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PART 1

WEATHERING OF ADHESIVE-BONDED LAP JOINTS OF CLAD ALUMINUM ALLOY

H. W. EICKNER

FOREST PRODUCTS LABORATORY

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FOREWORD

This report was prepared by the Forest Products Laboratory under Purchase Order No. 33(038)-51-4326 E. The contract was initiated under Project No. 7340, "Rubber, Plastic and Composite Materials", Task No. 73401, "Structural Adhesives", formerly RDO No. 614-11, "Structural Adhesives", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Mr. F. W. Kuhn acting as project engineer.

This report is the first of a series of reports to be made on the same subject, covering work performed from July 1952 to May 1954.

This report covers an evaluation of the performance of a number of products under specific conditions. The materials tested may not have been developed or intended by the manufacturer for the conditions to which they have been subjected. Any failure or poor performance of a material is therefore not necessarily indicative of the utility of that material under less stringent conditions or for other applications.

ABSTRACT

Lap-joint panels of clad 24S-T3 aluminum bonded with 5 metal-bonding adhesives were exposed to weathering at the Panama Canal Zone; Fairbanks, Alaska; Miami, Fla.; State College, N. M.; and Madison, Wis., with panels being removed for testing after 3 months and 1 year of exposure. Panels were exposed when stressed in bending and in the unstressed condition. Test panels were also exposed to several laboratory-controlled exposure conditions in addition to the weathering exposure.

The exterior exposure of panels for 1 year at the Panama Canal Zone has caused an appreciable deterioration in the quality of bonds with 2 of the 5 adhesives, and these same 2 adhesives have also shown some deterioration during 1 year of exposure at Miami, Fla. There was no deterioration in the bonds exposed for 1 year at the other exposure sites.

The adhesives showing deterioration were of the phenolic-neoprene-nylon and epoxy-resin types, with the deterioration of the phenolic-neoprene-nylon being the more drastic. The phenolic-neoprene-nylon bonds were deteriorated in both the stressed and unstressed condition while the epoxy-resin bonds were not seriously affected, except in the stressed condition.

Laboratory tests consisting of continuous exposure at 120° F. and 97 percent relative humidity or a cyclic exposure involving the same temperature and humidity provided results that showed good correlation with the results obtained after exterior exposure in the Panama Canal Zone.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

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INTRODUCTION

Various laboratories have investigated the durability of metal-bonding adhesives used in aircraft fabrication by exposing bonded lap-joint specimens to salt water, tap water, and aircraft fluids, as described in Military Specification MIL-A-8331 (USAF) "Adhesive, Aircraft Structural, Metal to Metal," and to other laboratory exposures involving high humidities and high and low temperatures.

It was the purpose of this present study to investigate further the durability of selected metal-bonding adhesives by exposing bonded lap-joint panels of clad 24S-T3 aluminum to exterior weathering in various climates. Because weather resistance of adhesive bonds to metals may be affected by the character of the metal surface at the time of bonding, all of the panels were prepared for bonding by the sulfuric acid-sodium dichromate etch treatment. This treatment had been found, in previous studies,[1], [2] to result in bonds to this alloy that generally showed good resistance to corrosion during 30-day salt-water spray tests. Bonded lap-joint panels for this present study were exposed to weathering in both the unstressed and stressed conditions. Stresses were applied by bending the bonded panels.

Several continuous and cyclic exposures under controlled laboratory conditions were also included to determine if there might be a correlation between the results of the laboratory tests and the weathering tests.

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[1] Eickner, H. W. A Study of Methods for Preparing Clad 24S-T3 Aluminum Alloy Sheet Surfaces for Adhesive Bonding. Forest Products Laboratory Report No. 1813-A, 1950.

[2] Eickner, H. W. Adhesive Bonding Properties of Various Metals as Affected by Chemical and Anodizing Treatments of the Surfaces. Forest Products Laboratory Report No. 1842, Revised 1954.

I. PROCEDURE

Type and Number of Test Panels

Test panels of 0.064-inch 24S-T3 clad aluminum alloy (Federal Specification QQ-A-362) were prepared by bonding together, with a 1/2-inch overlap, two 4- by 8-inch pieces of the metal to result in a lap-joint panel having a width of 8 inches and a length of 7-1/2 inches. Five commercially available adhesives were used, and 108 test panels were prepared with each adhesive except Bloomingdale PA-101, with which 46 test panels were prepared.

Adhesives

The adhesives used in bonding these lap-joint test panels were:

Metlbond MN3C Nylon Tape - a high-temperature-setting adhesive formulation of neoprene, nylon, and phenol resins supported as a film on a nylon-fabric tape.

Epon VI Adhesive - an adhesive formulation of epoxy resins.

Scotchweld Bonding Film No. 585 - a high-temperature-setting formulation of acrylonitrile-butadiene rubber and phenol resin in the form of an unsupported tape.

Bloomingdale FM-47 - a high-temperature-setting formulation of the vinyl and phenolic type.

Bloomingdale PA-101 - a high-temperature-setting formulation of acrylonitrile-butadiene rubber and phenol resins. (Only 46 test panels were prepared with this adhesive formulation.)

Adhesive Bonding Conditions

The aluminum alloy sheets, sheared to the proper size and edges deburred by light hand filing, were prepared for bonding by wiping them with a clean cloth saturated in fresh acetone and immersing them for 10 minutes at 140° to 160° F. in a solution of 10 parts by weight concentrated sulfuric acid, 1 part sodium dichromate, and 30 parts water. The solution was then rinsed from the sheets with warm water, and the water was quickly dried from the surface of the metal by a circulating fan.

These metal pieces were then bonded according to the following bonding conditions, which were within the range of bonding conditions recommended by each of the adhesive manufacturers.

Metlbond MN3C Nylon Tape.--Four medium spray coats of the adhesive liquid (8 percent solids) were applied to each of the metal surfaces. A 15-minute period between coats and a final period of 4 hours was allowed for air-drying. This resulted in a dry film thickness of approximately 0.0015 inch. One layer of the tape adhesive was then placed between the faying surfaces, and the entire assembly was pressed at 50 pounds per square inch and held for 30 minutes after reaching a glueline temperature of 330° F. The pressing of these panels was started at a press-platen temperature of about 150° F., and this temperature was increased slowly so that the total time in the press was approximately 1-1/2 hours.

Epon VI Adhesive.--One brush coat of liquid adhesive, catalyzed with 6 parts by weight of curing agent A to 100 parts of the resin, was applied to both faying surfaces. The lap-joint panels were then assembled immediately and cured for 45 minutes at 200° F. under a pressure of 5 to 10 pounds per square inch.

Scotchweld Bonding Film No. 585.--One layer of the adhesive film (0.005 inch thick) was assembled between the faying surfaces. These joints were then cured for 30 minutes at a glueline temperature of 330° F. under a pressure of 150 pounds per square inch.

Bloomingdale FM-47.--Two double-pass spray coats of the liquid adhesive, thinned 1-1/2 parts by volume of its own thinner to 1 part of adhesive, were applied to each of the faying surfaces (0.002-inch film) with 30 minutes of air-drying between coats, and 18 hours of air-drying after the final coat. The adhesive films were then pre-cured for 1 hour at 150° F. in an oven followed by assembly of the joints and curing for 24 minutes at 300° F. in a hot press, the first 9 minutes without pressure and the last 15 minutes at a pressure of 200 pounds per square inch.

Bloomingdale PA-101.--Two brush coats of the adhesive, prepared by thoroughly mixing together the 3 adhesive components, were applied to each faying surface, with 60 minutes of air-drying between coats and a final air-drying period of 16 hours. The adhesive film (approximately 0.0015 inch thick) was then precured for 1 hour at 150° F. before assembly of the joint and cured for 15 minutes at a glueline temperature of 300° F. and a pressure of 100 pounds per square inch.

Exposure and Testing Specimens

The test panels (108 panels with each adhesive except Bloomingdale PA-101, with which 46 panels were prepared) were trimmed to 5 inches wide by removal of two 1-inch specimens, one from each end, for tests as controls. Test panels for exposure under the conditions described below were then randomly selected from the panels prepared with each adhesive. The distribution of the test panels among the various exposure conditions is given in table 1. Tests on all of the 1-inch wide specimens cut from the panels as controls or after exposure were made by loading them to failure in tension at a rate of 300 pounds per minute. The ends of the specimens were held in 1-inch wide Templin-type grips that extended down from the ends of the specimens to within 1 inch of the edge of the lap. Testing was done at a temperature of 72° to 76° F.

A. Control Tests.--Two 1-inch wide specimens, one from each end of all panels prepared in this study, were cut and tested as controls to determine the quality of bonds before exposure began.

B. Laboratory exposure tests - 120° F. and 97 percent relative humidity.--Nine unstressed panels with each adhesive (excluding Bloomingdale PA-101 adhesive) were exposed continuously at 120° F. and 97 percent relative humidity. Three panels with each adhesive were removed from exposure after 3 and 6 months, and each was cut into four 1-inch wide specimens and tested. Another series of these panels **is** being continued in exposure for 3 years.

C. Laboratory exposure tests - Repeated cyclic exposure to 120° F. and 97 percent relative humidity; 158° F. and 20 percent relative humidity; and 0° F.--Twelve unstressed panels with each adhesive (excluding Bloomingdale PA-101 adhesive) were exposed to repeating cycles each consisting of 2 weeks at 120° F. and 97 percent relative humidity, followed by 2 weeks at 158° F. and 20 percent relative humidity and then by 1 week at 0° F. ± 10° F. Three panels with each adhesive were removed from exposure after 2, 5, 7, and 10 cycles, and each was cut into four 1-inch wide test specimens and tested.

D. Laboratory exposure tests - Salt-water boil.--Nine unstressed panels with each adhesive (excluding Bloomingdale PA-101 adhesive) were exposed to boiling in a saturated sodium chloride solution for periods up to 6 hours. Three panels with each adhesive were removed after 1, 3, and 6 hours of exposure, and each was cut into four 1-inch wide test specimens and tested.

E. Laboratory exposure tests - Salt-water spray.--Five unstressed panels with each adhesive (excluding Bloomingdale PA-101 adhesive) were exposed by the Materials Laboratory, Wright Air Development Center to the standard 30-day exposure to salt-water spray as specified in part 5, section IV of Federal Specification QQ-M-151a, "General Specifications for the Inspection of Metals." After exposure, the test panels were each cut into four 1-inch wide specimens and tested.

F. Laboratory exposure tests - 80° F. and 65 percent relative humidity.--Five stressed and five unstressed panels with each adhesive (excluding Bloomingdale PA-101 adhesive) are being exposed continuously at 80° F. and 65 percent relative humidity. These panels are to be each cut into four 1-inch wide specimens and tested after 3 years of exposure.

G. Exterior exposure.--With each of the adhesives, Metlbond MN3C Nylon Tape, Epon VI, Scotchweld No. 585, and Bloomingdale FM-47, 15 test panels (trimmed to 5 inches wide after removal of control specimens), 9 unstressed and 6 stressed, were exposed on the roof of the Forest Products Laboratory at Madison, Wis.; on a ground-level, open site at the University of Alaska, Fairbanks, Alaska; and on a ground-level site shaded by trees at the Naval Research Laboratory Tropical Exposure Site in the Panama Canal Zone, near Ft. Sherman on Limon Bay. Nine unstressed panels bonded with each adhesive were also exposed on a ground-level, open site at New Mexico College of Agriculture and Mechanical Arts, State College, N. M. and nine were exposed on a roof 50 yards from the seashore by the South Florida Testing Service, Miami, Fla. Panels bonded with Bloomingdale PA-101 adhesive were exposed at all sites, with the exception of Madison, Wis.

The stressed panels were mounted as shown in figure 1 over zinc-chromate-primed steel bending frames to give a 0.25-inch deflection at the center in a center-load, 6-inch span flexure test. (Maximum computed tensile stress in the metal for this span and deflection is 31,000 pounds per square inch. This is approximately 55 percent of the computed maximum tensile stress developed in the metal when the minimum required load of 150 pounds is applied in the standard bend test of Military Specification MIL-A-5090B.)

Both the stressed and unstressed panels were mounted on preservative-treated wood frames (as shown in figs. 2 and 3) with the edge of the overlap on the exposed face parallel to the ground and facing downward. The unstressed specimens were mounted on aluminum-painted, wood-spacer blocks attached to the frames. The panels were exposed to the south and at an angle of 45 degrees from the vertical. These metal bonds were exposed unprotected, without any paint coating protecting the metal or adhesive joint.

Three unstressed panels and two stressed panels for each adhesive were removed after 3 and after 12 months of exposure. These panels were each cut into four 1-inch wide specimens and tested. Another series of these panels are being continued in exposure for 3 years.

II. RESULTS

The results of the lap-joint tests made on the adhesive bonds to aluminum after laboratory-controlled exposures and after exterior exposures for periods up to 1 year in various climatic conditions are given in tables 2, 3, and 4.

Control Tests

The results of the average control tests (table 2, exposure A) for all end specimens cut from each of the bonded panels before exposure indicated that all panels included in this study met the requirements of Military Specification MIL-A-8331 (USAF) for joint strength at 72° to 76° F. (2,500 pounds per square inch), and that in general the joint strength was within the range normally obtained in tests by the adhesive manufacturer. A few extra panels were prepared with each adhesive so that any panels in which the control tests indicated substandard bond quality were immediately eliminated from the study.

For the purpose of determining if there has been any deterioration during exposure (tables 2, 3, and 4), the values for percent of control strength after exposure were computed by using the average control test values obtained from the panels exposed and tested at the particular exposure condition rather than the average control test value for all panels bonded with the particular adhesive.

Laboratory Exposure Tests

Of the laboratory exposure conditions used (table 1), the 6 months' continuous exposure at 120° F. and 97 percent relative humidity (exposure B), and the exposure for 5 to 10 cycles in the cyclic condition (exposure C) involving this same 120° F. and 97 percent relative humidity condition were the most severe. In these exposures, Scotchweld No. 585 and Bloomingdale FM-47 adhesive did not show definite loss of bond quality. Metlbond MN3C Nylon Tape and Epon VI adhesives, however, did show definite losses in strength in these exposures. Even the 3 months' continuous exposure in condition B, or 2 exposure cycles of condition C, had reduced the strength of bonds made with Metlbond MN3C Nylon Tape to less than 70 percent of the original control strength, and 6 months' continuous exposure or 5 exposure cycles had reduced the strength to less than 15 percent of the original control strength. This deterioration of the bonds made with Metlbond MN3C Tape was generally uniform with all specimens across a panel and between panels.

Bonds made with Epon VI adhesive also generally showed a decrease in strength under these two exposure conditions. The deterioration, however, was not so consistent as that observed with Metlbond MN3C Tape.

Some panels bonded with Epon VI showed better resistance to deterioration than others, particularly in exposure condition C, and the bond strength after exposure varied considerably from the end to the center of some panels. The average bond strength after 5 to 10 cycles of the cyclic condition was less than 65 percent of the original control strength. There, however, has not been any progressive deterioration of joints with Epon VI between 5 and 10 cycles of this cyclic exposure as noted for Metlbond MN3C Tape. After 6 months of continuous exposure at 120° F. and 97 percent relative humidity, the bonds made with Epon VI had only 41 percent of the original control strength.

The contact areas of the failed specimens bonded with the two adhesives that showed a decrease in strength under these two exposure conditions generally showed more failure in adhesion to the metal than was observed in the original tests. Corrosion of the metal was noted in some areas of the bond when there was a large decrease in bond strength.

The exposure of specimens to a 30-day salt-water spray condition (exposure E) was also found to cause some decrease in bond quality in those panels bonded with Metlbond MN3C Tape and Scotchweld 585. Only Metlbond MN3C Tape, however, failed to have an average strength of 2,000 pounds per square inch as required after 30-days of salt-water spray exposure by Military Specification MIL-A-8331 (USAF).

Boiling the test panels for periods up to 6 hours in concentrated salt-water solution (exposure D) did not cause deterioration of any of the adhesive bonds included in this study.

Climatic Exterior Exposure Tests

The strength of the bonds after exterior exposures at various sites for periods up to 1 year (tables 3 and 4) indicated in general that the strength was more than 80 percent of the strength of the original control panels with the following exceptions:

Panama Canal Zone.--Bonds made with Metlbond MN3C Nylon Tape had only 70 percent of their original strength after 3 months' exposure in the unstressed condition and 57 percent in the stressed condition, and after 12 months' exposure the unstressed bonds with this adhesive had decreased to 28 percent of the original strength, and all of the stressed bonds failed on the frame or while being removed from the frame.

Bonds made with Epon VI adhesive had slightly less than 80 percent of their original joint strength after 3 and 12 months' exposure for the unstressed panels, and the stressed panels had decreased in strength after 12 months of exposure so that one panel failed in handling and the other panel averaged only 13 percent of the original strength. A considerable degree of corrosion of the aluminum was noted in these panels.

Florida.--The unstressed panels of both Metlbond MN3C Tape and Epon VI showed slightly less than 80 percent of their original bond strength after 12 months of exposure, and there was evidence of some corrosion in the bond line.

In general, the continuous exposure of bonded but unstressed aluminum specimens for 6 months at 120° F. and 97 percent relative humidity was a more severe condition than the 30-day salt-water spray exposure and may be considered to be representative of at least 1 year of exterior exposure in the Panama Canal Zone. Stressing of the adhesive bonds by flexural loading during exterior exposure accelerated the deterioration for those bonds showing some deterioration. There has been no deterioration, however, in any of the bonds exposed for 1 year at Madison, Wis.; Fairbanks, Alaska; or State College, N. M., and only 2 of the 5 types of adhesive bonds exposed at Miami, Fla., and Panama Canal Zone showed deterioration during this period. In each case where significant deterioration of bond strength was noted, some corrosion of the metal was also observed.

Table 1.--Distribution of adhesive-bonded lap-joint aluminum panels in interior and exterior exposure tests[1]

Exposure	Total number of panels[2]	Stressed: Number of panels	Stressed: Exposure time	Unstressed: Number of panels	Unstressed: Exposure time
Interior[3]					
80° F., 65 percent relative humidity	10	5	36 months	5	36 months
120° F., 97 percent relative humidity	9			3	3 months
				3	6 months
				3	36 months
Repeated cycles, 120° F., 97 percent relative humidity; 158° F., 20 percent relative humidity; 0° F.	12			3	2 cycles
				3	5 cycles
				3	7 cycles
				3	10 cycles
Boiling salt water	9			3	1 hour
				3	3 hours
				3	6 hours
Salt water spray	5			5	30 days
Exterior					
Madison[3]	15	2	3 months	3	3 months
		2	12 months	3	12 months
		2	36 months	3	36 months
Panama	15	2	3 months	3	3 months
		2	12 months	3	12 months
		2	36 months	3	36 months
Alaska	15	[3]2	3 months	3	3 months
		2	12 months	3	12 months
		2	36 months	3	36 months
New Mexico	9			3	3 months
				3	12 months
				3	36 months
Florida	9			3	3 months
				3	12 months
				3	36 months

[1] Two specimens, one from each end of all panels prepared, were tested for quality of bond before exposure.

[2] Total number of panels bonded with each adhesive, except as noted by footnote 3.

[3] Panels bonded with Bloomingdale PA-101 were not exposed.

Table 2.--Results of shear tests on adhesive-bonded 1/2-inch lap joints of 0.064-inch clad 24S-T3 aluminum alloy before and after various laboratory-controlled exposure conditions

Exposure	Test results for -- [1]																			
	Metlbond MN3C Nylon Tape					Epon VI					Scotchweld Bonding Film 585					Bloomingdale FM-47				
	Shear strength				Average cohesion failure	Shear strength				Average cohesion failure	Shear strength				Average cohesion failure	Shear strength				Average cohesion failure
	Average	Minimum	Maximum	Percent of control strength[2]		Average	Minimum	Maximum	Percent of control strength[2]		Average	Minimum	Maximum	Percent of control strength[2]		Average	Minimum	Maximum	Percent of control strength[2]	
	P.s.i.	P.s.i.	P.s.i.		Percent	P.s.i.	P.s.i.	P.s.i.		Percent	P.s.i.	P.s.i.	P.s.i.		Percent	P.s.i.	P.s.i.	P.s.i.		Percent
A. Original control tests - 108 panels	2,820	2,500	3,457	....	76	3,976	3,218	4,715	....	99	3,405	2,910	3,880	....	68	4,976	4,320	5,600	....	57
B. 120° F. and 97 percent relative humidity																				
3 months	1,880	1,500	2,370	69	[3]45	3,295	2,520	3,970	80	[3]98	3,795	3,300	4,050	109	55	4,435	4,090	4,700	93	58
6 months	334	85	780	12	[2]16	1,685	310	3,117	41	[3]51	3,990	3,489	4,234	116	54	5,012	4,000	5,400	99	56
C. Cyclic - 120° F. and 97 percent relative humidity, 158° F. and 20 percent relative humidity, and 0° F.																				
2 cycles (10 weeks)	1,513	320	2,590	53	44	3,422	2,830	4,420	89	95	4,183	3,820	4,600	120	53	4,668	3,640	5,220	92	63
5 cycles (25 weeks)	364	98	754	13	[3]23	2,288	490	3,500	57	[3]66	4,502	4,260	4,770	130	56	4,826	4,205	5,191	100	72
7 cycles (35 weeks)	176	0	570	6	[2]0	1,443	540	2,788	36	[3]45	4,506	4,100	4,830	137	49	4,492	4,100	4,890	90	69
10 cycles (50 weeks)	0	0	0	0	[2]0	2,498	135	3,317	64	[3]60	4,744	4,600	4,960	135	56	4,295	3,840	4,740	87	51
D. Salt-water boil																				
1 hour	2,730	2,600	3,030	96	74	3,856	3,410	4,340	98	99	3,457	3,090	3,790	100	42	4,938	4,120	5,260	98	69
3 hours	2,698	2,340	2,990	94	72	3,848	3,650	4,120	97	98	3,490	3,030	3,750	103	49	5,081	4,840	5,280	99	70
6 hours	2,705	2,250	2,950	95	81	3,645	3,020	4,150	93	98	3,747	3,590	3,860	111	50	5,195	4,880	5,760	104	53
E. Salt-water spray 30 days	1,519	120	2,733	58	[3]33	2,704	766	3,961	68	[3]77	2,974	1,952	3,810	88	[3]48	[4]5,363	4,738	5,772	107	54

[1] The average test results given for the control tests are for 216 specimens (1 specimen from each end of 108 test panels); for the tests B, C, and D for 12 specimens (4 specimens from each of 3 test panels); and for test E for 20 specimens (4 specimens from each of 5 test panels).

[2] The values for percent of control strength are computed using the average original control test values obtained on the end specimens from the same panels exposed and tested at the particular exposure condition.

[3] Some evidence of corrosion of the metal noted in the bond lines.

[4] An average value for only 15 test specimens,as the other test specimens in this group were tested before machine was properly adjusted.

Table 3.--Results of shear tests on adhesive-bonded 1/2-inch lap joints of 0.064-inch clad 24S-T3 aluminum alloy after weathering in various climates

Exterior exposure	Test results for --[1]														
	Metlbond MN3C Nylon Tape					Epon VI					Scotchweld Bonding Film 585				
	Shear strength				Average cohesion failure	Shear strength				Average cohesion failure	Shear strength				Average cohesion failure
	Average	Minimum	Maximum	Percent of control strength[2]		Average	Minimum	Maximum	Percent of control strength[2]		Average	Minimum	Maximum	Percent of control strength[2]	
	P.s.i.	P.s.i.	P.s.i.		Percent	P.s.i.	P.s.i.	P.s.i.		Percent	P.s.i.	P.s.i.	P.s.i.		Percent
Madison, Wis.															
3 months - stressed	2,232	2,052	2,500	83	65	3,628	3,259	3,910	90	98	3,753	3,560	3,900	110	53
3 months - unstressed	2,581	2,320	3,110	89	71	3,522	3,125	4,038	93	99	3,681	3,150	4,060	110	34
12 months - stressed	2,542	2,360	2,740	91	92	3,510	2,808	4,232	83	100	2,742	2,376	3,176	81	52
12 months - unstressed	2,668	2,280	2,896	95	77	3,841	3,488	4,340	96	100	3,779	3,544	3,980	113	60
Panama Canal Zone															
3 months - stressed	1,457	882	1,800	57	[3]17	[4]3,630	3,550	3,730	91	96	3,068	2,916	3,322	92	64
3 months - unstressed	1,947	990	2,625	70	[2]49	3,148	2,682	3,520	79	92	3,431	3,140	3,875	100	64
12 months - stressed	0	0	0	0	[3]0	515	0	1,680	13	[3]16	3,476	3,232	3,616	97	49
12 months - unstressed	723	180	1,652	28	[2]13	3,248	2,528	3,640	78	86	3,340	2,024	3,888	100	53
Fairbanks, Alaska															
3 months - stressed	2,779	2,673	2,895	100	59	3,734	3,333	4,086	91	100	3,544	2,950	4,239	110	61
3 months - unstressed	2,882	2,520	3,177	103	69	3,641	3,317	3,894	94	100	3,883	3,680	4,170	110	63
12 months - stressed	2,797	2,530	2,980	101	78	3,529	2,240	4,040	90	93	3,172	2,970	3,460	93	55
12 months - unstressed	2,598	1,860	3,100	92	82	3,458	3,180	3,800	86	99	3,743	3,630	3,860	111	48
New Mexico															
3 months - unstressed	2,588	2,330	2,958	92	77	4,008	3,622	4,460	100	100	3,610	3,230	4,030	105	67
12 months - unstressed	2,660	2,360	3,128	90	73	3,601	3,384	4,148	92	100	3,995	3,720	4,288	117	62
Florida															
3 months - unstressed	2,621	2,197	3,063	89	59	3,292	3,105	3,500	87	100	3,540	3,187	3,900	105	76
12 months - unstressed	2,119	924	2,724	73	[3]54	3,007	1,324	3,580	76	[3]88	3,650	1,008	4,176	106	[3]55

[1]The average results given are for 8 specimens (4 specimens from each of 2 panels) for the stressed test conditions and for 12 specimens (4 specimens from each of 3 panels) for the unstressed test conditions, except where otherwise noted.

[2]The values for the percent of control strength are computed using the average original control test values obtained on the end specimens from the same panels exposed and tested at the particular exposure condition.

[3]Some evidence of corrosion of metal noted in the bond lines.

[4]Test result for only 1 panel as other test panel for this group was damaged and failed before test.

Table 4.--Results of shear tests on adhesive-bonded 1/2-inch lap joints of 0.064-inch clad 24S-T3 aluminum alloy after weathering in various climates

Exterior exposure	Test results for -- [1]									
	Bloomingdale FM-47					Bloomingdale PA-101				
	Shear strength				Average cohesion failure	Shear strength				Average cohesion failure
	Average	Minimum	Maximum	Percent of control strength[2]		Average	Minimum	Maximum	Percent of control strength[2]	
	P.s.i.	P.s.i.	P.s.i.		Percent	P.s.i.	P.s.i.	P.s.i.		Percent
Madison, Wis.										
3 months - stressed	4,383	3,173	4,885	87	53	......	......	......	....	....
3 months - unstressed	4,690	3,721	5,028	95	50	......	......	......	....	....
12 months - stressed	4,325	3,860	4,720	88	59	......	......	......	....	....
12 months - unstressed	4,934	4,720	5,200	103	43	......	......	......	....	....
Panama Canal Zone										
3 months - stressed	4,802	4,150	5,120	95	70	3,259	2,541	3,627	87	76
3 months - unstressed	5,677	5,019	5,980	114	57	3,843	3,395	4,208	98	93
12 months - stressed	4,291	3,120	4,730	89	69	3,122	2,572	3,928	86	70
12 months - unstressed	5,002	4,452	5,310	100	72	3,644	2,344	4,064	95	78
Fairbanks, Alaska										
3 months - stressed	[3]4,987	4,680	5,320	97	61	......	......	......	....	....
3 months - unstressed	5,406	5,093	5,660	102	66	3,724	3,416	4,180	102	89
12 months - stressed	4,633	4,150	5,050	96	58	3,602	3,260	4,030	96	85
12 months - unstressed	5,241	5,000	5,580	100	68	4,081	3,620	4,500	106	91
New Mexico										
3 months - unstressed	5,212	4,850	5,490	107	50	3,757	3,250	4,130	101	91
12 months - unstressed	4,967	4,650	5,380	100	56	3,620	2,990	4,072	94	77
Florida										
3 months - unstressed	5,423	4,920	6,041	115	54	3,768	2,790	4,425	96	85
12 months - unstressed	5,480	5,260	5,680	102	60	3,880	2,820	4,216	95	[4]89

[1] The average results given are for 8 specimens (4 specimens from each of 2 panels) for the stressed test conditions and for 12 specimens (4 specimens from each of 3 panels) for the unstressed test conditions, except where otherwise noted.

[2] The values for the percent of control strength are computed using the average original control test values obtained on the end specimens from the same panels exposed and tested at the particular exposure condition.

[3] Test result for only 1 panel as other test panel for this group was damaged and failed before test.

[4] Some evidence of corrosion of metal noted in the bond lines.

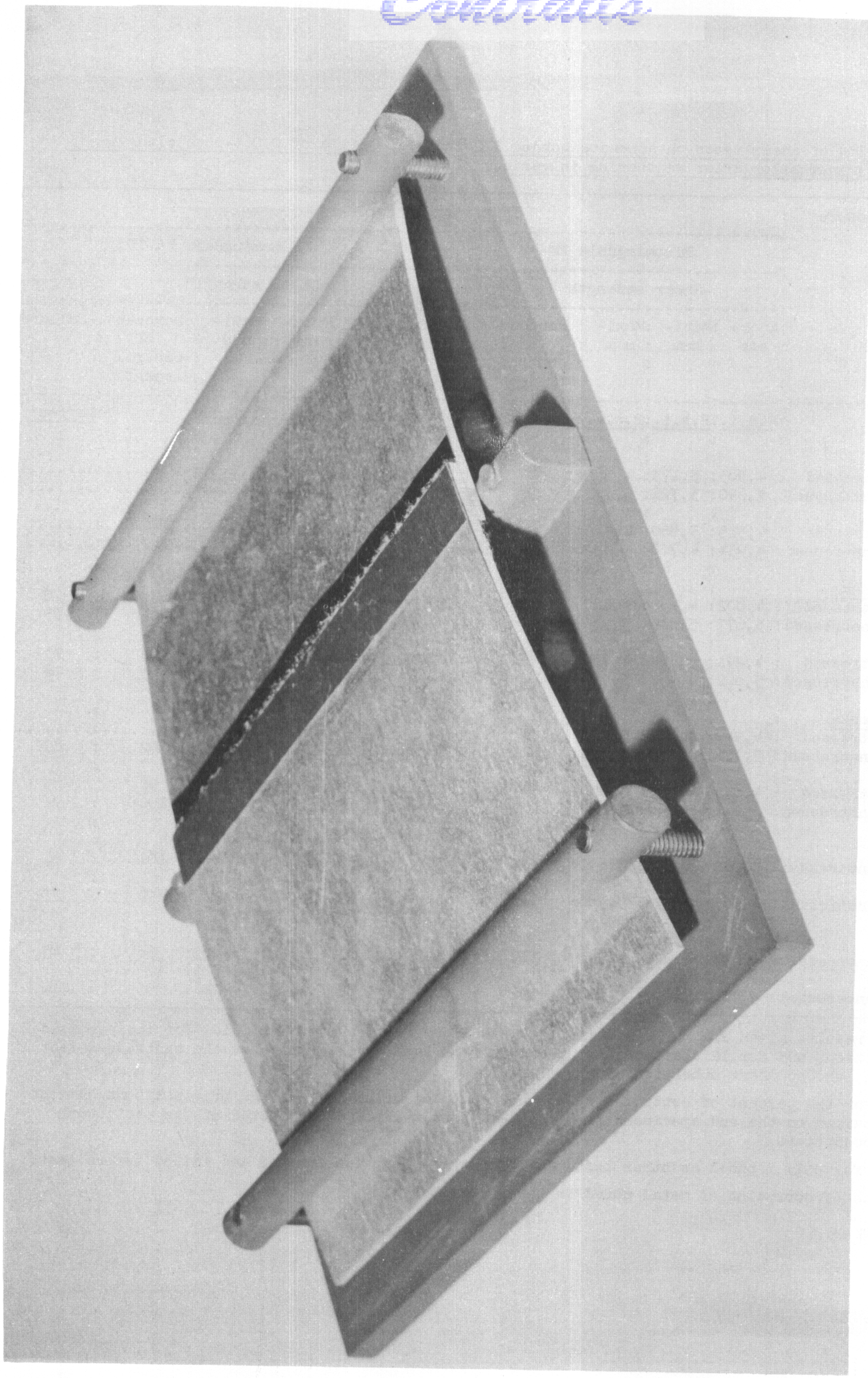

Figure 1. Method of stressing aluminum lap-joint panels in bending to a 0.25-inch deflection over a 6-inch span by means of steel bending frames (zinc-chromate primed).

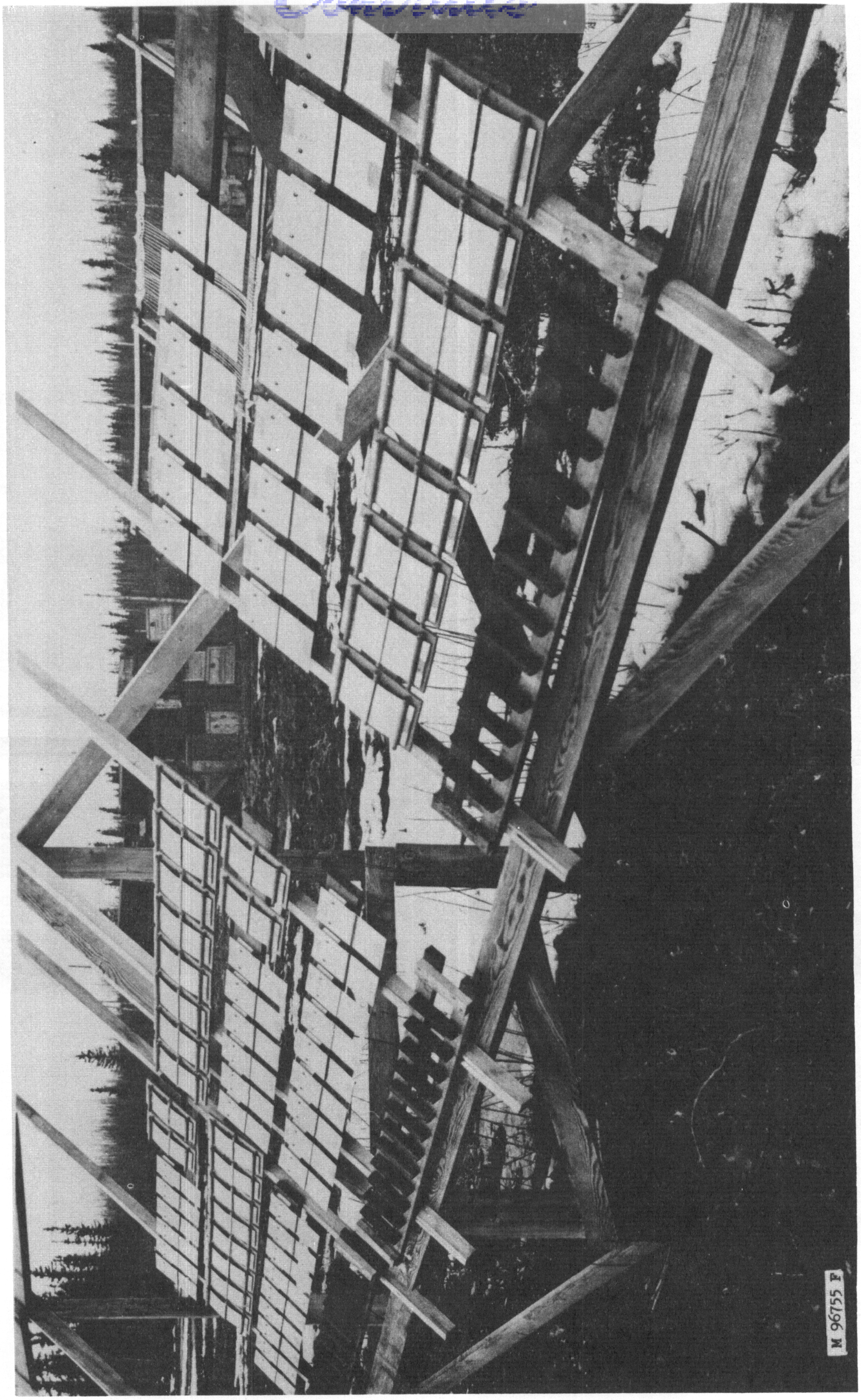

Figure 2. Exposure installation of the lap-joint aluminum panels at Fairbanks, Alaska

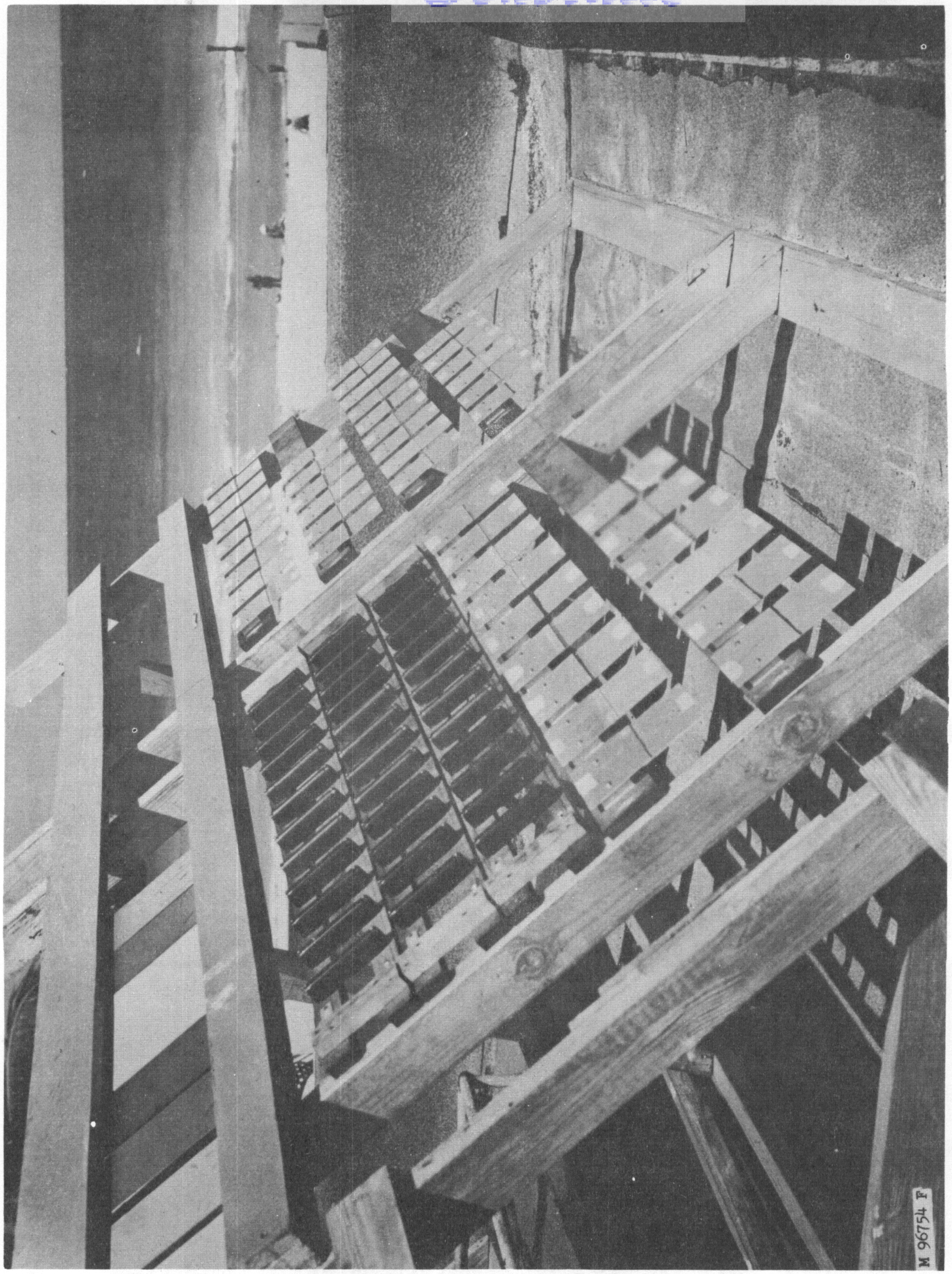

Figure 3. Exposure installation of the lap-joint aluminum panels at Miami, Florida.