AFWAL-TR-88-4065

CAST ALUMINUM BONDING STUDY

Ronald J. Kuhbander
Steven J. Caldwell
Scott E. Fiscus

University of Dayton
Research Institute
300 College Park Avenue
Dayton, OH 45469-0001

MAY 1988

Interim Technical Report - December 1986-December 1987

Approved for public release; distribution unlimited

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

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE:

3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S): UDR-TR-87-137

5. MONITORING ORGANIZATION REPORT NUMBER(S): AFWAL-TR-88-4065

6a. NAME OF PERFORMING ORGANIZATION: University of Dayton Research Institute

6b. OFFICE SYMBOL (If applicable): N/A

7a. NAME OF MONITORING ORGANIZATION: (AFWAL/MLSE) Materials Laboratory Air Force Wright Aeronautical Laboratories

6c. ADDRESS (City, State and ZIP Code): 300 College Park Avenue Dayton, Ohio 45469-0001

7b. ADDRESS (City, State and ZIP Code): Wright-Patterson Air Force Base, Ohio 45433-6553

8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Materials Laboratory

8b. OFFICE SYMBOL (If applicable): AFWAL/MLSE

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: F33615-86-C-5031

8c. ADDRESS (City, State and ZIP Code): Wright-Patterson Air Force Base, Ohio 45433-6533

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
62102F	2418	04	53

11. TITLE (Include Security Classification): Cast Aluminum Bonding Study

12. PERSONAL AUTHOR(S): Ronald J. Kuhbander, Steven J. Caldwell, and Scott E. Fiscus

13a. TYPE OF REPORT: Interim Tech. Report

13b. TIME COVERED: FROM 12/86 TO 12/87

14. DATE OF REPORT (Yr., Mo., Day): May 1988

15. PAGE COUNT: 22

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB. GR.
11	01	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Adhesive Bonding; Surface Preparation; Aluminum Castings; Epoxy Adhesives

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

High quality aluminum alloy castings are finding application on Air Force weapon systems due to the significant cost savings over those components machined from plate stock. However, it is unknown if durable adhesively bonded joints can be fabricated using present bonding technology with castings. The cast aluminum alloy used was A357. The surface preparation was phosphoric acid anodize (PAA) which has proven to be an excellent prep for aluminum plate stock, in particular if durability was considered. Specimens were prepared with two aircraft type epoxy adhesives, and the effects of temperature, environmental exposure, and long-term durability were measured and are presented. It appears that high quality adhesively bonded joints can be achieved using cast aluminum adherends and current aluminum surface preparation technology.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL: Robert B. Urzi

22b. TELEPHONE NUMBER (Include Area Code): (513) 255-7480

22c. OFFICE SYMBOL: AFWAL/MLSE

DD FORM 1473, 83 APR — EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED

SUMMARY

Current aluminum surface preparation technology, phosphoric acid anodize (PAA), has proven to be an excellent preparation for aluminum plate stock and appears to be applicable to cast aluminum. Adherends were prepared from a cast aluminum alloy designated A357. The bonding surfaces of the adherends were prepared using PAA. One primer and two adhesives considered applicable to aircraft structures were used. Concurrently, test specimens were prepared using 2024-T3 sheet aluminum for baseline data.

The effects of temperature and of environmental exposure were investigated and seem to have similar effects on adhesively bonded cast aluminum and adhesively bonded 2024-T3 sheet aluminum, although tensile lap shear strengths of the cast aluminum joints are generally slightly lower.

High quality adhesively bonded joints apparently can be achieved using cast aluminum adherends. Current aluminum surface preparation technology is applicable to cast aluminum.

PREFACE

This interim technical report was prepared by the University of Dayton Research Institute (UDRI), Dayton, Ohio 45469-0001, under Contract F33615-86-C-5031, "Composites Supportability Rapid Test and Evaluation," for the Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio 45433-6533. The work was administered by Mr. Robert Urzi and directed by Mr. Theodore Reinhart, AFWAL/MLSE.

This report covers work performed during the period from December 1986 to December 1987 and was submitted by the authors in January 1988. The contractor's report number is UDR-TR-87-137. The work was performed in the Plastics, Adhesives, and Composites Laboratory under Mr. Ronald J. Kuhbander as Principal Investigator. The laboratory work was performed by Messrs. Steven J. Caldwell and Scott E. Fiscus.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION 1
INTRODUCTION

High quality aluminum alloy castings are finding application on Air Force weapon systems due to the significant cost savings over those components machined from plate stock. However, it is unknown if durable adhesively bonded joints can be fabricated using present bonding technology with castings. This report describes the effort and results of a program to determine the feasibility of adhesively bonding aluminum castings using the same surface preparation techniques developed for plate aluminum. Also presented are the long-term durability, effects of temperature, and environmental exposure on the properties of those bonds.

SECTION 2
MATERIALS

It would have been desirable to obtain flat cast aluminum sheet having similar thickness as sheet aluminum normally used to evaluate adhesives and/or environmental effects upon adhesives. Foundries who are capable of casting aluminum were contacted but do not ordinarily cast such sheet. The cost of obtaining specially cast aluminum would have been prohibited. The AFWAL/MLSE Project Engineer located sections of a large cast aluminum aircraft bulkhead from another Air Force sponsored program which was available and suitable for this investigation. A further description of the cast aluminum follows. Concurrently, data were obtained on 2024-T3 sheet aluminum for baseline data. We have proven that the surface preparation used is state of the art with sheet aluminum of this type.

2.1 CAST ALUMINUM BULKHEAD

Test specimens were obtained from pieces of the Station 170 bulkhead of a YC-14 fuselage. The bulkhead was cast aluminum using an alloy of A357. A357 is an age-hardenable aluminum-silicon-magnesium alloy characterized by excellent castability, good response to heat treatment, high resistance to corrosion and good weldability. Details of the Air Force sponsored program, conducted by the Boeing Company, are discussed in AFFDL-TR-78-62, "Cast Aluminum Structures Technology (CAST) Manufacturing Methods." The chemical composition of aluminum alloy A357 is shown in Table 1 and the heat treatment used is shown in Table 2.

2.2 ADHESIVES

Two adhesive types were used in this investigation. One, a 250°F curing system, was Hysol EA9628. Unfortunately, two types of EA9628 were used; EA9628H has a nylon skrim and weighs 0.080 lb/ft^2, and EA9628NW has a nonwoven mat scrim and weighs 0.060 lb/ft^2. Each is identified in the appropriate place in the data and we felt that this had no detrimental effect on the outcome

TABLE 1

A357 CHEMICAL COMPOSITION

Elements	Percent, Minimum	Percent, Maximum
Copper	---	0.20
Silicon	6.5	7.5
Iron	---	0.10
Manganese	---	0.10
Zinc	---	0.10
Magnesium	0.55	0.65
Titanium	0.10	0.20
Beryllium	0.04	0.07
Others, each	---	0.05
Others, total	---	0.15
Aluminum	Remainder	

TABLE 2

A357 HEAT TREATMENT

Solution Heat Treatment	Quench Delay	Quenchant	Natural Aging	Precipitation Heat Treatment (Aging)
1010°F ± 10°F for 16 hrs. min. ▷1	8 sec. max.	170°F ± 30°F water	Room temp. for 16-24 hrs.	325°F ± 10°F for 8 hrs ± 1 hr

▷1 For castings with 1 inch maximum thickness. Add 2 hours soak for each additional 1/2 inch thickness.

of this investigation. The second adhesive type was a 350°F curing system, American Cyanamid FM-300.

All specimens were primed with BR-127 corrosion inhibiting primer. The thickness of primer was difficult to control due to the roughness of the aluminum casting but we believed this was close to that usually recommended, 0.0002 inch.

2.3 TEST SPECIMEN MACHINING

The cast aluminum bulkhead pieces were difficult to work with due to the size, roughness, and location of ribs. Figure 1 shows large ribs in the casting that made cutting and handling these pieces difficult. Throughout the casting, there were 1/8-inch-thick ridges approximately 5/8 inches to 7/8 inches apart, with the exception of a few ridgeless areas. These ridgeless areas provided the 1-inch-wide wedge crack adherends.

Once the flat sections between the ribs were cut out, these sections, usually about 3 inches by 10 inches, were cut into smaller pieces as shown in Figure 2. These smaller pieces, very close to the required size, were then machined to the specified dimensions on a milling machine.

Some of the finished specimens had small bumps or other extrusions on the surface. These were either milled clean or ground off with a manual die grinder. All lap shear bonds were bonded on the as-received rough casting surface. The wedge crack specimens were bonded with the as-received rough casting surface or areas with minimum grinding. Figure 3 shows a ground off area on a piece of casting prior to machining into adherends. Usually, these high ground areas were restricted to the side opposite the bonding surface.

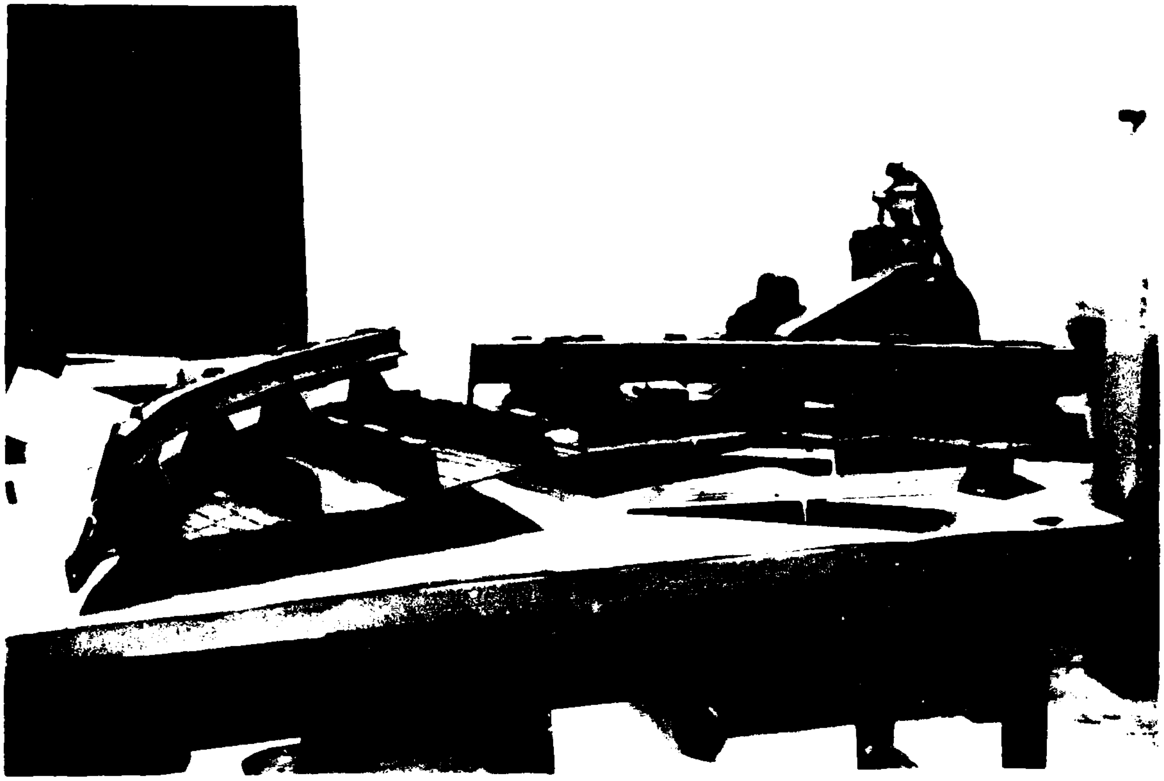


Figure 1. As-Received Casting.

Figure 2. Flat Section being Bandsawed into Adherends.

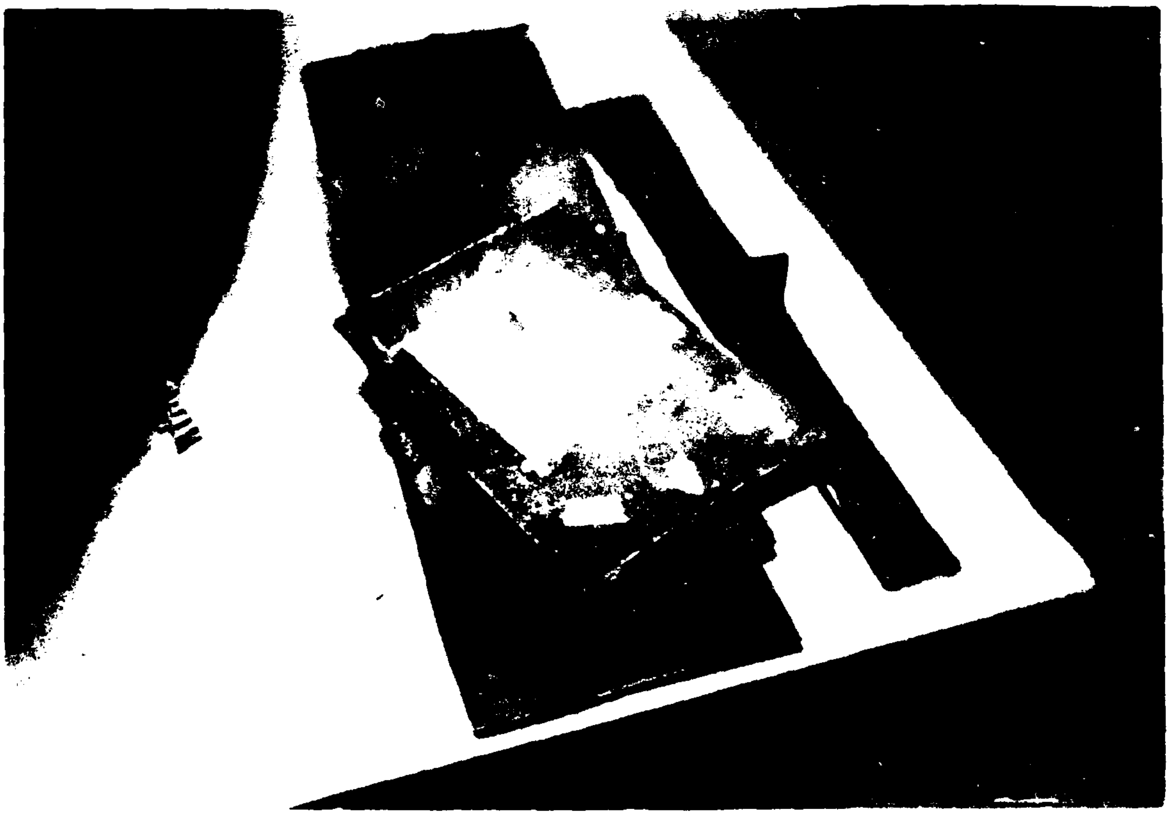


Figure 3. Casting Pieces which Required Grinding.

SECTION 3

SURFACE PREPARATION

Surface preparation procedures used in this study are standard procedures that represent current aluminum bonding technology. The process listed below was used for both the cast aluminum and 2024-T3 aluminum adherends.

Adherend Etch Procedure

1. Solvent wipe with acetone.
2. Vapor degrease for 10 minutes in trichloroethane.
3. Alkaline wash for 10 minutes at 155 ± 5°F (Note 1).
4. Water rinse for 10 minutes in a continuous flow tap water bath.
5. Etch for 10 minutes in optimized FPL (OFPL) etch solution for 10 minutes at 155 ± 5°F (Note 2).
6. Water rinse for 10 minutes in an agitated continuous flow tap water bath.
7. Anodize for 20 minutes in a 9 to 12 percent by weight phosphoric acid anodize solution per ASTM D3933 at 15 ± 1 volts (Note 3).
8. Water rinse for 10 minutes in a continuous flow tap water bath.
9. Force dry with a heat gun or in an oven for 10 minutes at 150°F.

NOTES:

1. Alkaline solution:
   a. 1 gallon tap water
   b. 170 grams Turco 4215
   c. 7 ml Turco 4215 additive

2. OFPL etch solution:
   a. 11.1 liters tap water
   b. 417 grams sodium dichromate ($Na_2Cr \cdot 2\ H_2O$)
   c. 2 liters sulfuric acid (reagent grade)
   d. 26 grams shredded 2024-T3 aluminum

3. Phosphoric acid anodize solution:
   a. 1 liter tap water
   b. 69 ml phosphoric acid, 85 percent
      or
      84.5 ml phosphoric acid, 75 percent

3.1 SEM INVESTIGATION

Samples from both types of adherends were submitted for scanning electron microscope (SEM) evaluation. Figures 4 and 5 show the cast aluminum sample at 100X and 1000X magnification, respectively. The porosity of the casting is apparent, making it difficult to detect any anodization.

3.2 PRIMER APPLICATION

The primer, American Cyanamid BR-127, was applied with either a spray gun or an air brush. The primer was applied in several passes rather than a one- or two-pass buildup. After spraying, the adherends were air dried at room temperature for one-half hour and then dried in an oven at 250°F for an hour. The primed adherends were covered with Kimwipes and all panels were bonded within 24 hours of adherend priming.

3.3 BONDING PROCEDURES

The 2024-T3 specimens were bonded in a press using the standard procedure: apply 30 psi, heat to the required temperature (250°F or 350°F depending on the system), and cool. Because they were bonded in panel form, these panels were easy to lay up using standard fixturing.

The cast aluminum specimens had to be laid up individually. Figure 6 shows application of adhesive to a lap shear adherend with completed specimens nearby. Figure 7 shows the implementation of binder clips to apply pressure to the bond area, and to keep the adherends from slipping. The specimens were cured in an oven at either 250°F or 350°F, depending on the system.

Wedge crack specimens were laid up and cured the same way, although more binder clips per specimen were used.

Figure 4. Cast Aluminum, 100x, after PAA.

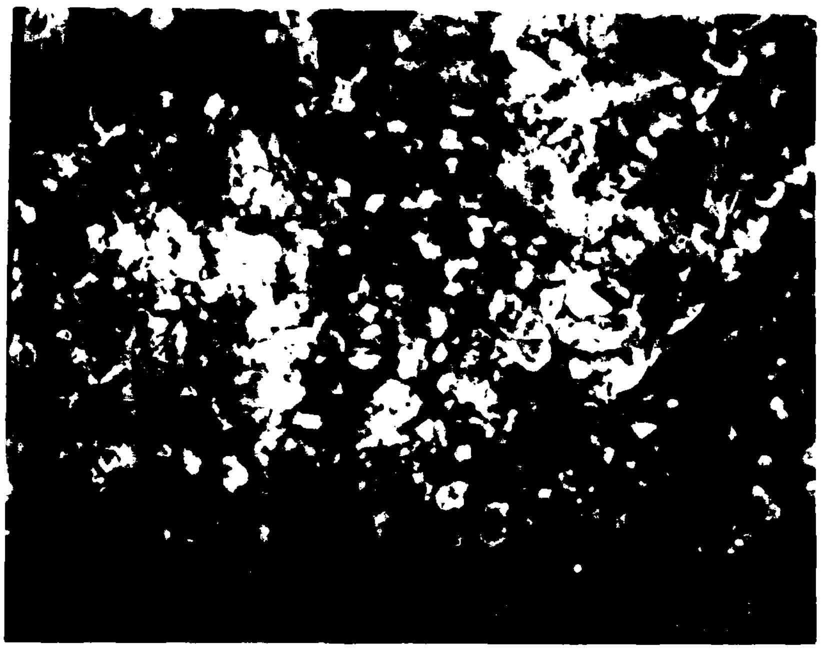


Figure 5. Cast Aluminum, 1000x, after PAA.

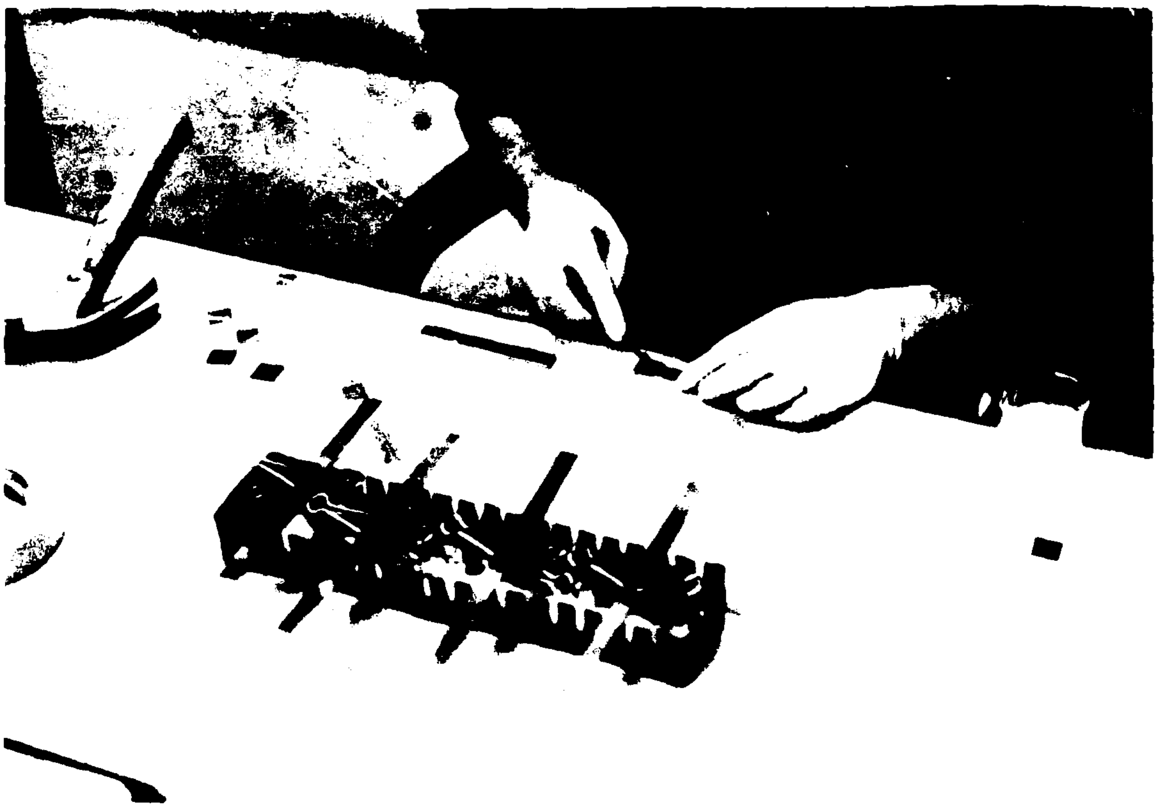


Figure 6. Application of Adhesive to Individual Cast Aluminum Lap Shear Adherend.

Figure 7. Implementation of Binder Clips on Cast Aluminum Lap Shear Specimens.

SECTION 4
TEST PARAMETERS

Two types of mechanical tests were used in this program, lap shear and wedge crack. Both tests were performed similar to standard procedures developed by ASTM.

4.1 LAP SHEAR TESTING

Lap shear tests were conducted similar to ASTM D1002. Specimens using 2024-T3 aluminum were the standard (fully machined after bonding) type of test panel. The casting specimens did not meet this specification per se, because they were 0.475-inch wide and of slightly varying thicknesses in the neighborhood of one-eighth inch. We attempted to match the thicknesses of both adherends used in a specimen.

Due to the roughness of the cast specimens, it was difficult to determine the applied primer thickness. The method used to approximate was to compare the color of the primer on a machined portion of the adherend to a pair of model panels that were coated with the minimum and maximum allowable primer thickness. Figure 8 shows a primed lap shear adherend.

As indicated earlier, a purpose of this study was to determine the effects of temperature and environmental exposure on adhesively bonded joints using aluminum castings. Table 3 outlines the test matrix.

4.2 WEDGE CRACK TESTING

Wedge crack tests were conducted similar to ASTM D3762. All specimens were the specified size, although the 2024-T3 specimens were bonded as a panel and machined into individual specimens, while the cast aluminum specimens were bonded individually.

Primer thickness for the cast aluminum adherends was as determined in Paragraph 4.1. The test matrix used in this portion of the study is outlined in Table 4.

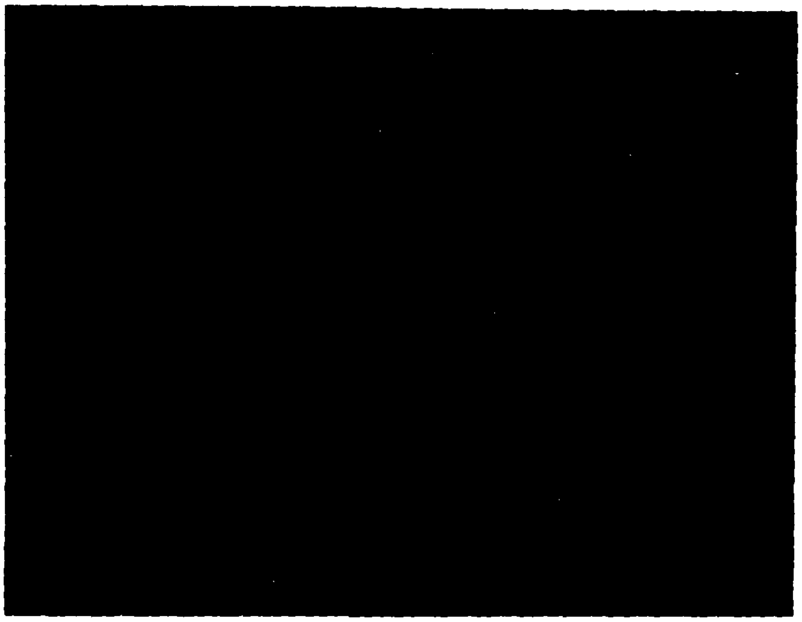


Figure 8. Primed Lap Shear Adherend, Cast Aluminum.

TABLE 3

LAP SHEAR TEST MATRIX

<u>250°F Adhesive System</u>

- R.T., dry
- 180°F, dry
- R.T., after 2 wks. @ 120°F, 100% R.H.
- 180°F, after 2 wks. @ 120°F, 100% R.H.

<u>350°F Adhesive System</u>

- R.T., dry
- 300°F, dry
- 350°F, dry
- R.T., after 2 wks. @ 140°F, 100% R.H.
- 300°F, after 2 wks. @ 140°F, 100% R.H.
- 350°F, after 2 wks. @ 140°F, 100% R.H.

Replications, 5 at each data point with both types of adherends.

TABLE 4

WEDGE CRACK TEST MATRIX

250°F Adhesive System

- Salt spray aging, 3 mos. @ 95°F per ASTM B117
- Humid aging, 3 mos. @ 120°F, 100% R.H.

350°F Adhesive System

- Salt spray aging, 3 mos. @ 95°F per ASTM B117
- Humid aging, 3 mos. @ 160°F, 100% R.H.

Reading of crack length was taken at following times: at initial penetration, 1 hr., 4 hrs., 8 hrs., 24 hrs., 48 hrs., 7 days, 14 days, 1 month, 2 months, 3 months.

Replications, 5 at each data point with both types of adherends.

SECTION 5
DISCUSSION OF RESULTS

The goals of this study should be reviewed before discussing results. First and foremost, the testing and evaluation of the surface preparation for aluminum castings was to be studied. Other factors to be determined included (a) the effects of temperature and humidity on lap shear strength, (b) determining the effects of salt spray and humidity on crack growth, and (c) comparing values gathered from cast aluminum adherends to values obtained using 2024-T3 aluminum.

5.1 LAP SHEAR TEST RESULTS

Lap shear specimens were prepared according to Paragraph 3.3 and were tested as described in Paragraph 4.1. Figure 9 depicts an aluminum casting specimen undergoing this test. Figure 10 shows both failed adherends with the 250°F system, while Figure 11 shows the 350°F system. Lap shear test results are presented in Table 5 and represent an average of five test specimens for each condition. From the limited amount of data obtained, tensile lap shear strengths are slightly lower, but satisfactory, when cast aluminum adherends are compared with 2024-T3 adherends. Comparative strengths between the adherends are generally closer with the 350°F adhesive system than the 250°F system.

5.2 WEDGE CRACK TEST RESULTS

Wedge crack specimens were prepared as stated in Paragraph 3.3, and the test method was done as described in Paragraph 4.2. The results (Tables 6 and 7) represent an average of five specimens for each test condition. Crack growth data, which have generally proven to be a very successful method of evaluating surface preparation, appears to be very similar when comparing cast aluminum and 2024-T3 aluminum.

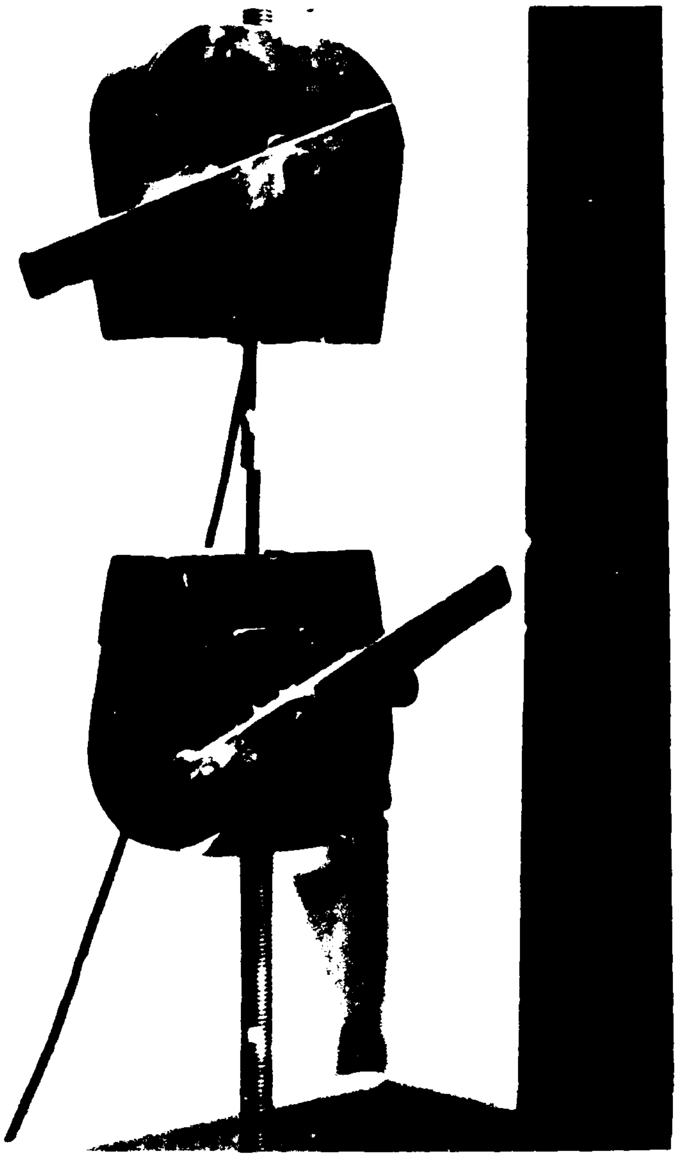
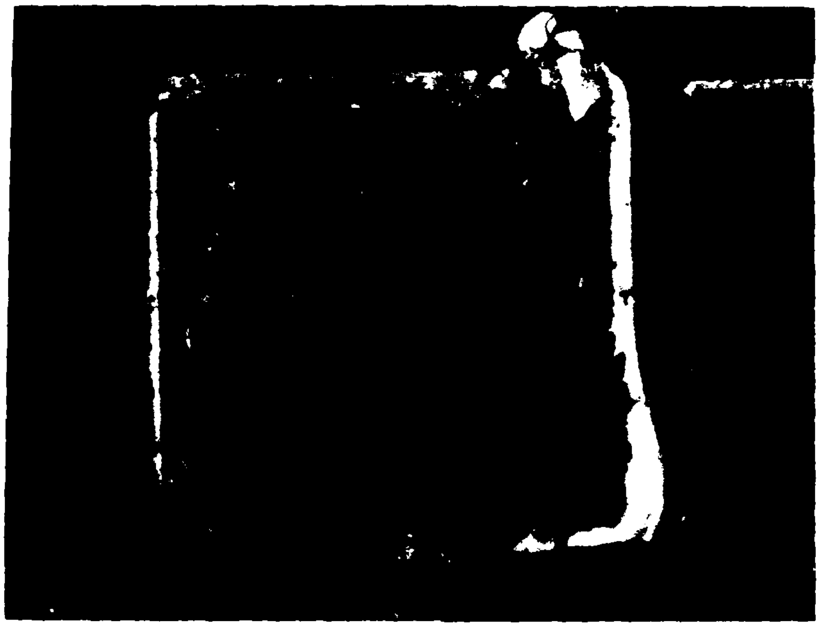


Figure 9. Tensile Lap Shear Test, Cast Aluminum Adherends.



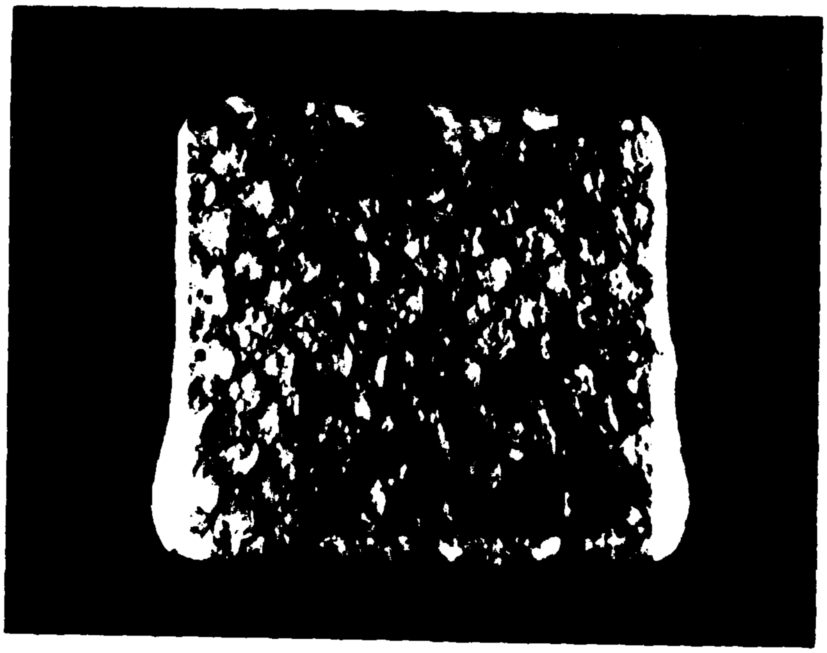


Figure 10. Bond Area of 250°F Adhesive System, Cast Aluminum Lap Shear.

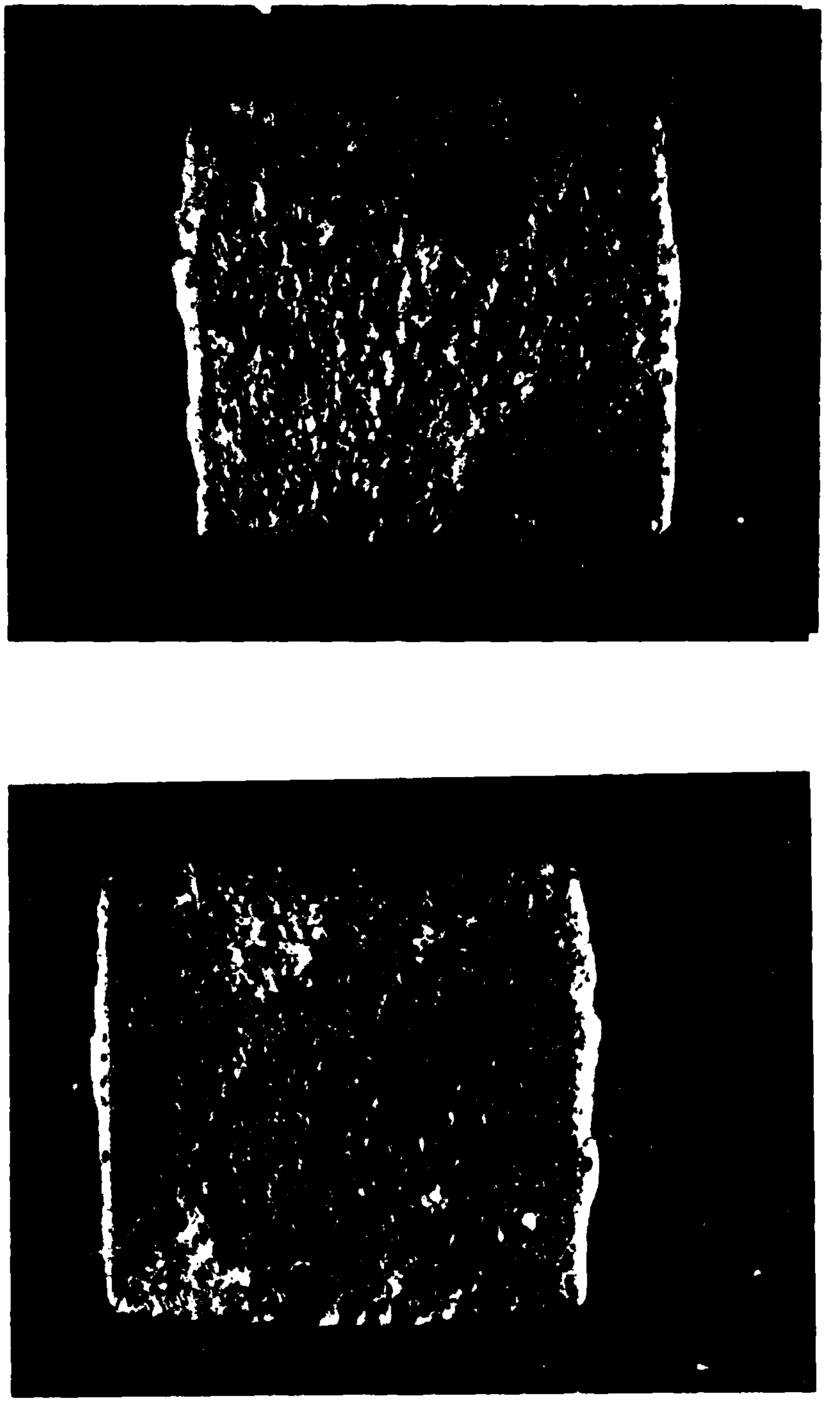


Figure 11. Bond Area of 350°F Adhesive System, Cast Aluminum Lap Shear.

TABLE 5

TENSILE LAP SHEAR DATA,
A357 CAST ALUMINUM vs. 2024-T3 SHEET ALUMINUM

Adhesive System	Test Condition	Aging Condition	Cast Aluminum Lap Shear Strength (psi)	2024-T3 Aluminum Lap Shear Strength (psi)
250°F (EA 9628H)	R.T.	Dry	5690	6510
		Wet	5430	6390
	180°F	Dry	4090	4590
		Wet	3350	4240
350°F (FM-300)	R.T.	Dry	4300	4410
		Wet	4730	4800
	300°F	Dry	1660	2570
		Wet	1780	2440
	350°F	Dry	570	460
		Wet	320	430

TABLE 6

WEDGE CRACK GROWTH DATA,
250°F CURING ADHESIVE SYSTEM,
A357 CAST ALUMINUM vs. 2024-T3 SHEET ALUMINUM

Time	Salt Spray Aging 5% Salt Fog & 95°F		Humid Aging, 120°F and 95-100% R.H.	
	Cast Aluminum EA 9628H	2024-T3 Aluminum EA 9628NW	Cast Aluminum EA 9628H	2024-T3 Aluminum EA 9628NW
Initial	1.3927	1.2957	1.3368	1.3058
1 Hr.	0.0066	0.0288	0.0200	0.0598
4 Hrs.	0.0131	0.0492	0.0200	0.0864
8 Hrs.	0.0195	0.0544	0.0200	0.0916
24 Hrs.	0.0289	0.0630	0.0287	0.0980
48 Hrs.	0.0289	0.0830	0.0287	0.1006
7 Days	0.0456	0.1330	0.0405	0.1227
14 Days	0.0609	0.1719	0.0580	0.1518
1 Month	0.0609	0.1719	0.0628	0.2387
2 Months	0.1390	0.1836	0.1623	0.2899
3 Months	0.1390	0.1993	0.1623	0.3056

TABLE 7

WEDGE CRACK GROWTH DATA,
350°F CURING ADHESIVE SYSTEM (FM-300),
A357 CAST ALUMINUM vs. 2024-T3 SHEET ALUMINUM

Time	Salt Spray Aging		Humid Aging	
	Cast Aluminum	2024-T3 Aluminum	Cast Aluminum	2024-T3 Aluminum
Initial	1.6430	1.8282	1.6033	1.8779
1 Hr.	0.0436	0.0168	0.0714	0.0323
4 Hrs.	0.0588	0.0444	0.0748	0.0345
8 Hrs.	0.0691	0.0444	0.0748	0.0388
24 Hrs.	0.0757	0.0632	0.0842	0.0472
48 Hrs.	0.0957	0.0688	0.0842	0.0472
7 Days	0.1045	0.0688	0.0896	0.0548
14 Days	0.1045	0.0779	0.0993	0.0675
1 Month	0.1045	0.0779	0.1081	0.0675
2 Months	0.1045	0.1039	0.1152	0.0765
3 Months	0.1157	0.1039	0.1298	0.0765