024T81 Bare

Surface Prep PAA

Primer BR227

Adhesive FM61



TB 8
BR 227 A
PAA

Panel No.: 1J103

Alloy: 2024T81 Bare

Surface Prep: PAA

Primer: BR227A

Adhesive: FM61

Figure B2. Ultrasonic C-Scans of Peel Panels.

TABLE B2

INDIVIDUAL PEEL STRENGTH RESULTS ON 7075-T76 BARE
ALUMINUM WITH PAA ETCHED SURFACE PREPARATION

Adhesive/Primer System	Test Temperature °F (°C)	Specimen Number	Peel Strength		Failure Mode (%)				
			lbs/in width	N/cm of width	M/P	P	P/A	A	V
RB398/RB500	-65(-54)	1A603-2	3.3	5.8	0	90	0	0	10
		1A603-3	2.8	4.9	0	90	0	0	10
		1A603-4	2.8	4.9	0	90	0	0	10
		Avg	3.0	5.2	0	90	0	0	10
		Std Dev	0.3	0.5					
MB329/MB6725-1	-65(-54)	1B603-2	2.5	4.4	0	100	0	0	0
		1B603-3	2.5	4.4	0	95	0	0	5
		1B603-4	3.2	5.6	0	90	0	0	10
		Avg	2.7	4.8	0	95	0	0	5
		Std Dev	0.4	0.7					
FM400/BR400	-65(-54)	1C603-2	4.2	7.4	0	90	0	0	10
		1C603-3	3.2	5.6	0	95	0	0	5
		1C603-3	3.6	6.3	0	90	0	0	10
		Avg	3.7	6.4	0	92	0	0	8
		Std Dev	0.5	0.9					
EA9649/EA9205	-65(-54)	1D603-2	3.4	6.0	0	100	0	0	0
		1D603-3	3.7	6.5	0	100	0	0	0
		1D603-4	3.4	6.0	0	100	0	0	0
		Avg	3.5	6.2	0	100	0	0	0
		Std Dev	0.2	0.3					
AF130/EC3917	-65(-54)	1E603-2	3.3	5.8	0	95	0	0	5
		1E603-3	3.4	6.0	0	90	0	0	10
		1E603-4	3.4	6.0	0	90	0	0	5
		Avg	3.4	6.0	0	93	0	0	7
		Std Dev	0.1	0.1					
AF31/EC2174	-65(-54)	1F603-2	2.3	4.0	0	100	0	0	0
		1F603-3	2.3	4.0	0	100	0	0	0
		1F603-4	2.0	3.5	0	100	0	0	0
		Avg	2.2	3.8	0	100	0	0	0
		Std Dev	0.2	0.3					

PL729-3/PL728	-65(-54)	1G603-2	4.4	7.7	0	100	0	0	0
		1G603-3	4.4	7.7	0	100	0	0	0
		1G603-4	3.8	6.7	0	100	0	0	0
		Avg	4.2	7.4	0	100	0	0	0
		Std Dev	0.4	0.6					

HT424/HT424F	---	---	---	---	---	---	---	---	---
--------------	-----	-----	-----	-----	-----	-----	-----	-----	-----

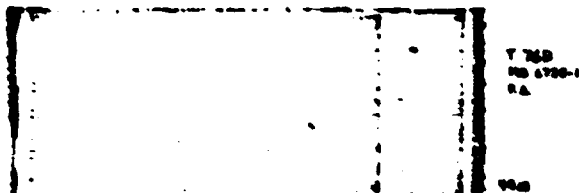
FM6 1/BR227	-65(-54)	1I603-2	4.3	7.5	0	100	0	0	0
		1I603-3	3.8	6.7	0	100	0	0	0
		1I603-4	4.3	7.5	0	100	0	0	0
		Avg	4.1	7.2	0	100	0	0	0
		Std Dev	0.3	0.5					

FM-61/BR227A	-65(-54)	1J603-2	2.7	4.7	0	90	10	0	0
		1J603-3	5.3	9.3	0	50	50	0	0
		1J603-4	5.3	9.3	0	40	60	0	0
		Avg	4.4	7.8	0	60	40	0	0
		Std Dev	1.5	2.7					

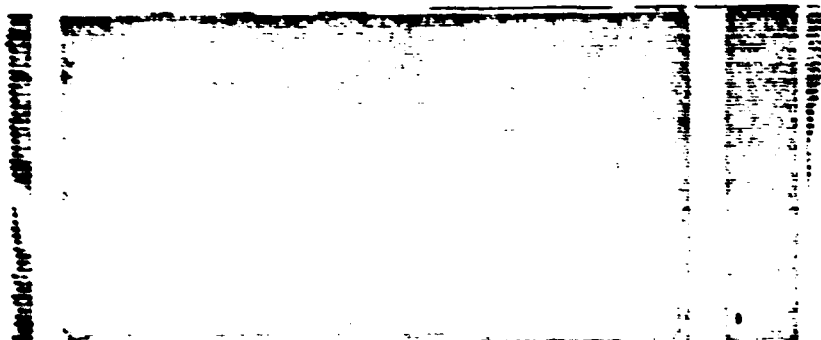
(1) Specimens not submitted for test.



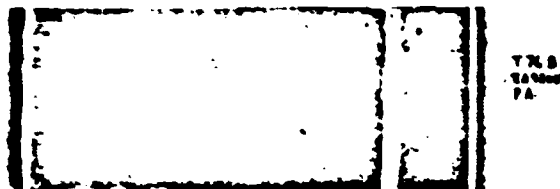
Panel No. 1A603
 Alloy 7075T76 Bare
 Surface Prep PAA
 Primer RB500
 Adhesive RB398



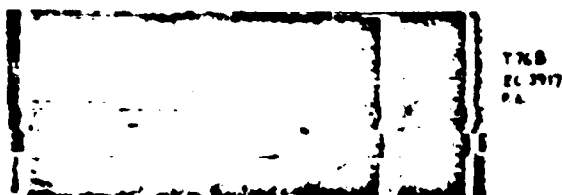
Panel No. 1B603
 Alloy 7075T76 Bare
 Surface Prep PAA
 Primer MB6725-1
 Adhesive MB329



Panel No. 1C603
 Alloy 7075T76 Bare
 Surface Prep PAA
 Primer BR400
 Adhesive FM400

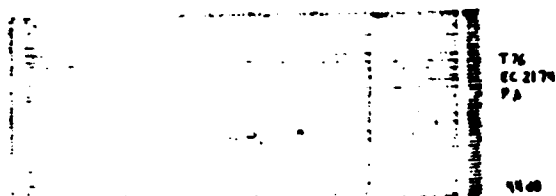


Panel No. 1D603
 Alloy 7075T76
 Surface Prep PAA
 Primer EA9205
 Adhesive EA9649

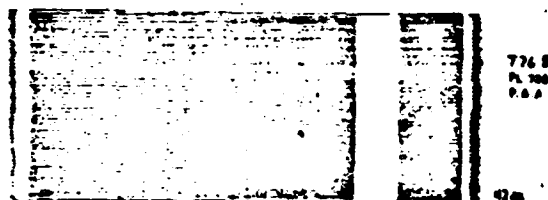


Panel No. 1E603
 Alloy 7075T76 Bare
 Surface Prep PAA
 Primer EC3917
 Adhesive AF130

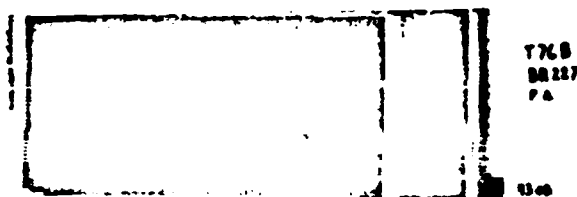
Figure B3. Ultrasonic C-Scans of Peel Panels.



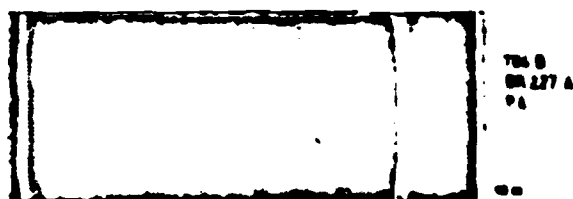
Panel No. 1F603
 Alloy 7075T76 Bare
 Surface Prep PAA
 Primer EC2174
 Adhesive AF31



Panel No. 1G603
 Alloy 7075T76 Bare
 Surface Prep PAA
 Primer PL728
 Adhesive PL729-3



Panel No. 1I603
 Alloy 7075T76 Bare
 Surface Prep PAA
 Primer BR227
 Adhesive FM61



Panel No. 1J603
 Alloy 7075T76 Bare
 Surface Prep PAA
 Primer BR227
 Adhesive FM61

Figure B4. Ultrasonic

AD-A181 241

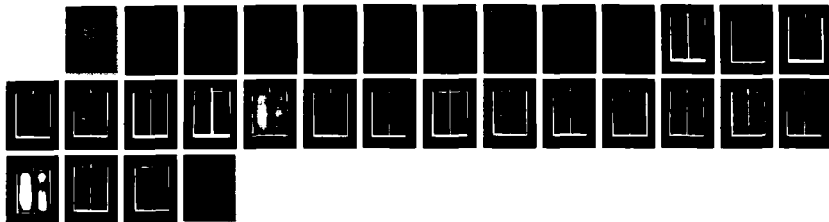
EVALUATION OF 350F CURING ADHESIVE SYSTEMS ON
PHOSPHORIC ACID ANODIZED AL. (U) DAYTON UNIV OH
RESEARCH INST D R ASKINS ET AL. AUG 86 UDR-TR-85-120
AFMNL-TR-86-4039 F33615-84-C-5130

2/2

UNCLASSIFIED

F/G 11/1

NL



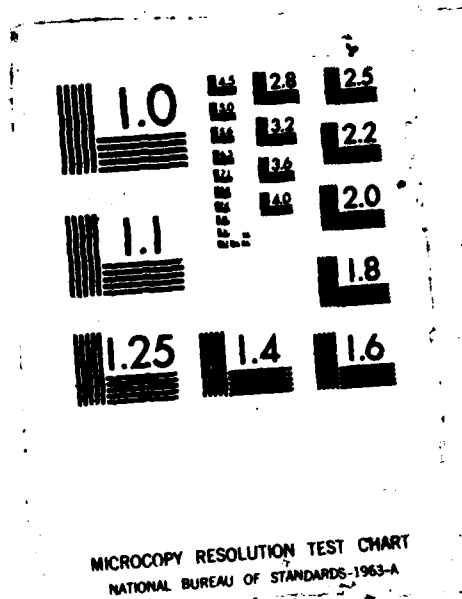


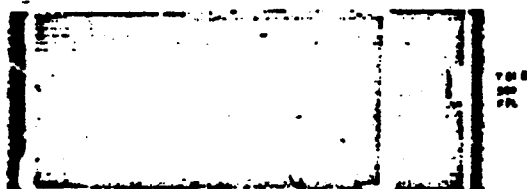
TABLE B3

**INDIVIDUAL PEEL STRENGTH RESULTS ON 2024-T81 BARE
ALUMINUM WITH OFPL ETCHED SURFACE PREPARATION**

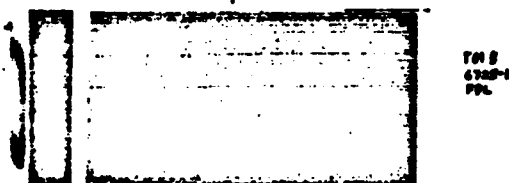
Adhesive/Primer System	Test Temperature °F (°C)	Specimen Number	Peel Strength		Failure Mode (%)				
			lbs/in width	N/cm of width	M/P	P	P/A	A	V
RB398/RB500	-65(-54)	2A103-1	4.1	7.2	0	100	0	0	0
		2A103-2	3.2	5.6	0	100	0	0	0
		2A103-3	3.2	5.6	0	100	0	0	0
		Avg	3.5	6.1	0	100	0	0	0
		Std Dev	0.5	1.0					
MB329/MB6725-1	-65(-54)	2B103-1	2.6	4.6	0	95	0	0	5
		2B103-2	3.2	5.6	0	95	0	0	5
		2B103-3	3.5	6.1	0	95	0	0	5
		Avg	3.1	5.4	0	95	0	0	5
		Std Dev	0.5	0.8					
FM400/BR400	-65(-54)	2C103-1	4.0	7.0	0	85	0	10	5
		2C103-2	3.5	6.1	0	85	0	10	5
		2C103-3	3.3	5.8	0	85	0	10	5
		Avg	3.6	6.3	0	85	0	10	5
		Std Dev	0.4	0.6					
EA9649/EA9205	-65(-54)	2D103-1	3.1	5.4	0	100	0	0	0
		2D103-2	3.0	5.3	0	100	0	0	0
		2D103-3	3.6	6.3	0	100	0	0	0
		Avg	3.2	5.6	0	100	0	0	0
		Std Dev	0.3	0.6					
AF130/EC3917 ¹	---	---	---	---	---	---	---	---	---
AF31/EC2174	-65(-54)	2F103-1	2.4	4.2	0	100	0	0	0
		2F103-2	3.0	5.3	0	100	0	0	0
		2F103-3	3.7	6.5	0	100	0	0	0
		Avg	2.5	4.5	0	100	0	0	0
		Std Dev	0.4	0.7					

PL729-3/PL728	-65(-54)	2G103-1	4.1	7.0	0	100	0	0	0
		2G103-2	3.6	6.3	0	100	0	0	0
		2G103-3	3.7	6.5	0	100	0	0	0
		Avg	3.8	6.6	0	100	0	0	0
		Std Dev	0.2	0.4					
HT424/HT424F	-65(-54)	2H103-1	18.8	32.9	0	0	30	70	0
		2H103-2	14.9	26.1	0	0	30	70	0
		2H103-3	11.9	20.8	0	0	30	70	0
		Avg	15.2	26.6	0	0	30	70	0
		Std Dev	3.5	6.1					
FM6 1/BR227	-65(-54)	2I103-1	5.9	10.3	0	0	90	10	0
		2I103-2	5.2	9.1	0	0	80	20	0
		2I103-3	7.7	13.5	0	0	20	80	0
		Avg	6.3	11.0	0	0	63	37	0
		Std Dev	1.3	2.3					
FM6 1/BR227A	-65(-54)	2J103-1	6.6	11.6	0	0	25	75	0
		2J103-2	6.6	11.6	0	0	0	100	0
		2J103-3	7.3	12.8	0	0	0	100	0
		Avg	6.8	12.0	0	0	8	92	0
		Std Dev	0.4	0.7					

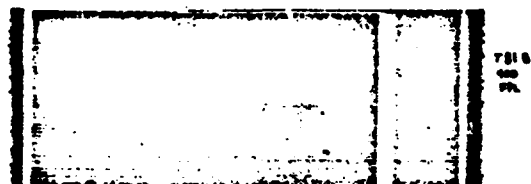
(1)Specimens not submitted for test.



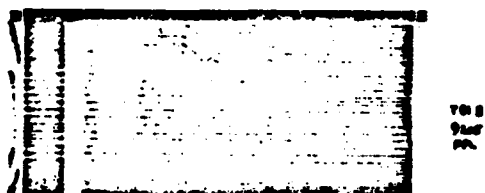
Panel No. 2A103
 Alloy 2024T81 Bare
 Surface Prep OFPL
 Primer RB500
 Adhesive RB398



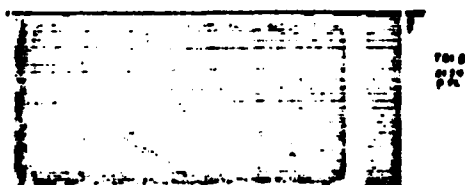
Panel No. 2B103
 Alloy 2024T81 Bare
 Surface Prep OFPL
 Primer MB6725-I
 Adhesive MB329



Panel No. 2C103
 Alloy 2024T81 Bare
 Surface Prep OFPL
 Primer BR400
 Adhesive FM400

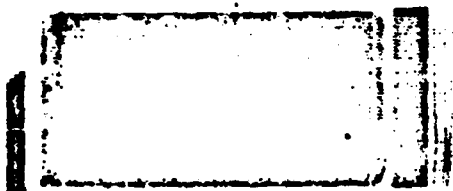


Panel No. 2D103
 Alloy 2024T81 Bare
 Surface Prep OFPL
 Primer EA9205
 Adhesive EA9649

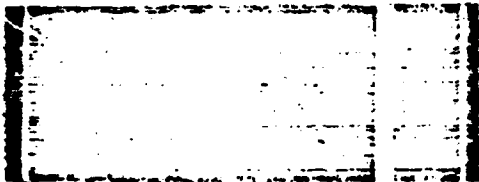


Panel No. 2E103
 Alloy 2024T81 Bare
 Surface Prep OFPL
 Primer EC2174
 Adhesive AF31

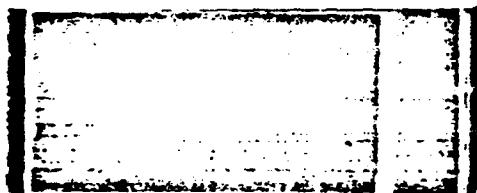
Figure B5. Ultrasonic C-Scans of Peel Panels.



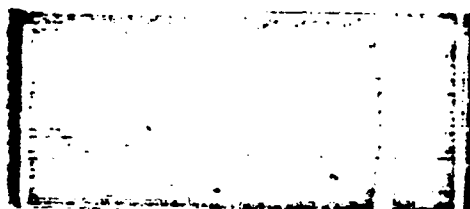
Panel No. 2F103
 Alloy 2024T81 Bare
 Surface Prep OFPL
 Primer PL728
 Adhesive PL729-3



Panel No. 2G103
 Alloy 2024T81 Bare
 Surface Prep OFPL
 Primer HT424F
 Adhesive HT424



Panel No. 2H103
 Alloy 2024T81 Bare
 Surface Prep OFPL
 Primer BR227
 Adhesive FM61



Panel No. 2I103
 Alloy 2024T81 Bare
 Surface Prep OFPL
 Primer BR227A
 Adhesive FM61

Figure B6. Ultrasonic C-Scans of Peel Panels.

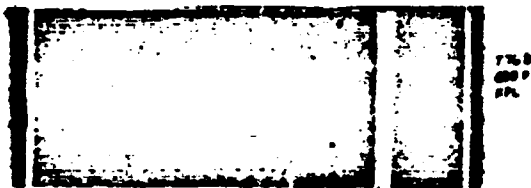
TABLE B4

**INDIVIDUAL PEEL STRENGTH RESULTS ON 7075-T76 BARE
ALUMINUM WITH OFPL ETCHED SURFACE PREPARATION**

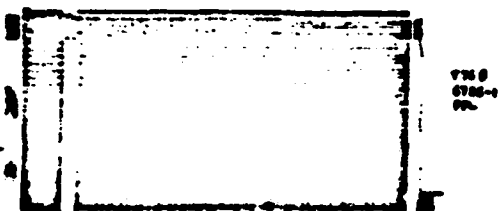
Adhesive/Primer System	Test Temperature °F (°C)	Specimen Number	Peel Strength		Failure Mode (%)				
			lbs/in width	N/cm of width	M/P	P	P/A	A	V
RB398/RB500	-65(-54)	2A603-1	3.6	6.3	0	100	0	0	0
		2A603-2	2.4	4.2	0	100	0	0	0
		2A603-3	2.4	4.2	0	100	0	0	0
		Avg	2.8	4.9	0	100	0	0	0
		Std Dev	0.7	1.2					
MB329/MB6725-1	-65(-54)	2B603-1	2.4	4.2	0	85	0	0	15
		2B603-2	3.9	6.8	0	90	0	0	10
		2B603-3	5.2	9.1	0	90	0	0	10
		Avg	3.8	6.7	0	90	0	0	10
		Std Dev	1.4	2.5					
FM400/BR400 ¹	---	---	---	---	---	---	---	---	---
EA9649/EA9205	-65(-54)	2D603-1	3.2	5.6	0	100	0	0	0
		2D603-2	3.5	6.1	0	100	0	0	0
		2D603-3	3.2	5.6	0	100	0	0	0
		Avg	3.3	5.7	0	100	0	0	0
		Std Dev	0.2	0.3					
AF130/EC3917 ¹	---	---	---	---	---	---	---	---	---
AF31/EC2174 ¹	---	---	---	---	---	---	---	---	---
PL729-3/PL728 ¹	---	---	---	---	---	---	---	---	---

HT424/HT424-F	-65(-54)	2H603-1	16.8	29.4	0	0	30	70	0
		2H603-2	13.6	23.8	0	0	30	70	0
		2H603-3	9.8	17.2	0	0	30	70	0
		Avg	13.4	23.5	0	0	30	70	0
		Std Dev	3.5	6.1					
FM6 1/BR227	-65(-54)	2I603-1	4.1	7.2	0	0	80	20	0
		2I603-2	2.9	5.1	0	0	80	20	0
		2I603-3	3.9	6.8	0	0	80	20	0
		Avg	3.6	6.4	0	0	80	20	0
		Std Dev	0.6	1.1					
FM6 1/BR22A	-65(-54)	2J603-1	6.8	11.9	0	0	50	50	0
		2J603-2	7.2	12.6					
		2J603-3	7.6	13.3	0	0	40	60	0
		Avg	7.2	12.6	0	0	33	67	0
		Std Dev	0.4	0.7					

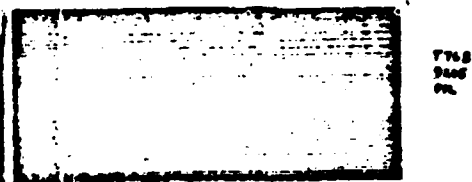
(1) Specimens not submitted for test.



Panel No. 2A603
 Alloy 7075T76 Bare
 Surface Prep OFPL
 Primer RB500
 Adhesive RB398

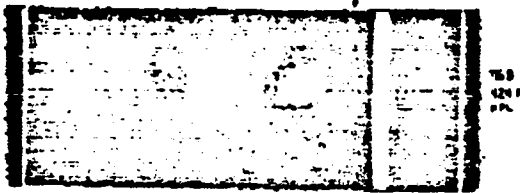


Panel No. 2B603
 Alloy 7075T76 Bare
 Surface Prep OFPL
 Primer MB6725-1
 Adhesive MB329

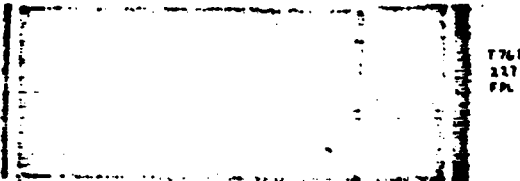


Panel No. 2D 603
 Alloy 7075T76 Bare
 Surface Prep OFPL
 Primer BR400
 Adhesive BR400

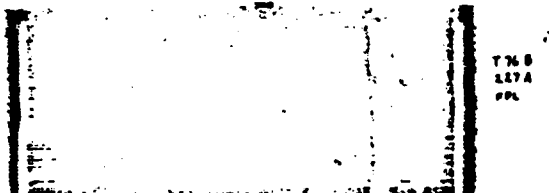
Figure B7. Ultrasonic C-Scans of Peel Panels



Panel No. 2H603
 Alloy 7075T76 Bare
 Surface Prep OFPL
 Primer HT424F
 Adhesive HT424



Panel No. 2I603
 Alloy 7075T76 Bare
 Surface Prep OFPL
 Primer BR227
 Adhesive FM61



Panel No. 2J603
 Alloy 7075T76 Bare
 Surface Prep OFPL
 Primer BR227
 Adhesive FM61

Figure B8. Ultrasonic C-Scans of Peel Panels.

APPENDIX C

ULTRASONIC C-SCAN INSPECTION RESULTS OF PANELS USED FOR STRESS-DURABILITY TESTS

Figures C1-C20 present the ultrasonically generated C-scans for each panel used for stress-durability testing. The C-scans were generated at AFWAL/MLSE before the panels were slotted into the RAAB configuration. Three specimens (each containing four test joints) were machined from each panel. Two were used for the humidity exposed stress-durability test and one for the salt-spray exposed stress-durability tests.

Panel No. _____
Alloy 2024T81 Bare
Surface Prep PAA
Primer RB500
Adhesive RB398

Panel No. _____
Alloy 7075T76 Bare
Surface Prep PAA
Primer RB500
Adhesive RB398

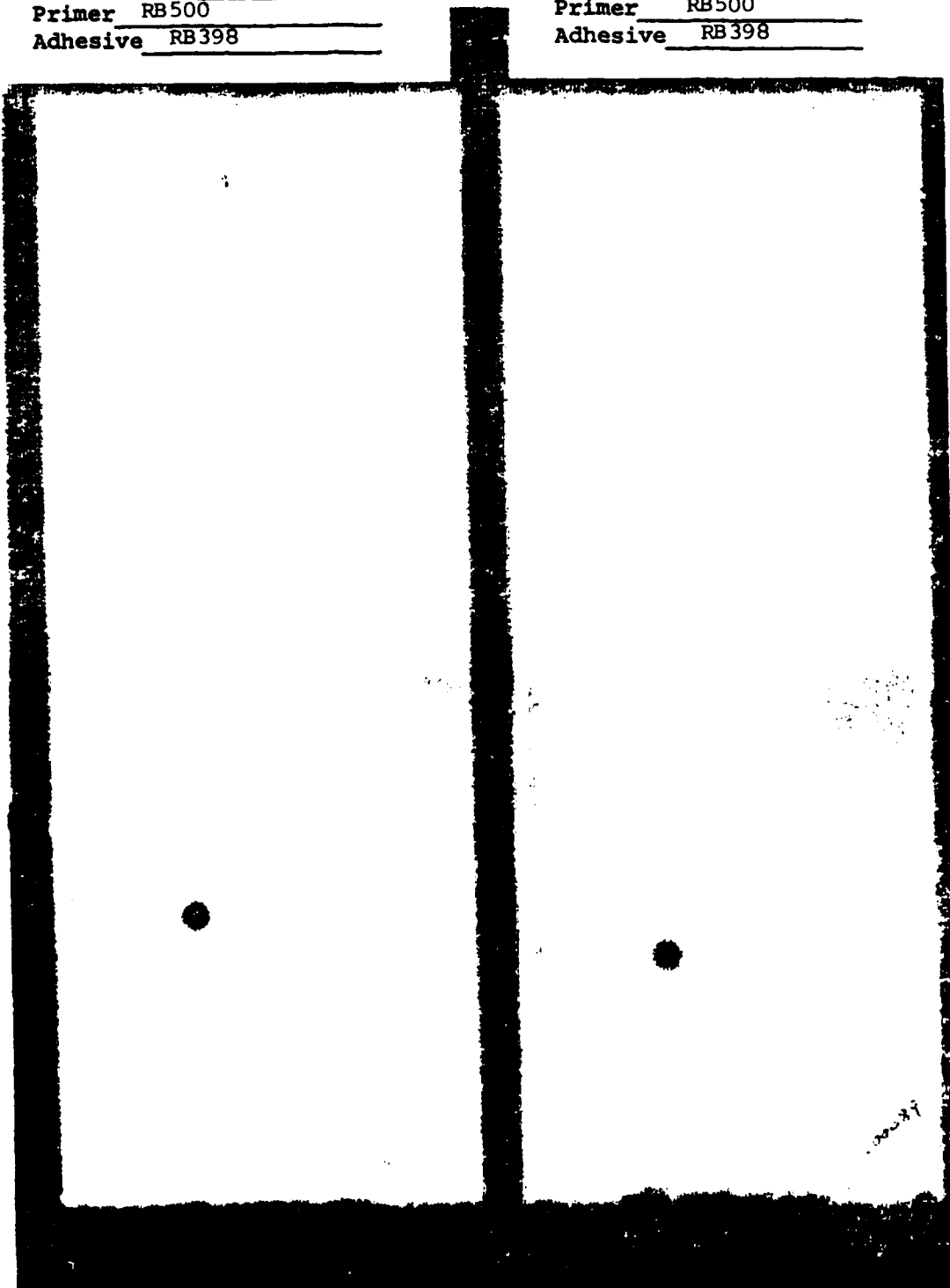


Figure C1. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No. _____
Alloy 2024T81 Bare
Surface Prep PAA
Primer MB6725-1
Adhesive MB329

Panel No. _____
Alloy 7075T76 Bare
Surface Prep PAA
Primer MB6725-1
Adhesive MB329

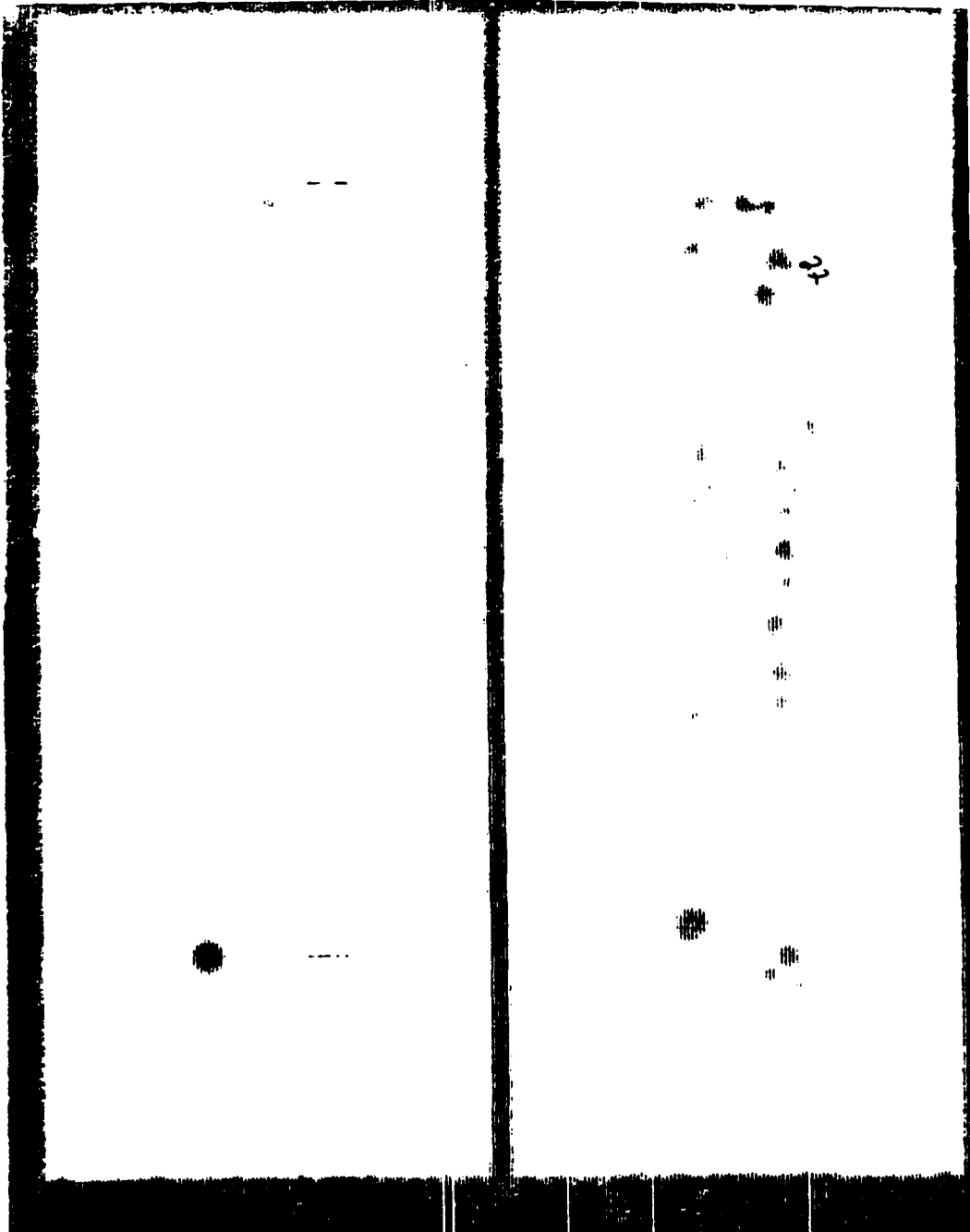


Figure C2. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No. _____
Alloy 2024T81 Bare
Surface Prep PAA
Primer 3R400
Adhesive FM400

Panel No. _____
Alloy 7075T76 Bare
Surface Prep PAA
Primer BR400
Adhesive FM400

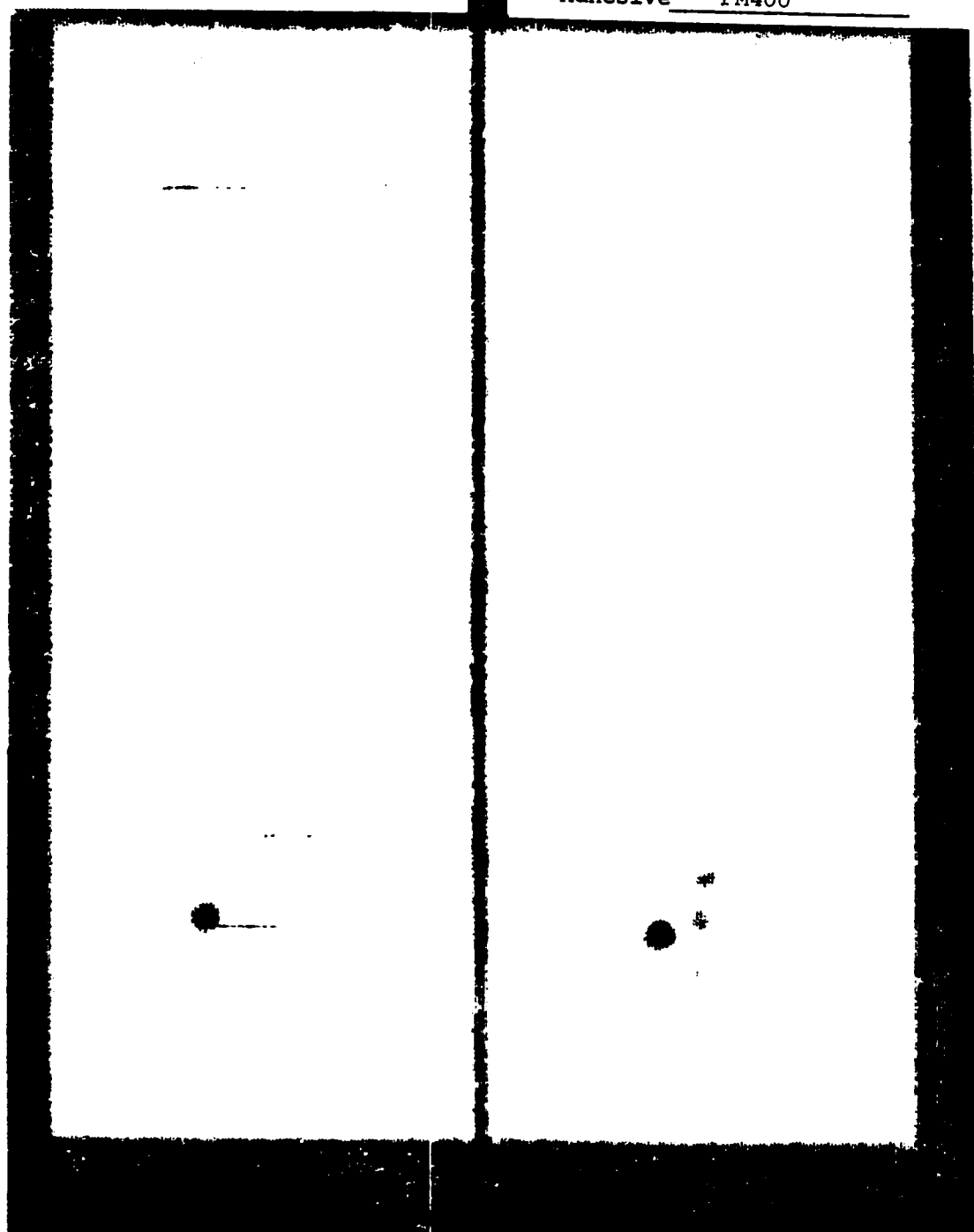


Figure C3. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No. _____
Alloy 2024T76 Bare
Surface Prep PAA
Primer EA9205
Adhesive EA9649

Panel No. _____
Alloy 7075T76 Bare
Surface Prep PAA
Primer EA9205
Adhesive EA9649

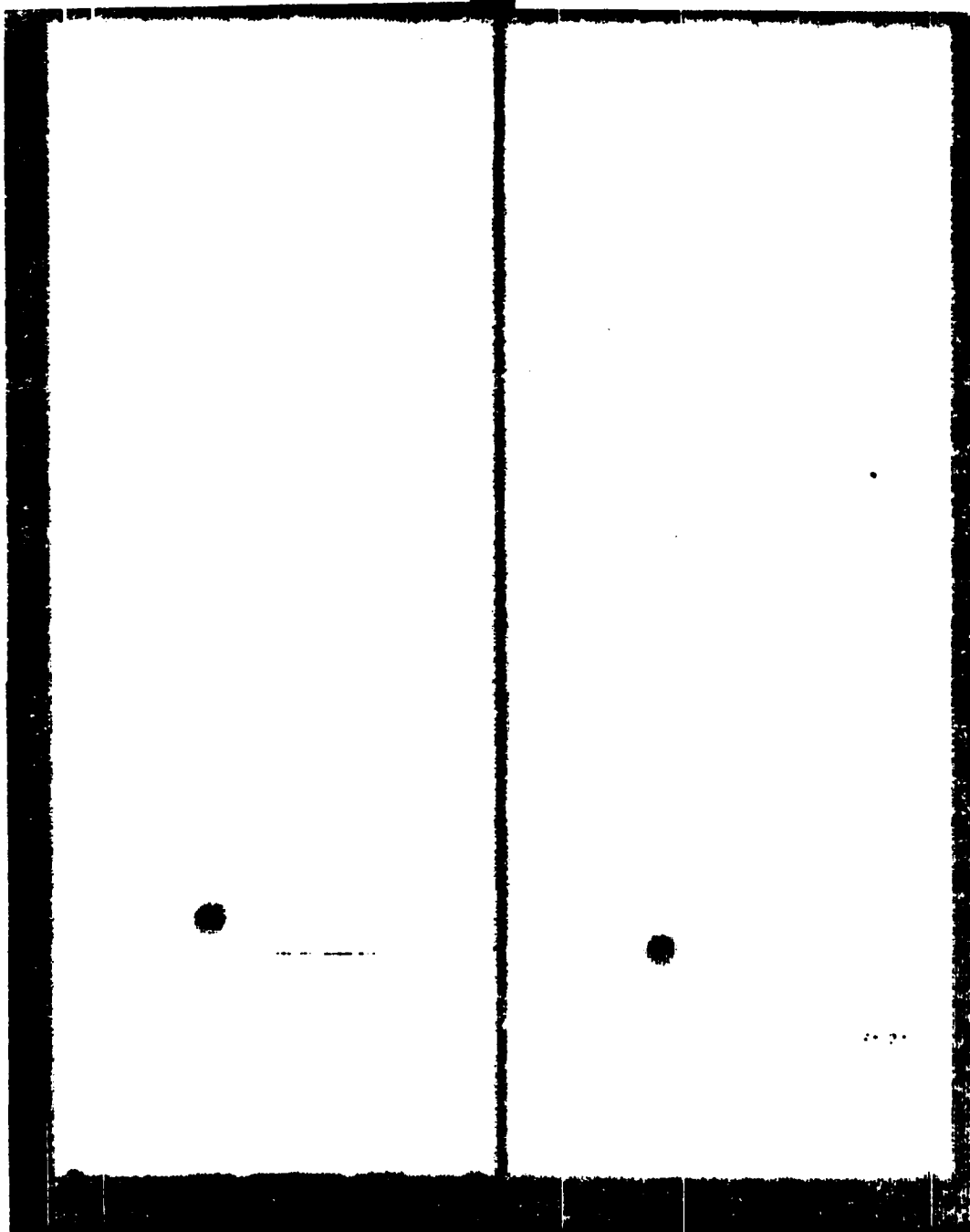


Figure C4. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No.: _____
Alloy: 2024T81 Bare
Surface Prep: PAA
Primer: EC3917
Adhesive: AF130

Panel No. _____
Alloy 7075T76 Bare
Surface Prep PAA
Primer EC3917
Adhesive AF130

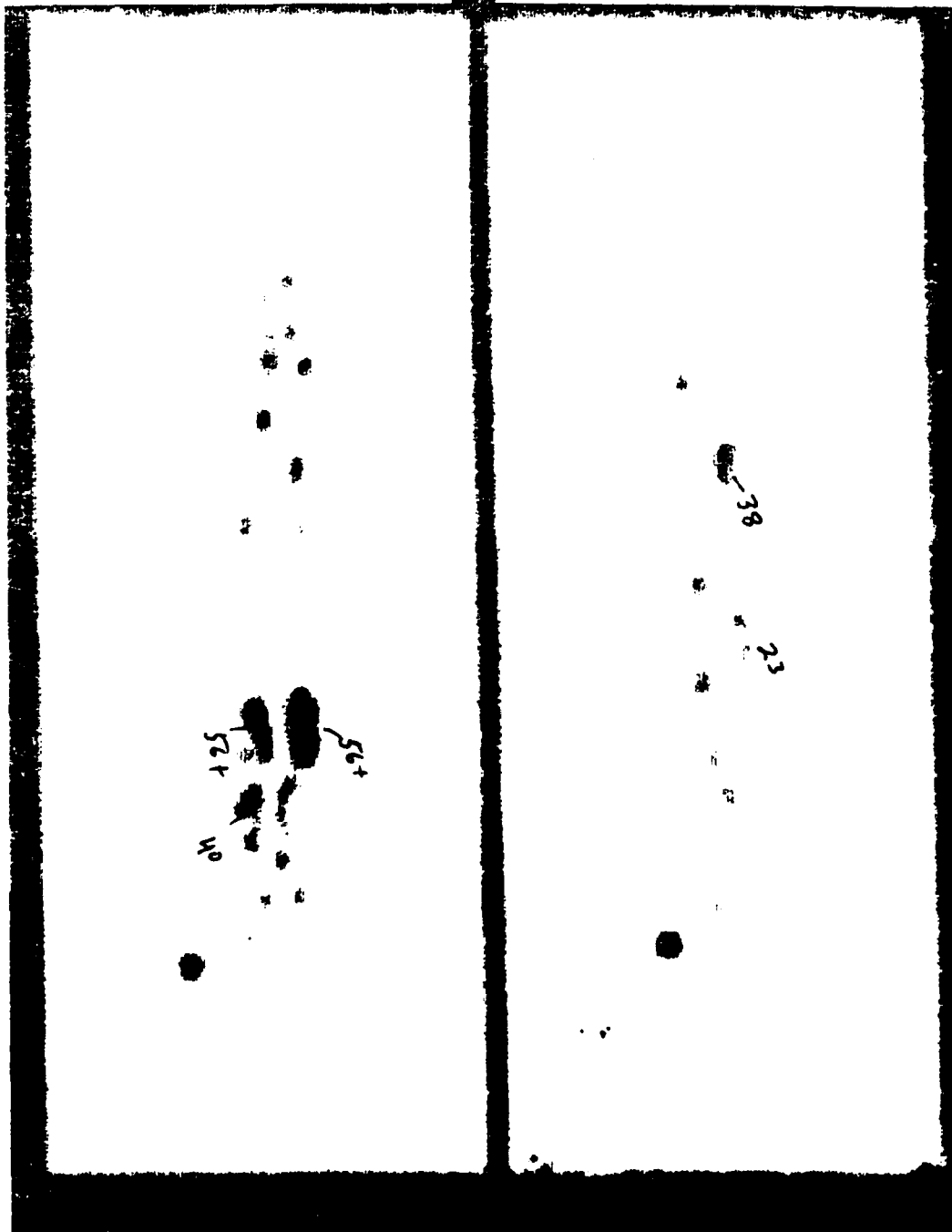


Figure C5. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No. _____
Alloy 2024T81 Bare
Surface Prep PAA
Primer EC2174
Adhesive AF31

Panel No. _____
Alloy 7075T76 Bare
Surface Prep PAA
Primer EC2174
Adhesive AF31

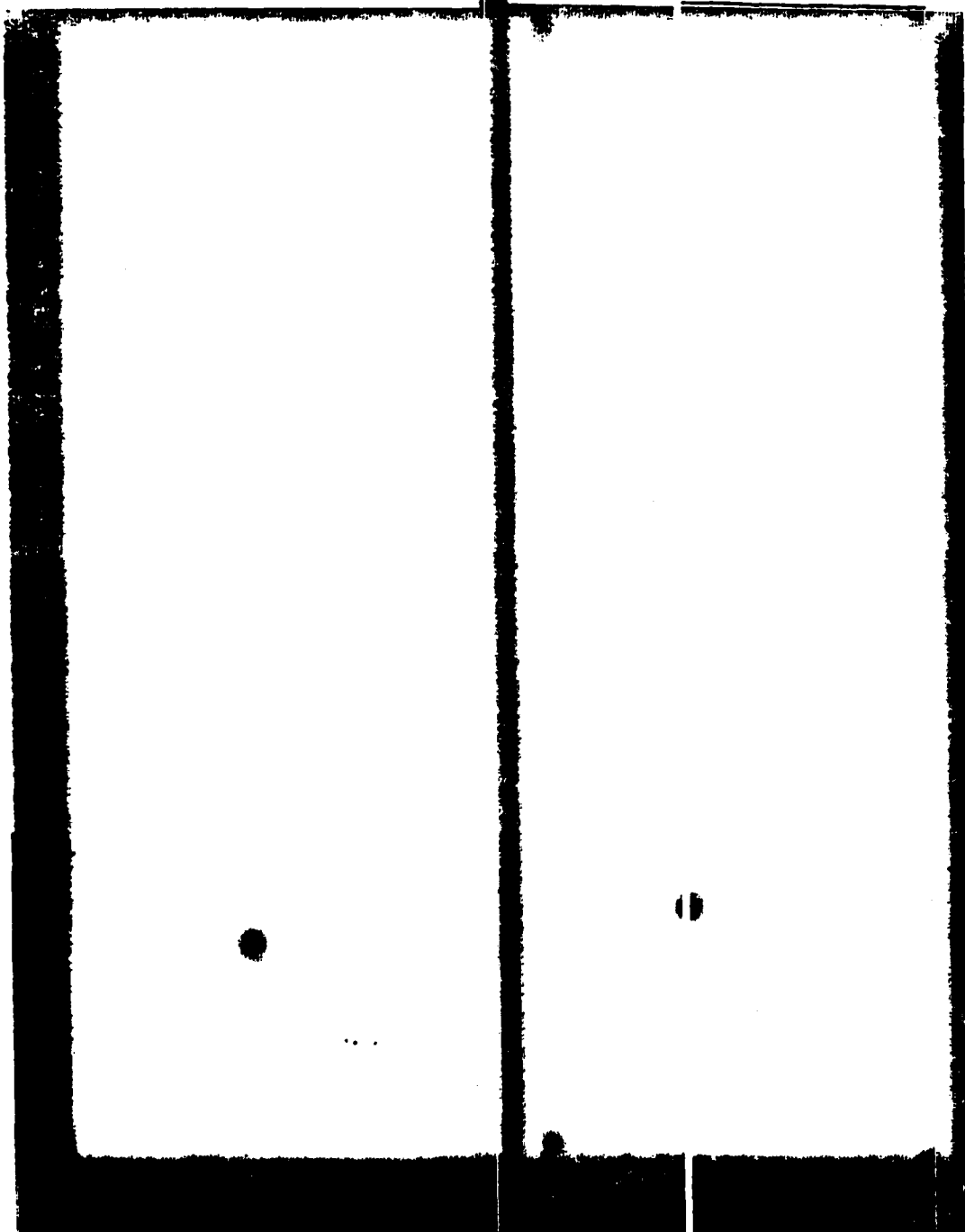


Figure C6. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No. _____
Alloy 2024T81 Bare
Surface Prep PAA
Primer PL728
Adhesive PL729-3

Panel No. _____
Alloy 7075T76 Bare
Surface Prep PAA
Primer PL728
Adhesive PL729-3

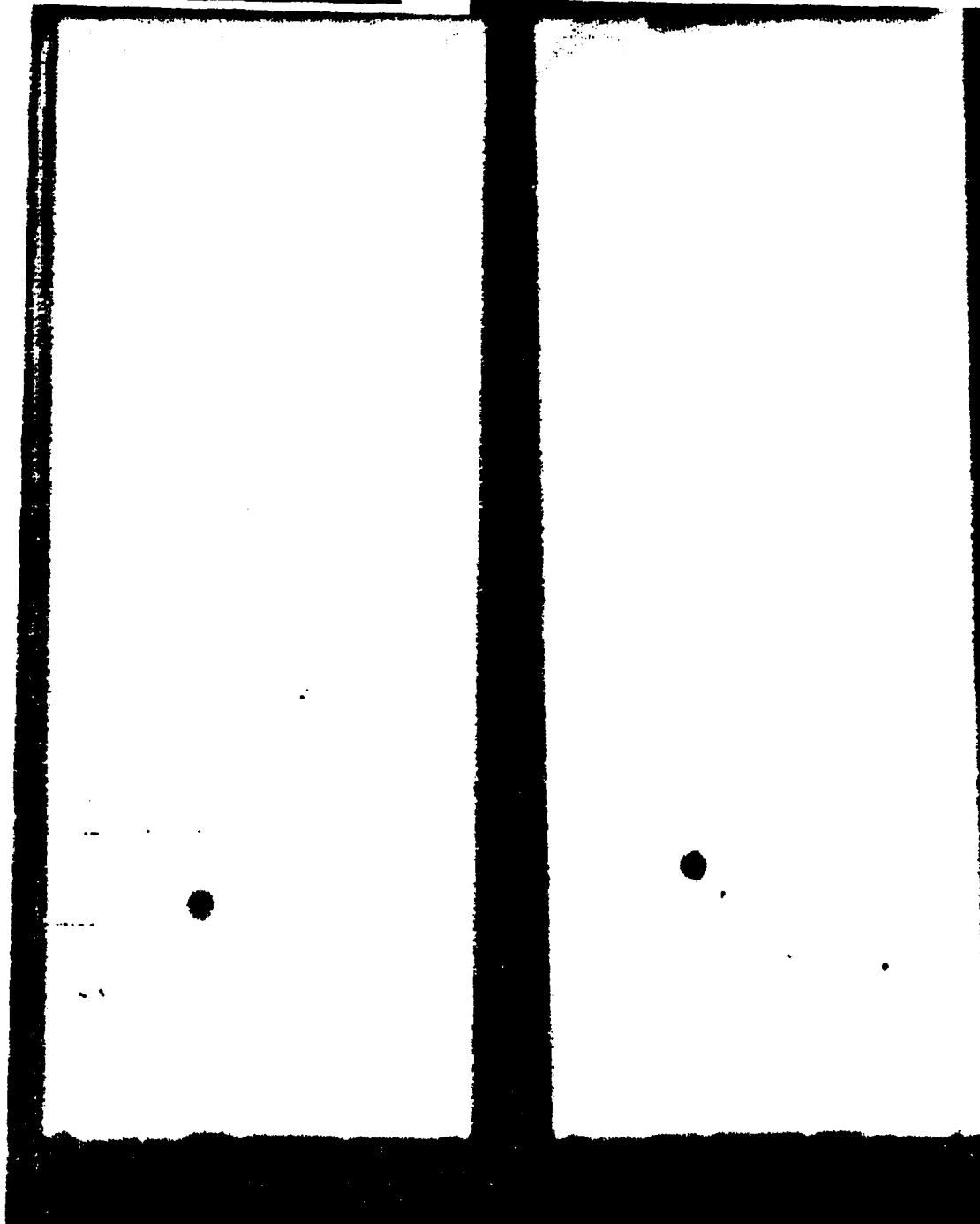


Figure C7. Ultrasonic C-Scans of Panels Used For Stress-Durability.

Panel No. _____
Alloy 2024T81 Bare
Surface Prep PAA
Primer HT424F
Adhesive HT424

Panel No. _____
Alloy 7075T76 Bare
Surface Prep PAA
Primer HT424F
Adhesive HT424

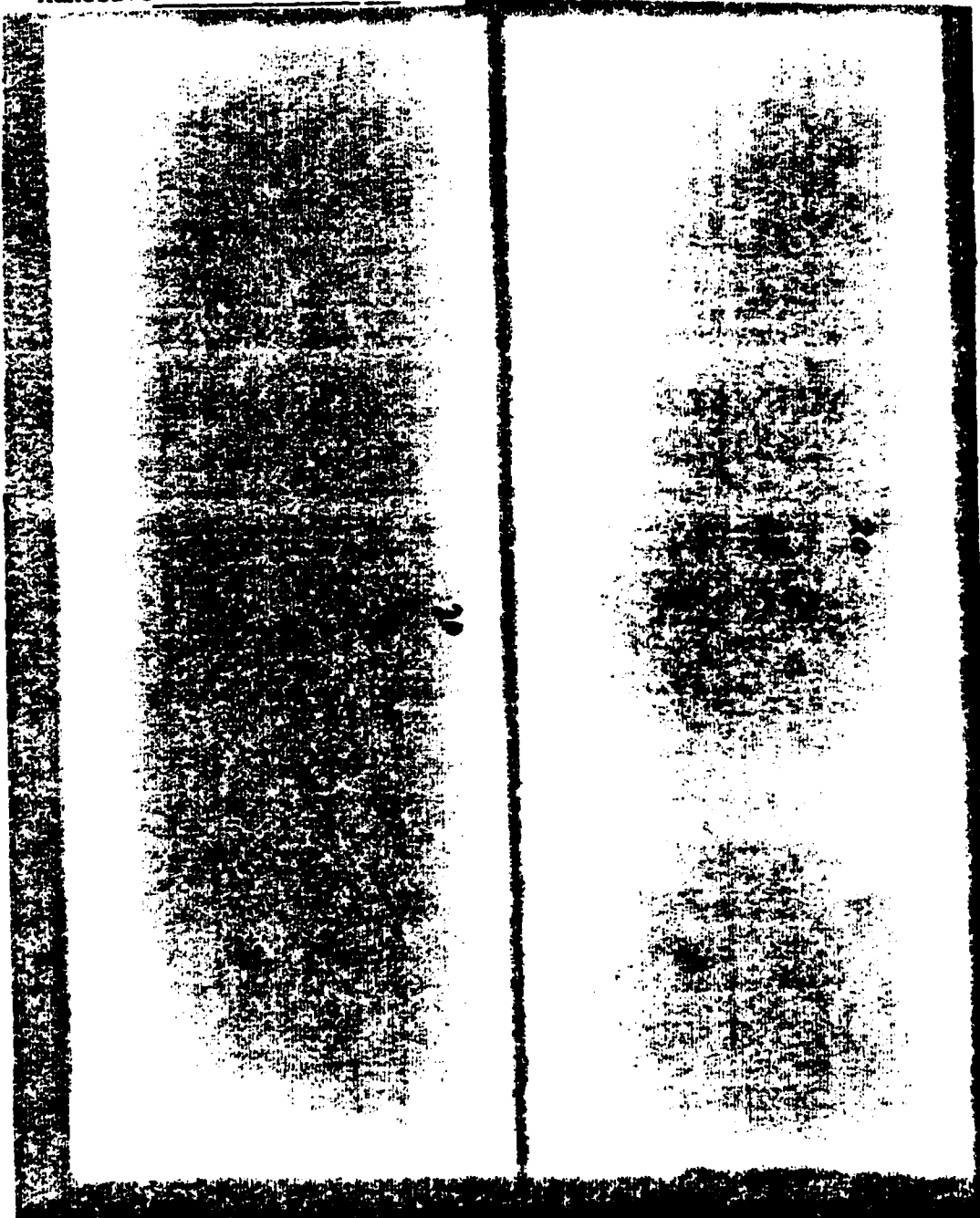


Figure (B). Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No. _____
Alloy 2024T81 Bare
Surface Prep PAA
Primer BR227A
Adhesive FM61

Panel No. _____
Alloy 7075T76 Bare
Surface Prep PAA
Primer BR227A
Adhesive FM61

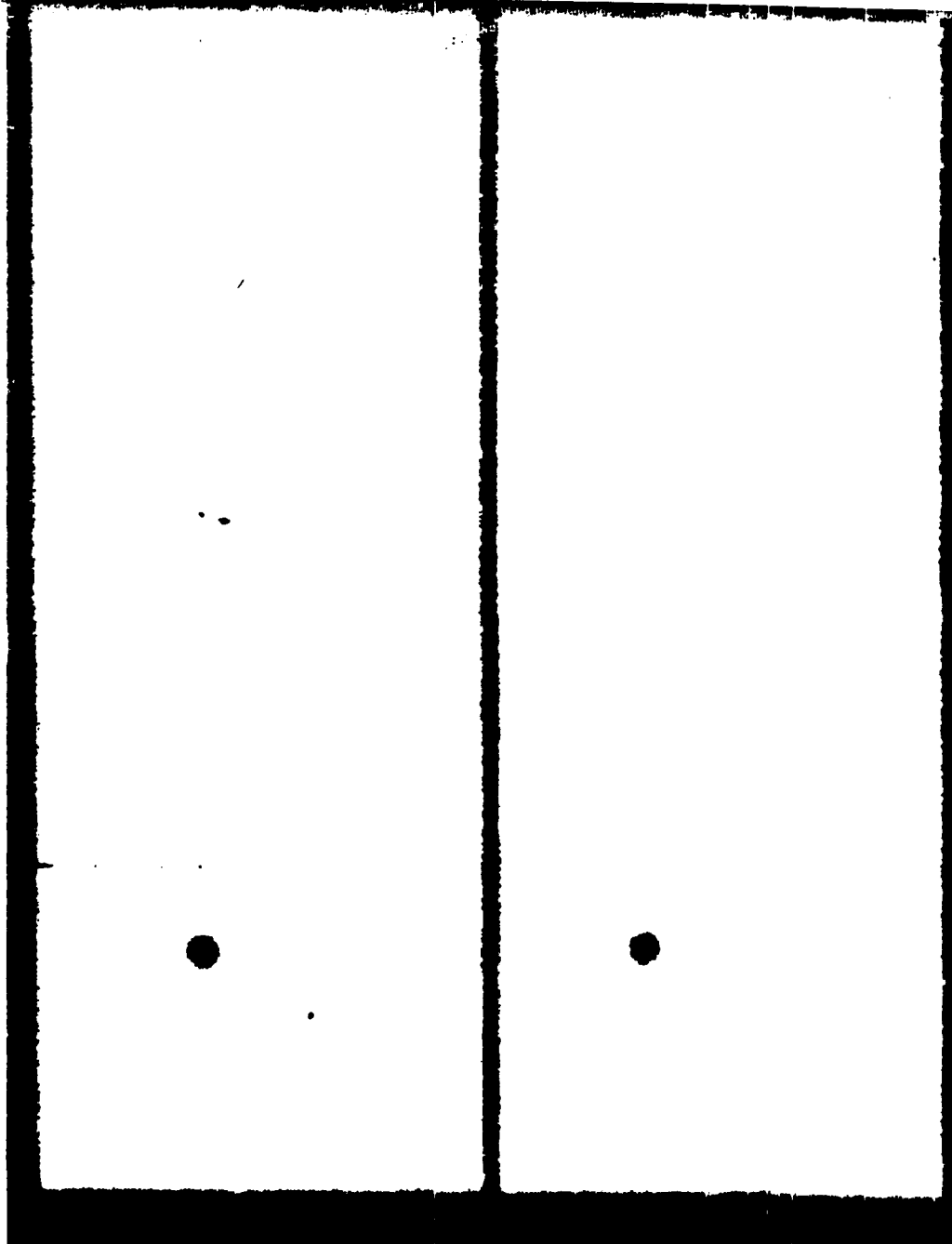


Figure C9. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No. _____
Alloy 2024T81 Bare
Surface Prep PAA
Primer BR227
Adhesive FM61

Panel No. _____
Alloy 7075T76 Bare
Surface Prep PAA
Primer BR227A
Adhesive FM61

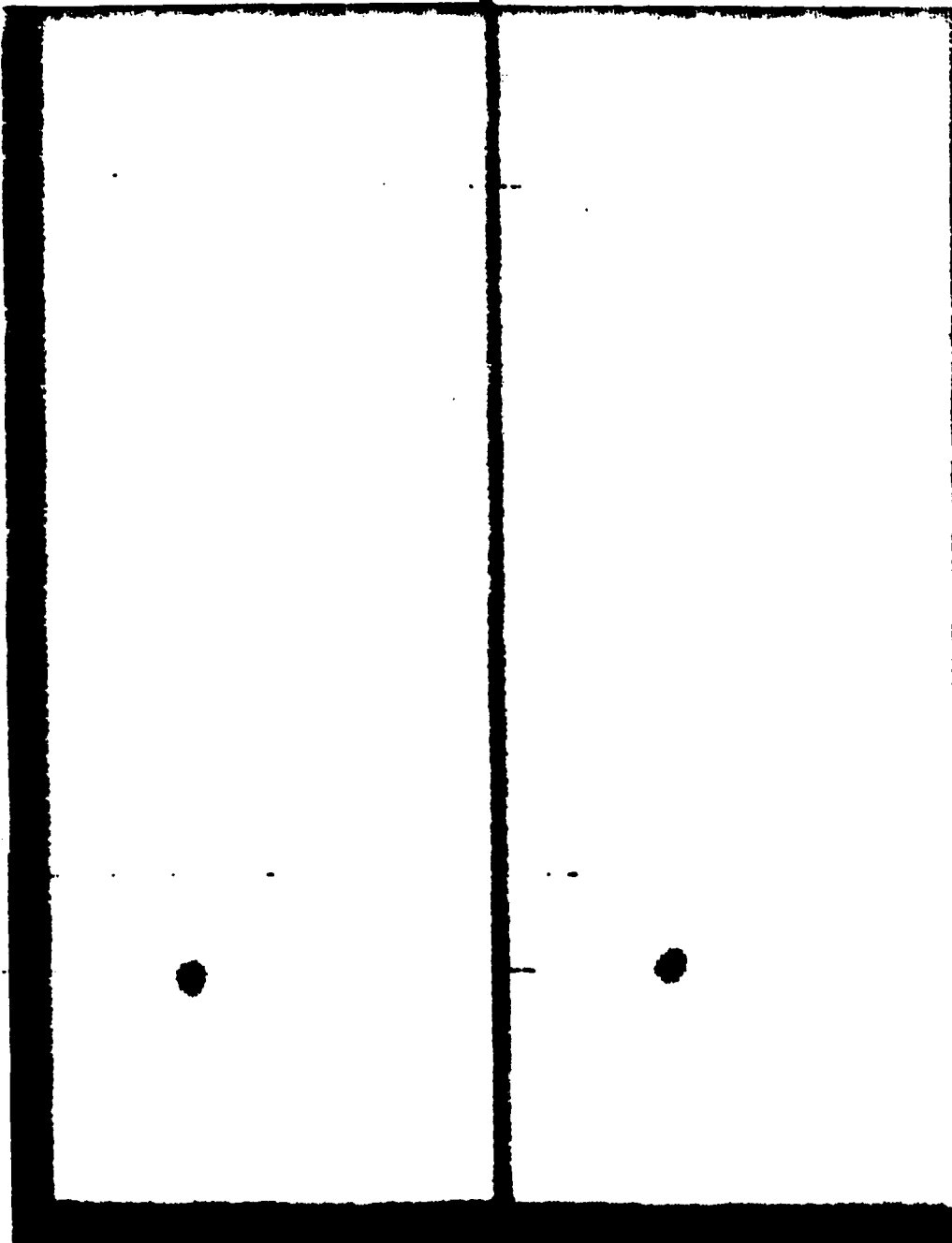


Figure C10. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No. _____
Alloy 2024T81 Bare
Surface Prep OFPL
Primer RB500
Adhesive RB398

Panel No. _____
Alloy 7075T76 Bare
Surface Prep OFPL
Primer RB500
Adhesive RB398

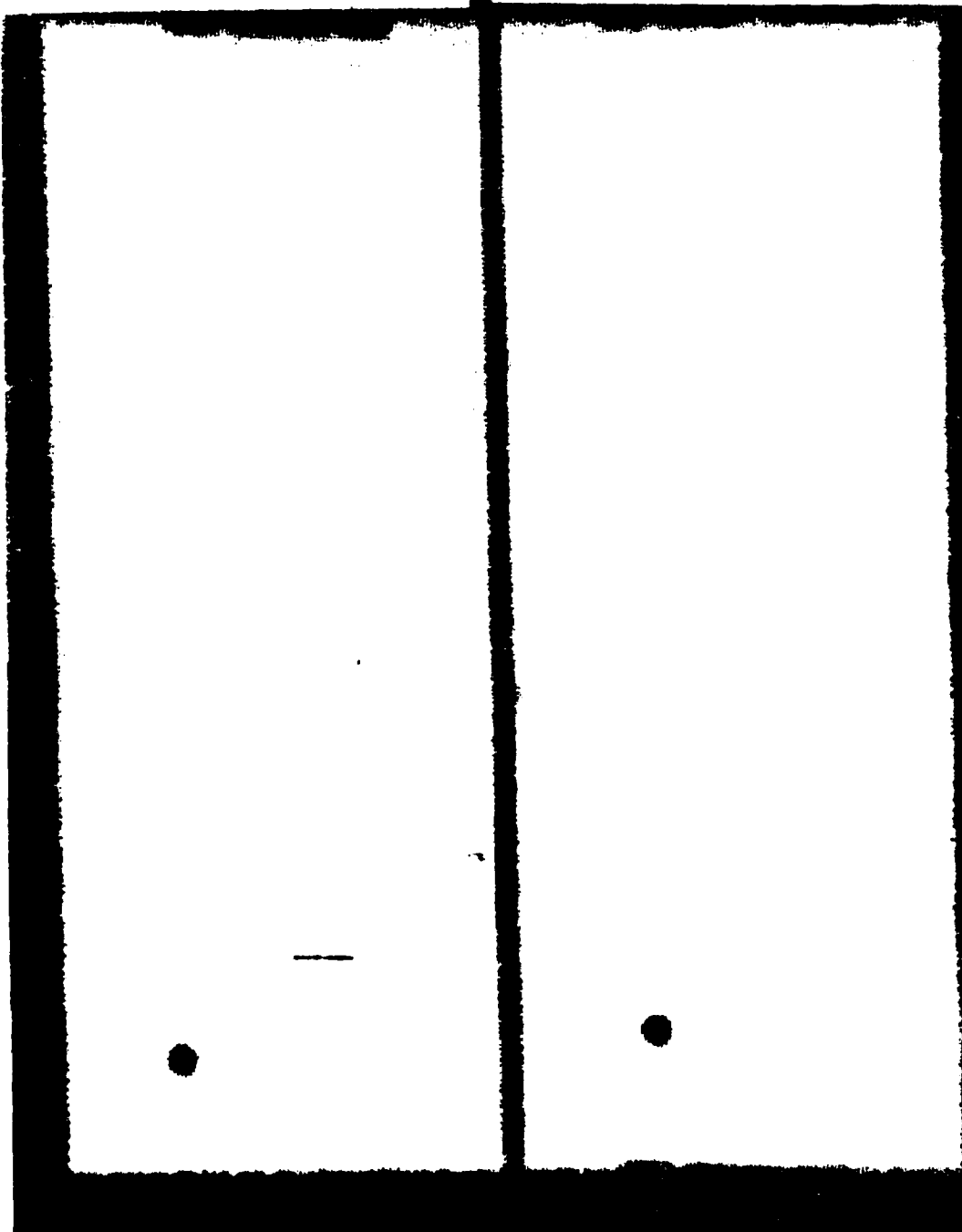


Figure C11. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No. _____
Alloy 2024T81 Bare
Surface Prep OFPL
Primer MB6725-1
Adhesive MB329

Panel No. _____
Alloy 7075T76 Bare
Surface Prep OFPL
Primer MB6725-1
Adhesive MB329

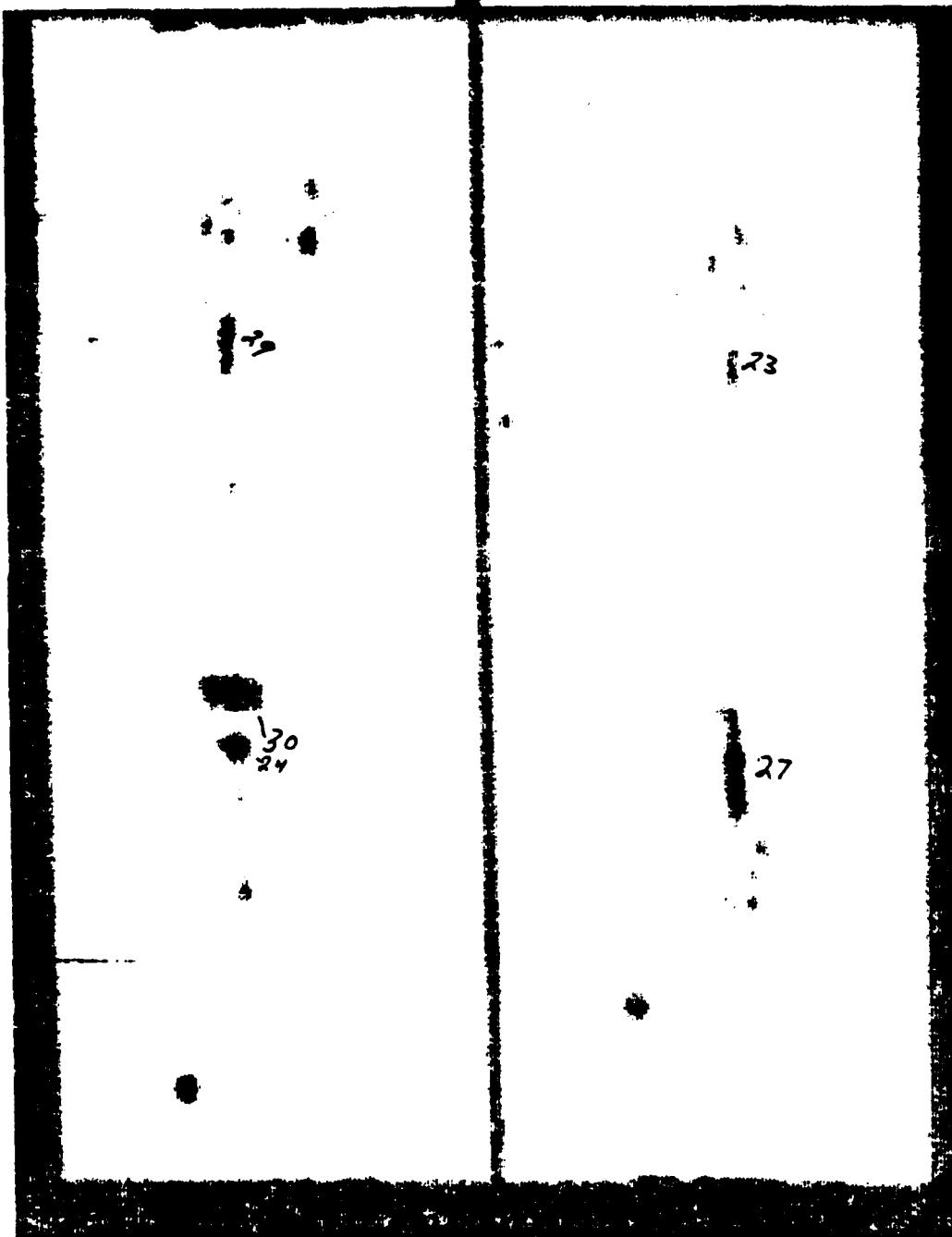


Figure C12. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No. _____
Alloy 2024T81 Bare
Surface Prep OFPL
Primer BR400
Adhesive EM 400

Panel No. _____
Alloy 7075T76 Bare
Surface Prep OFPL
Primer BR400
Adhesive FM400

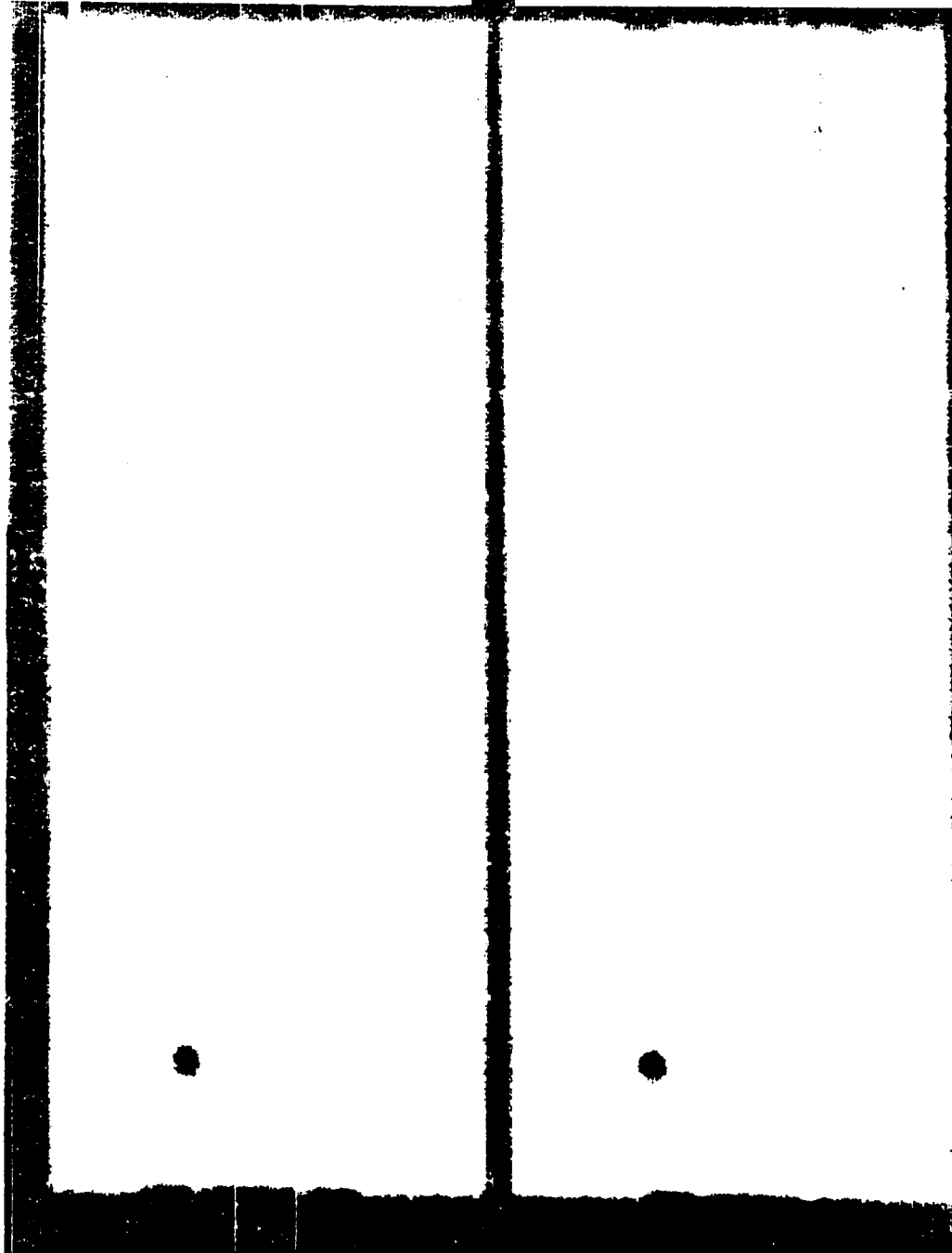


Figure C13. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No. _____
Alloy 2024T81 Bare
Surface Prep OFPL
Primer EA9205
Adhesive EA9649

Panel No. _____
Alloy 7075T76 Bare
Surface Prep OFPL
Primer EA9205
Adhesive EA9649

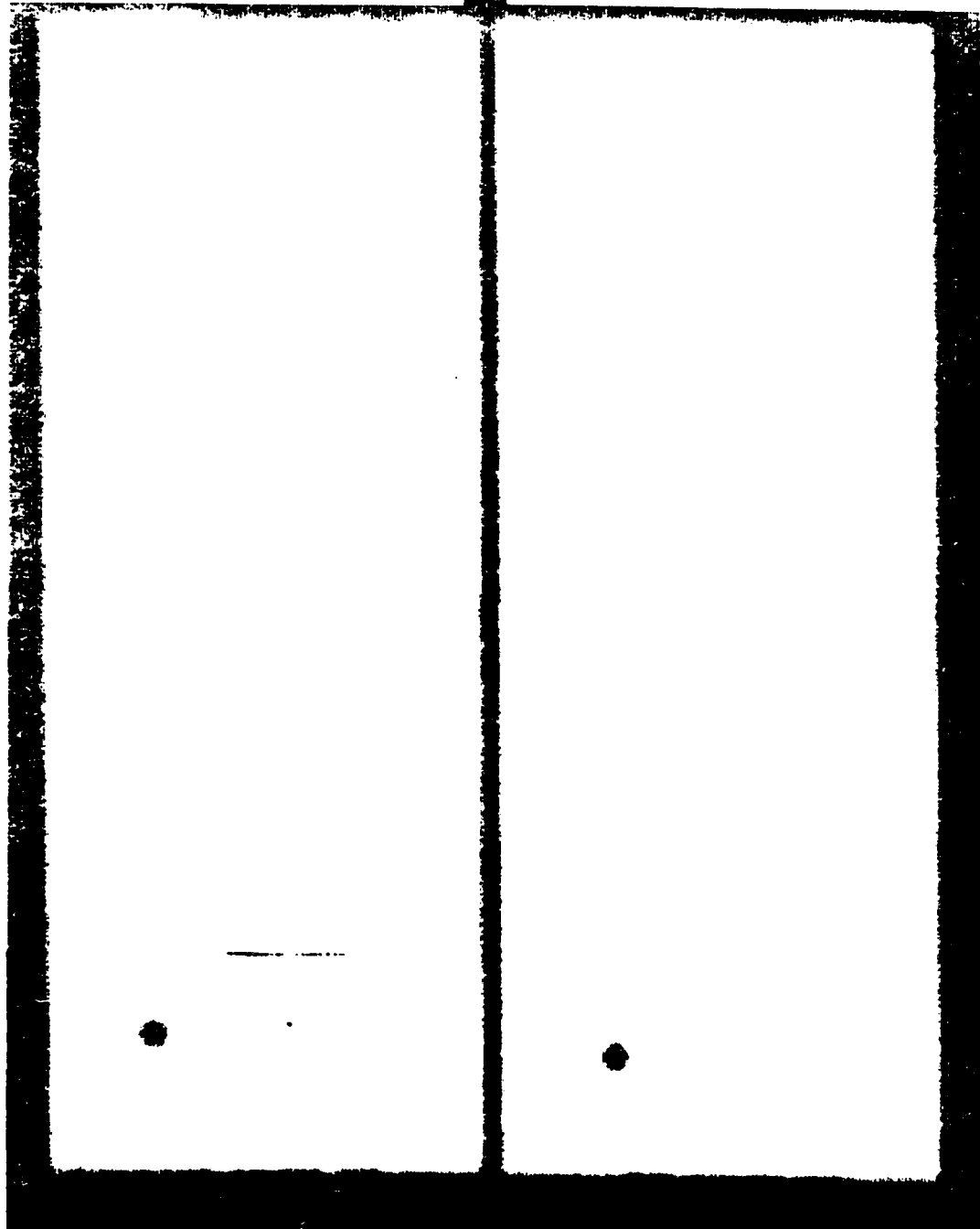


Figure C14. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No. _____
Alloy 2024T81 Bare
Surface Prep OFPL
Primer EC3917
Adhesive AF130

Panel No. _____
Alloy 7075T76 Bare
Surface Prep OFPL
Primer EC3917
Adhesive AF130

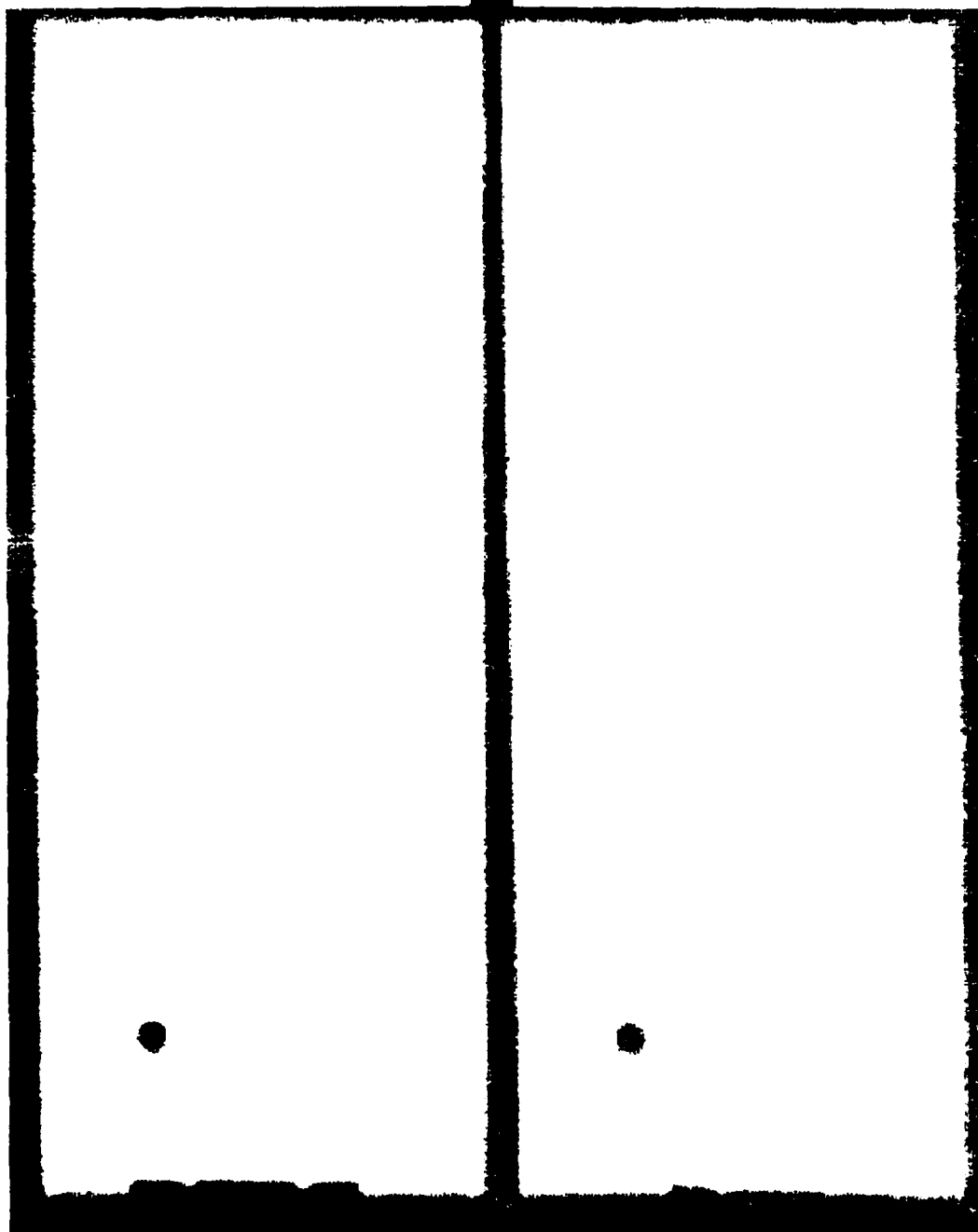


Figure C15. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No. _____
Alloy 2024T81 Bare
Surface Prep OFPL
Primer EC2174
Adhesive AF31

Panel No. _____
Alloy 7075T76 Bare
Surface Prep OFPL
Primer EC2174
Adhesive AF31

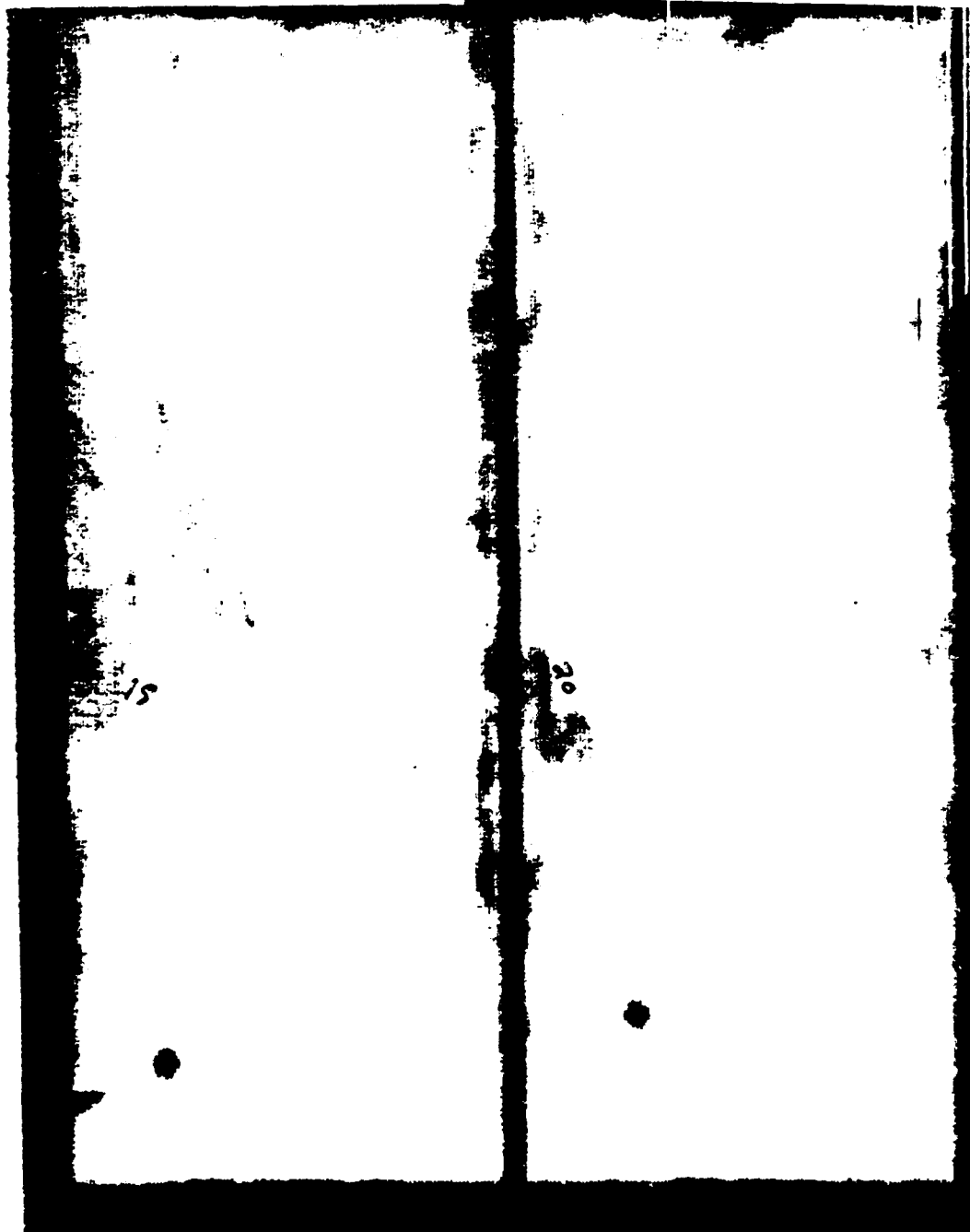


Figure C16. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No. _____
Alloy 2024T81 Bare _____
Surface Prep OFPL _____
Primer PL728 _____
Adhesive PL729-3 _____

Panel No. _____
Alloy 2024T81 Bare _____
Surface Prep OFPL _____
Primer PL728 _____
Adhesive PL729-3 _____

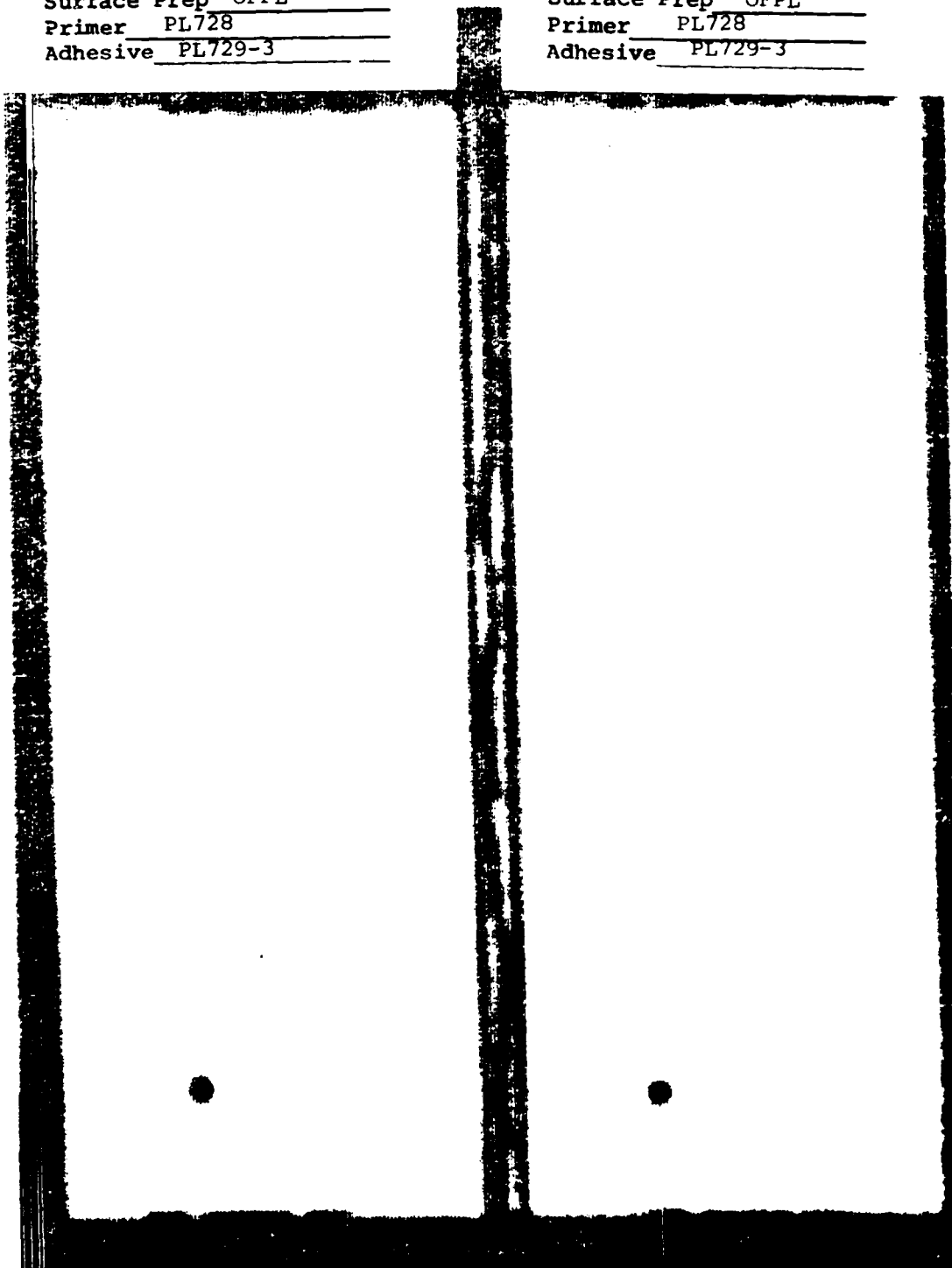


Figure C17. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No. _____
Alloy 2024T81 Bare
Surface Prep OFPL
Primer HT424F
Adhesive HT424

Panel No. _____
Alloy 7075T76 Bare
Surface Prep OFPL
Primer HT424F
Adhesive HT424

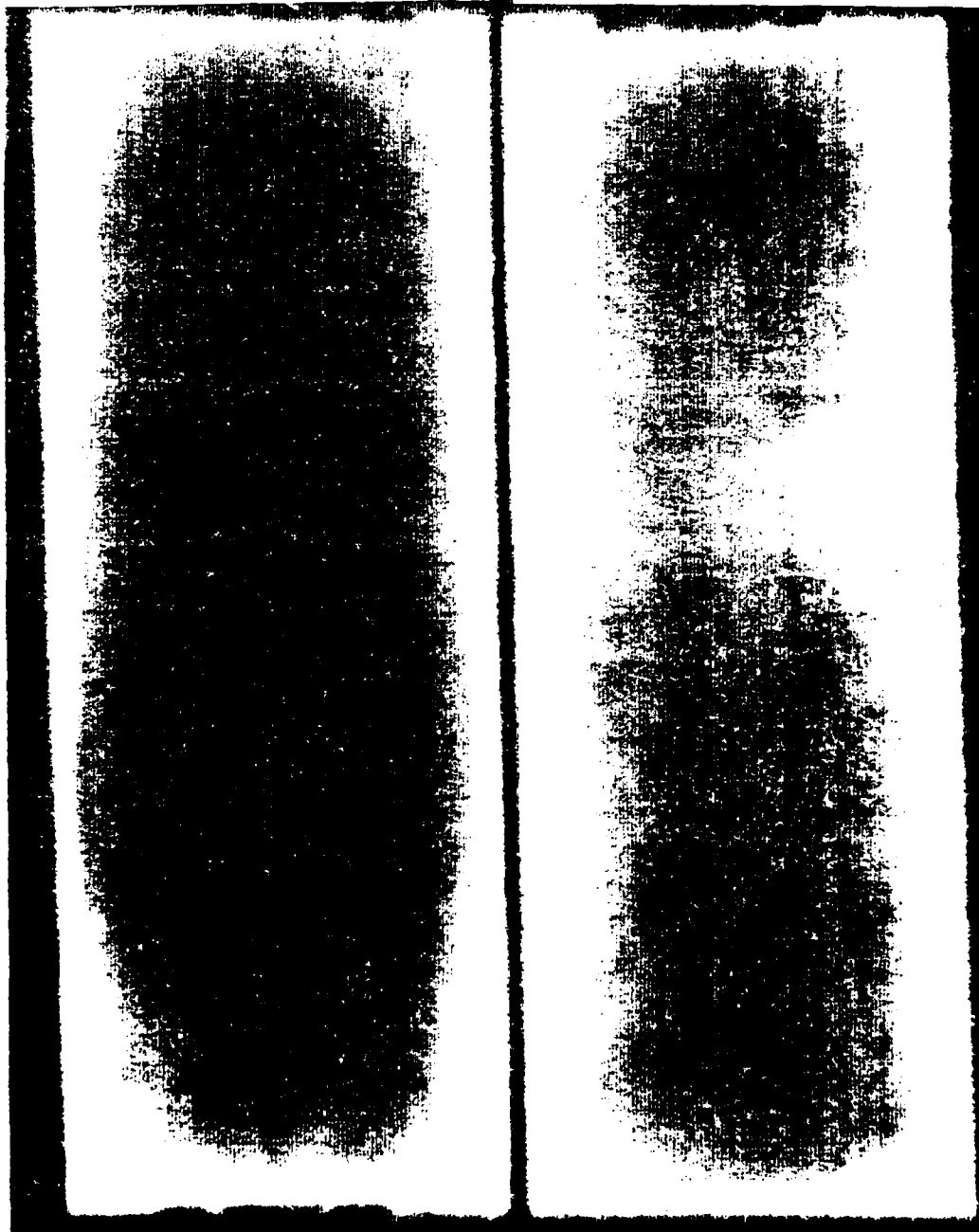


Figure C15. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No.: _____
Alloy: 2024T81 Bare
Surface Prep: OFPL
Primer: BR227
Adhesive: FM61

Panel No.: _____
Alloy: 7075T76 Bare
Surface Prep: OFPL
Primer: BR227
Adhesive: FM61

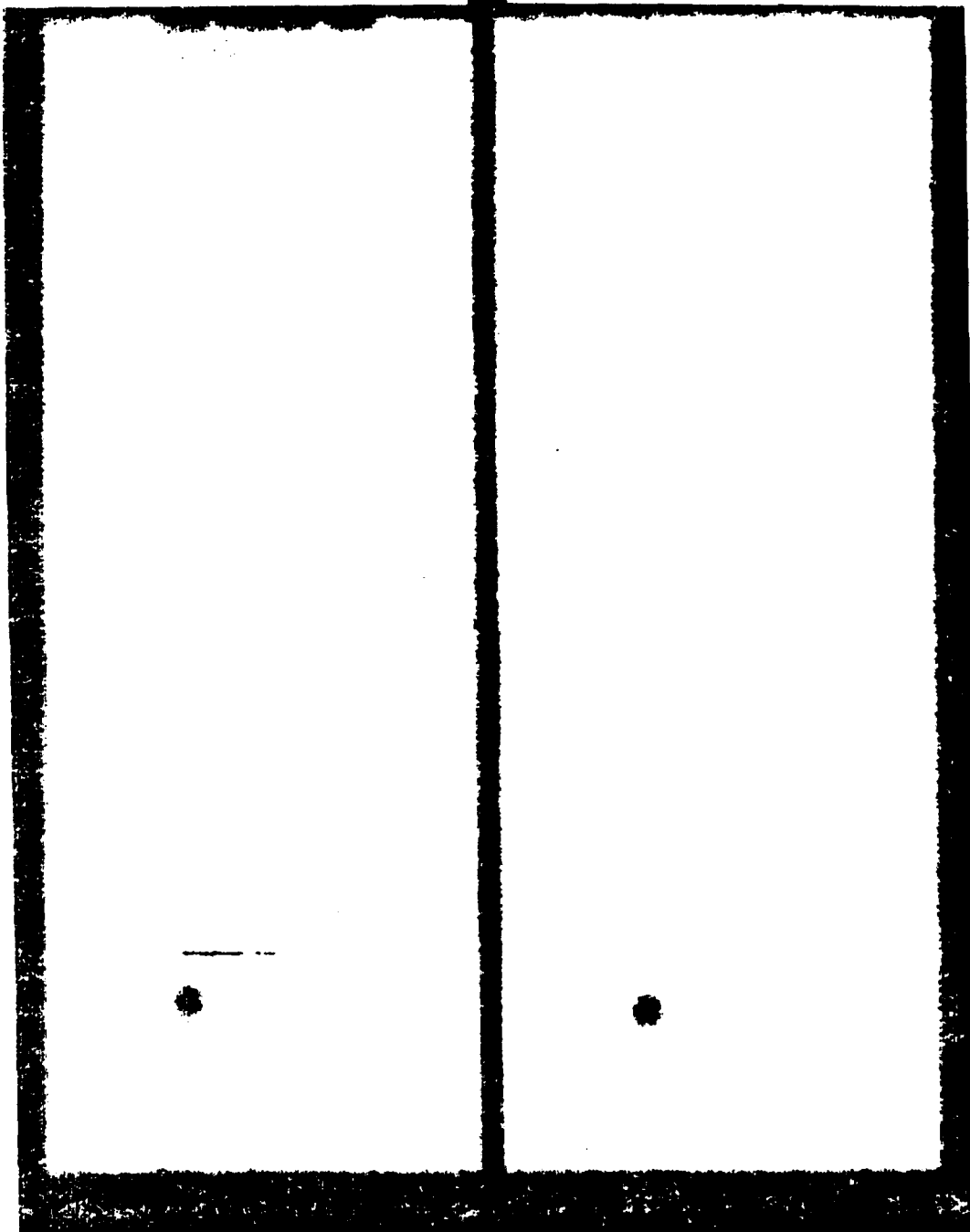


Figure C19. Ultrasonic C-Scans of Panels Used for Stress-Durability.

Panel No. _____
Alloy 2024T81 Bare
Surface Prep OFPL
Primer BR227A
Adhesive FM61

Panel No. _____
Alloy 7075T76 Bare
Surface Prep OFPL
Primer BR227A
Adhesive FM61

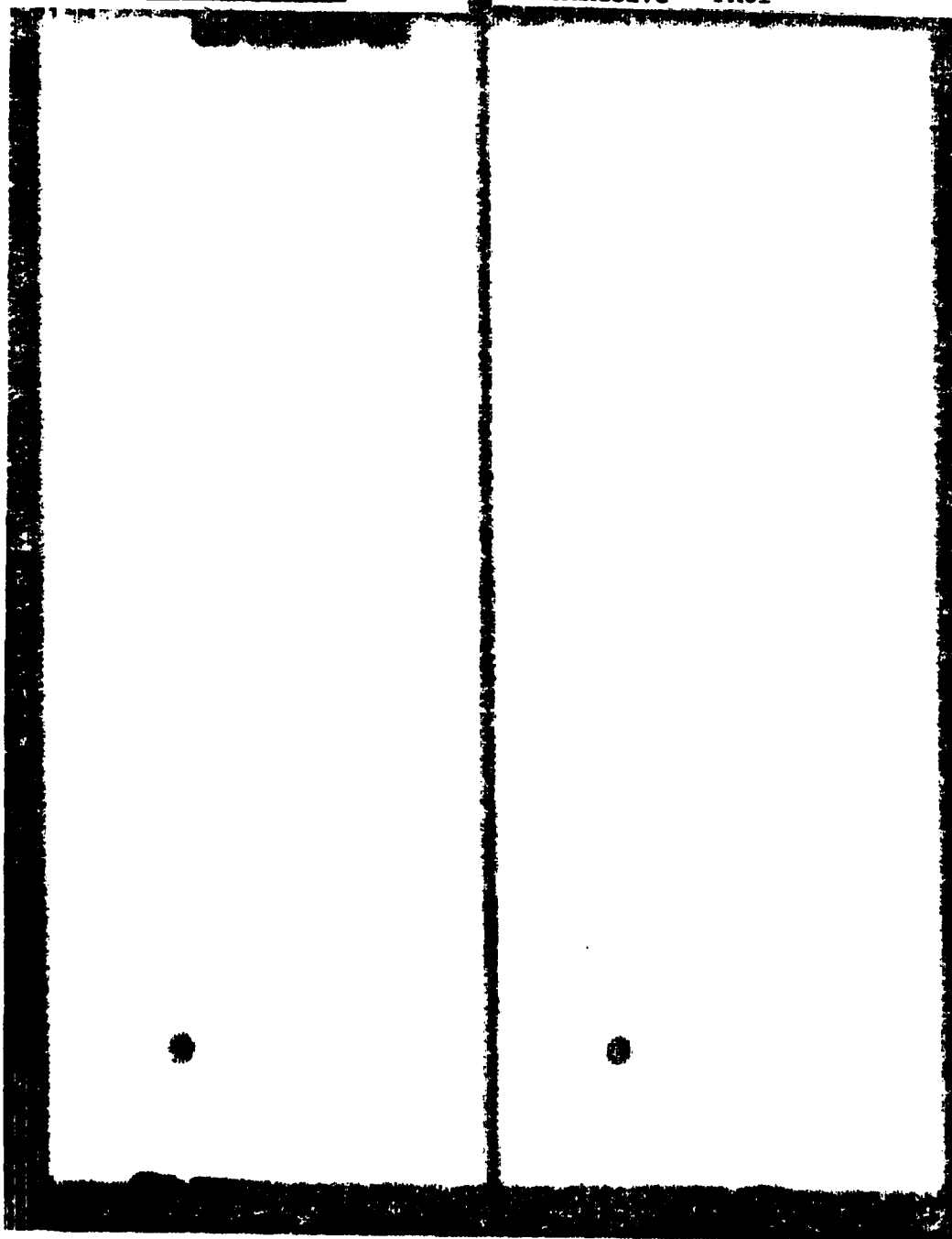


Figure C20. Ultrasonic C-Scans of Panels Used for Stress-Durability.

END

7-87

DTIC