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CORROSION FATIGUE OF 2219-T87 ALUMINUM ALLOY

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Materials and Processes Laboratory

February 1986

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16. ABSTRACT

Corrosion fatigue studies were conducted on bare, chemical conversion coated, and anodized 2219-T87 aluminum alloy. These tests were performed using a rotating beam machine running at a velocity of 2500 rpm. The corrosive environments tested were distilled water, 100 ppm NaCl, and 3.5 percent NaCl. Results were compared to the endurance limit in air. An evaluation of the effect of protective coatings on corrosion fatigue was made by comparing the fatigue properties of specimens with coatings to those without.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

TECHNICAL MEMORANDUM

CORROSION FATIGUE OF 2219-T87 ALUMINUM ALLOY

INTRODUCTION

In recent years, the premature and sometimes catastrophic fracture of engineering materials has become an increasingly important consideration in engineering design and research. In many engineering applications, such as the External Tank and Solid Rocket Booster Structures, aluminum alloys are used in their construction. These structures are generally subjected to cyclic loading and exposed to corrosive environments. The combined action of cyclic loading and aggressive environment often results in a significant reduction in fatigue performance compared with that obtained under cyclic loading in inert environments. Due to the planned reusability of many components in the Space Transportation System and their unavoidable exposure to coastal environments, and seawater, it is imperative that we evaluate their fatigue life under these conditions and also the effect of protective coatings where applicable.

PROCEDURES

Tests were conducted using the R. R. Moore High Speed Fatigue Testing Machine. It is a rotating beam machine in which the specimen acts as a simple beam loaded symmetrically at two points. The method of loading and specimen configuration is shown in Figure 1.

The material evaluated was 2219-T87 aluminun alloy. The initial cleaning of the specimens consisted of vapor degreasing followed by a 45 to 60 min. soak in hot alkaline cleaner. The specimens were rinsed in fresh water for a minimum of 15 min., allowed to dry, and finally wiped using alcohol. The specimens were loaded while rotating and the speed adjusted to 2500 rpm. The corrosive solution was dropped on the test section at a rate of 1 drop every 3 to 5 sec. The solutions used in the test were distilled water, 100 ppm NaCl, and 3.5 percent NaCl. All exposed parts of the fatigue tester and test specimens (except for the reduced section) were coated to protect them from the test solution. The protective coatings evaluated in these tests were: chemical conversion and sulfuric acid anodize (0.1 to 0.3 mils thickness). A plastic enclosure was placed around the rotating test components. The solution run off was collected and allowed to drain off. Tests were run until failure or for 10^8 cycles (approximately 28 days). Fatigue tests in air were run (to a maximum of 10^8 cycles) for comparative purposes. The test arrangement is shown in Figure 2.

RESULTS AND DISCUSSION

The data from the test conducted on bare aluminum sample is shown in Table 1, and those with protective coatings in Table 2. This is also plotted in Figures 3, 4, and 5 along with curves showing the lower boundary of the data in each environment.

The corrosion fatigue strength, CFS (alternating stress that a given material will survive 10^8 cycles), of bare aluminum and coated aluminum were determined from these curves and is shown in Table 4.

To determine the relative effect of fatigue strength loss due to the presence of corrosive mediums, ratios of CFS to endurance limits in air were calculated. These results are recorded in Table 4. The corrosion fatigue strength of 2219-T87 aluminum alloy was increasingly reduced as the corrosivity of the environment was increased. A further indication of the effects of corrosion can be seen in Figures 6 through 9 which show SEM fractographs of 2219-T87 aluminum in air and salt water environments. Figure 6 illustrates fatigue fractures of bare 2219 aluminum in air (typical fatigue failure), and 100 ppm NaCl where the predominant failure mode was corrosion. Figures 7, 8, and 9 show corrosion fatigue fractures of bare, conversion coated, and anodized aluminum samples, respectively, all exposed in a 3.5 percent NaCl environment. These fractographs reveal the actual pits that initiated failure.

It is evident, from data in Table 4, that the anodized coating increased the corrosion fatigue strength of this alloy exposed in corrosive environments. However, as expected, it decreased the overall endurance limit in air, where the predominant failure mode is fatigue and not corrosion. The anodized sample had a fatigue strength of 103 MPa (15 ksi) in air, while the bare sample yielded a fatigue strength of 138 MPa (20 ksi) (a ratio of 0.75). The conversion coated samples produced increased corrosion fatigue strength, over bare uncoated samples, with no loss in the overall endurance limit in air.

CONCLUSION

The results of these series of tests clearly indicate the adverse effect of corrosive environments on the fatigue life of this alloy. In all cases the effects were related to the general corrosivity of the test solution; i.e., the effect of 3.5 percent NaCl was greater than 100 ppm NaCl which was greater than distilled water. The corrosion fatigue strength of bare 2219 aluminum ranged from 104 MPa (15 ksi) in distilled water (a ratio to the endurance limit of 0.76) to 20 MPa (2.9 ksi) in 3.5 percent NaCl (a ratio of 0.15).

The effect of the protective coatings is evident as shown in Tables 2, 3, and 4. The corrosion fatigue strength of the conversion coated sample in a 100 ppm NaCl environment was 46 MPa (6.7 ksi) (a ratio of 0.34 to the endurance limit in air). This represents an increase in corrosion fatigue strength of 15 MPa (2.2 ksi) over values for bare aluminum samples in equivalent environments. Even further improvements were obtained with the use of anodized coatings, which yielded a corrosion fatigue strength of 69 MPa (10 ksi) in a 100 ppm NaCl environment. This value represented an increase of 38 MPa (5.5 ksi) in CFS over bare aluminum samples. Similar results were obtained in the 3.5 percent NaCl environments with corrosion fatigue strengths of 20 MPa for bare, 24 MPa for conversion coated, and 30 MPa for the anodized sample.

The results of these series of tests indicate that a significant reduction in fatigue strength can be expected when components are exposed to corrosive atmospheres. It has been determined that protective coatings can be effective in prolonging corrosion fatigue life depending on two factors: the type of coating used and the corrosivity of the atmosphere.

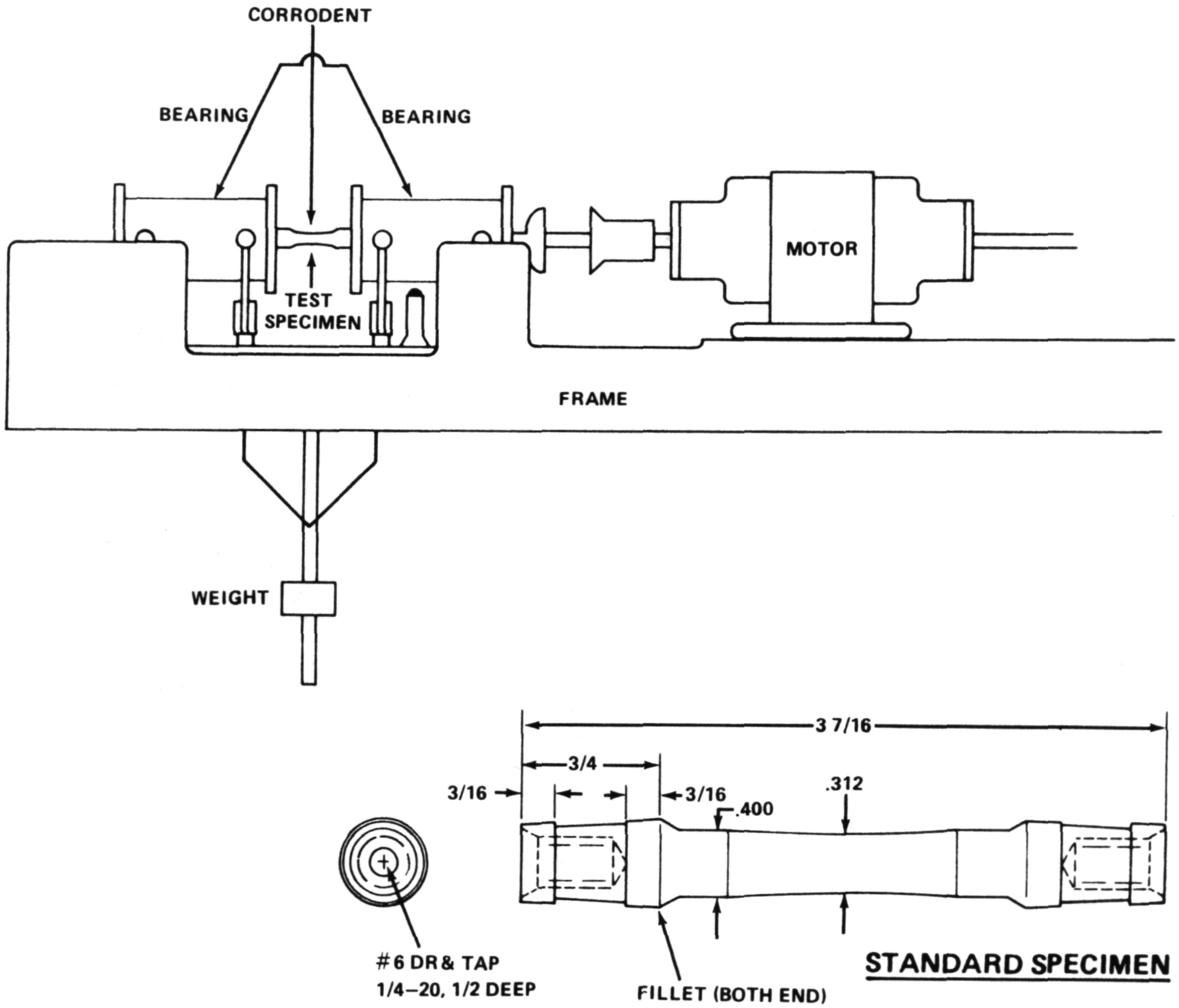


Figure 1. R. R. Moore High Speed Fatigue Testing Apparatus.

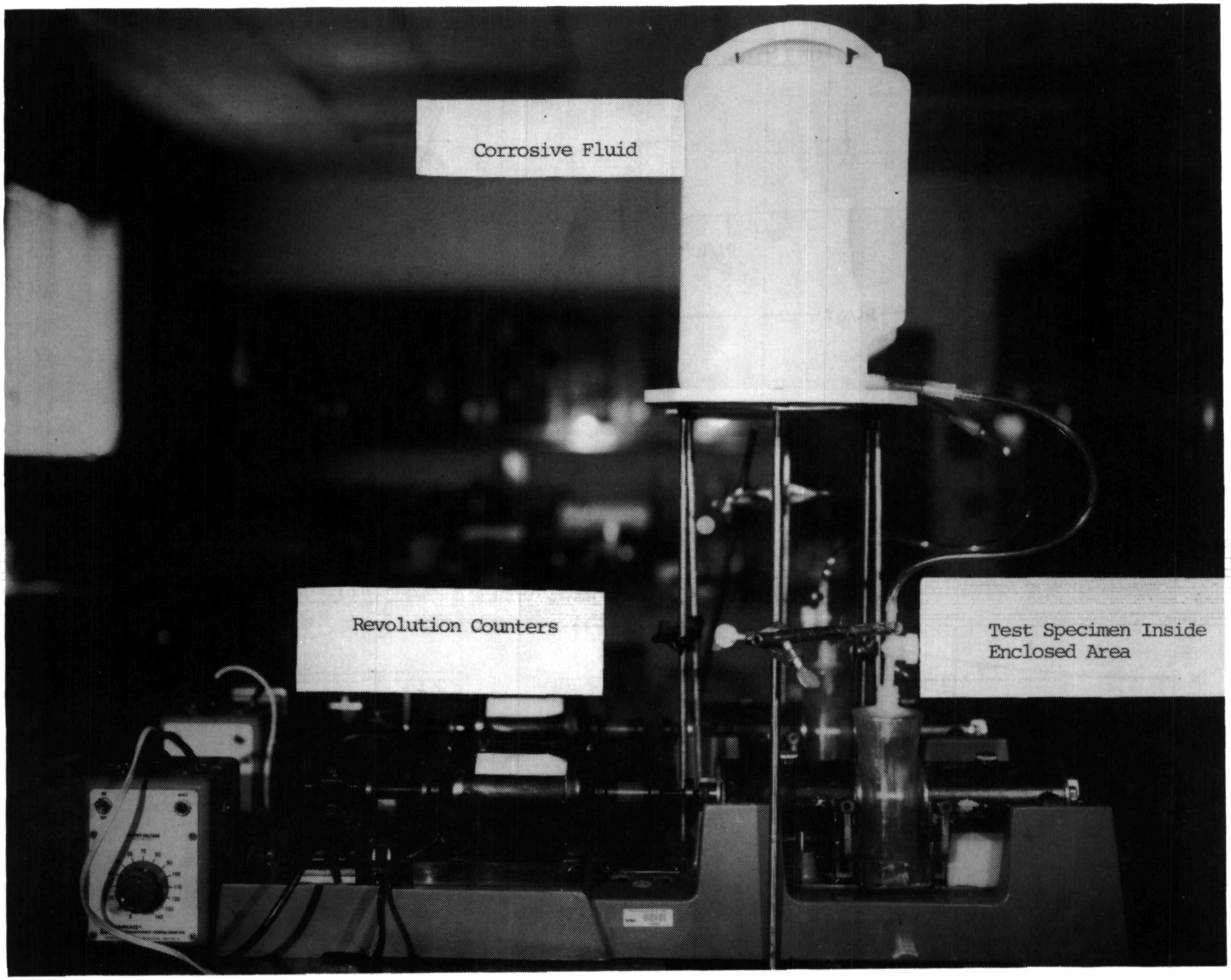


Figure 2. Corrosion Fatigue Test Arrangement.

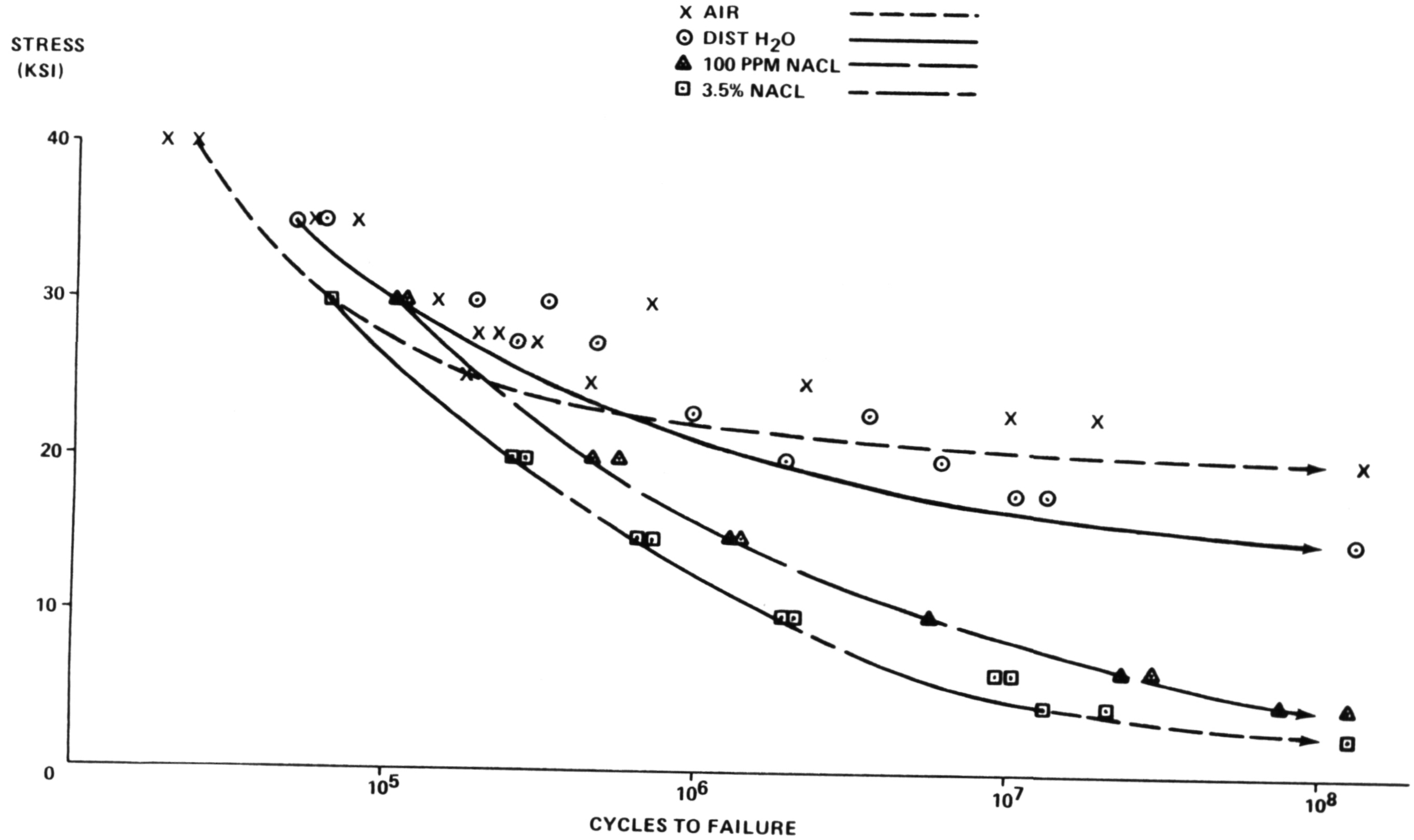


Figure 3. Corrosion fatigue strength of 2219 Al (Bare).

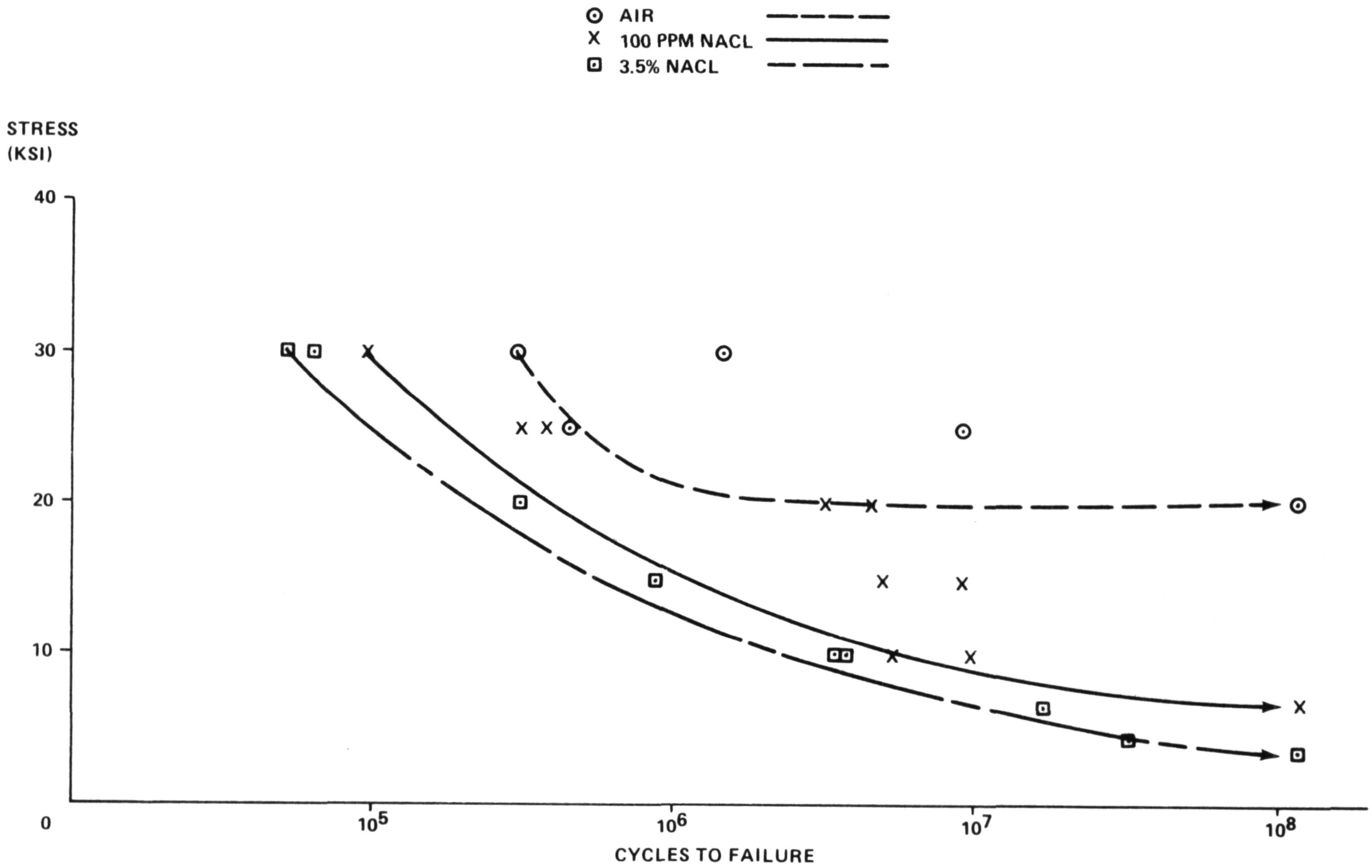


Figure 4. Corrosion fatigue strength of 2219 Al (Conversion Coated).

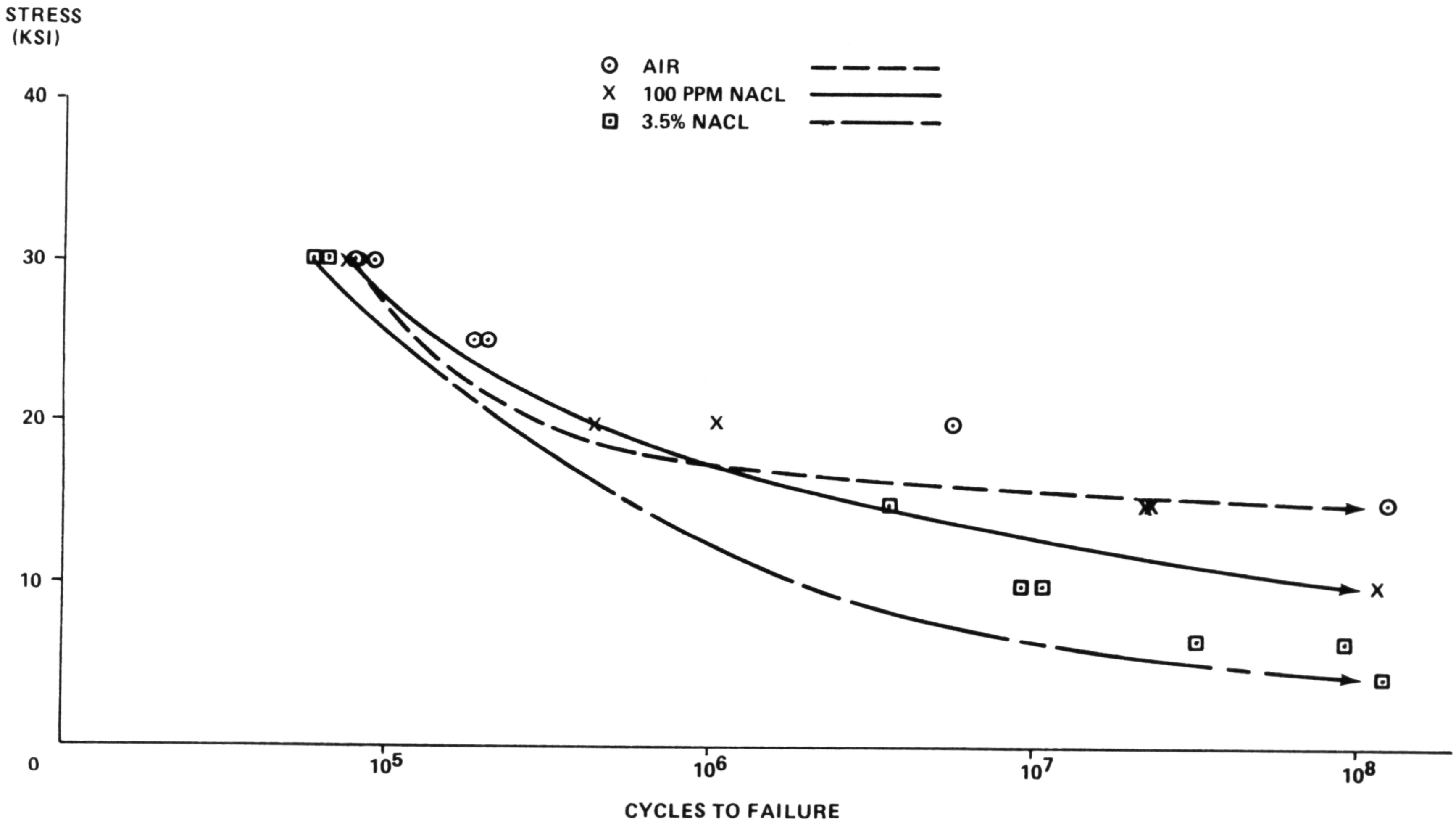
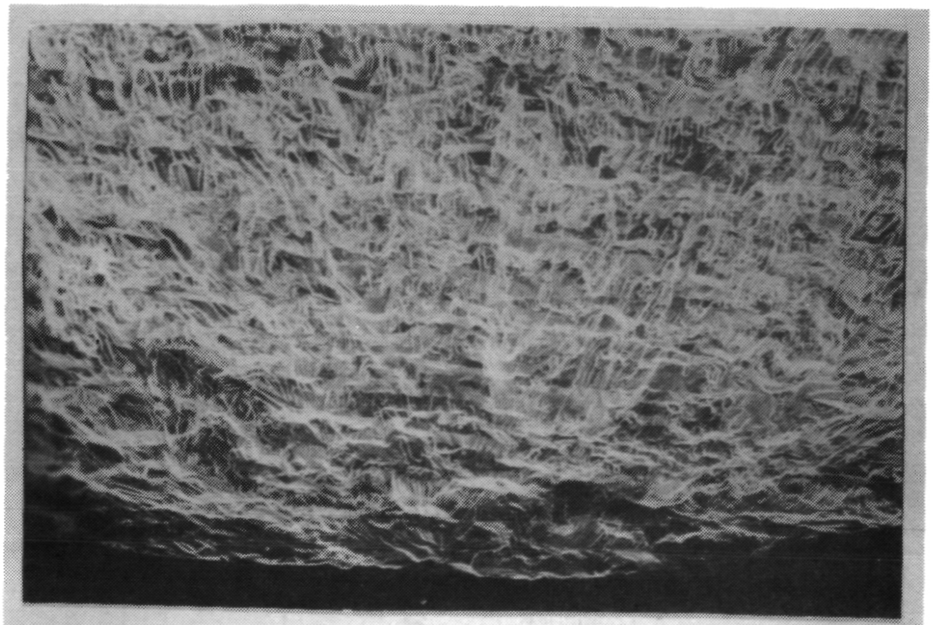
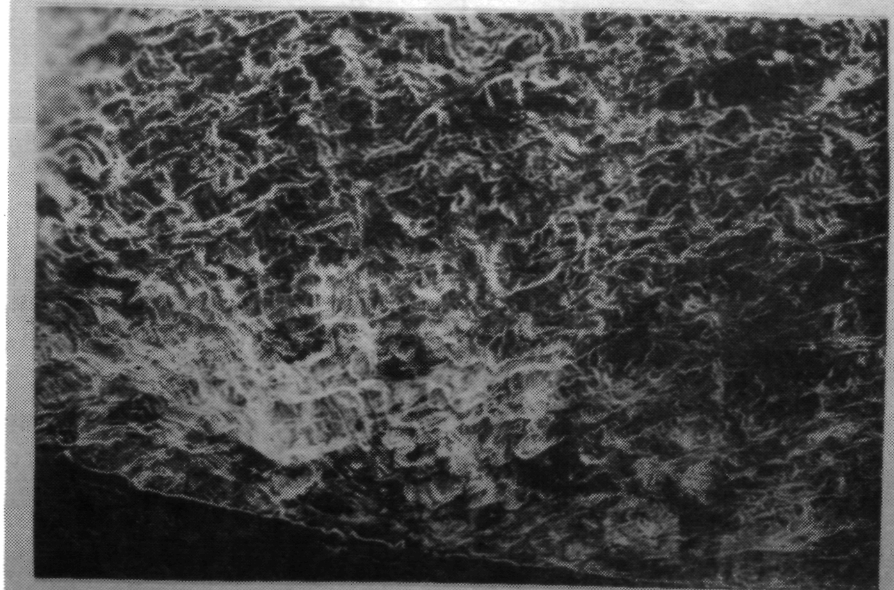


Figure 5. Corrosion fatigue strength of 2219 Al (Anodized).



AIR 19,390,000 CYCLES 50X MAG.



100 PPM NACL 1,333,000 CYCLES 50X MAG.

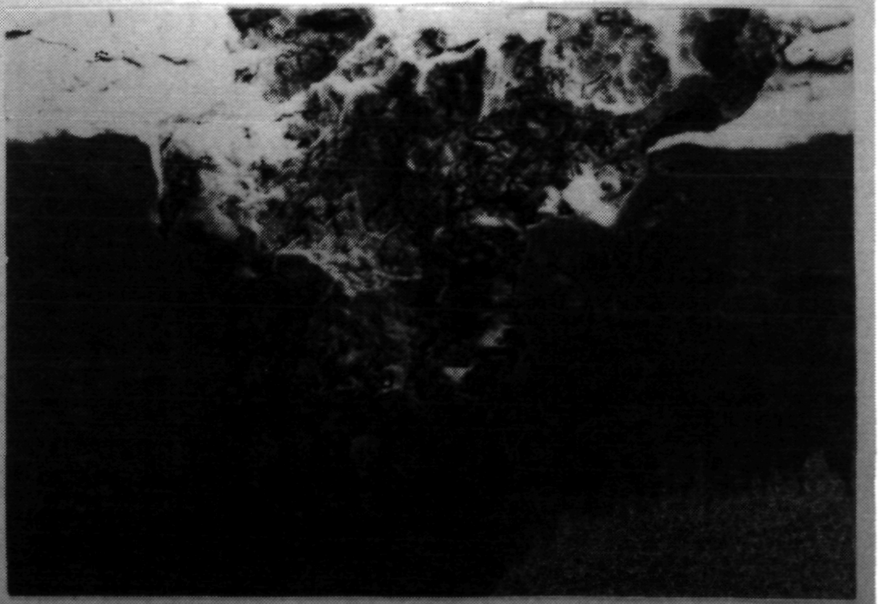
Figure 6. SEM micrographs of fractured 2219 Al (Bare).

50X MAG.

200X MAG.

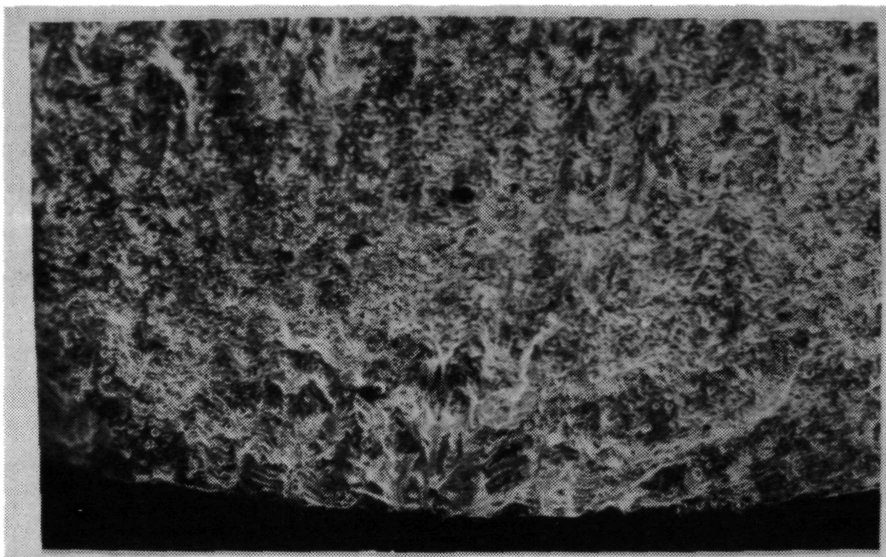
Figure 7. SEM micrograph of fractured bare 2219 Al test sample exposed in 3.5 percent NaCl environment.

50X MAG.

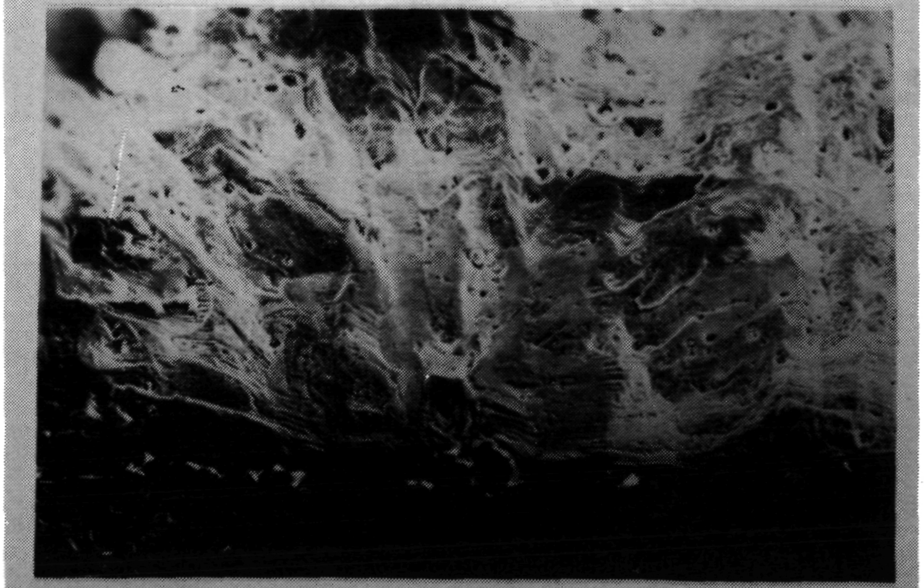


200X MAG.

Figure 8. SEM micrograph of fractured conversion coated 2219 Al test sample exposed in 3.5 percent NaCl environment.



50X MAG.



200X MAG.

Figure 9. SEM micrograph of fractured anodized 2219 Al test sample exposed in 3.5 percent NaCl environment.

TABLE 1. CORROSION FATIGUE OF 2219-T87 Al (BARE)

AIR			DISTILLED H_2O			100 ppm NaCl			3.5% NaCl		
STRESS MPa	(KSI)	CYCLES	STRESS MPa	(KSI)	CYCLES	STRESS MPa	(KSI)	CYCLES	STRESS MPa	(KSI)	CYCLES
275.6	(40)	19,000	241.2	(35)	50,000	206.7	(30)	110,000	206.7	(30)	64,000
275.6	(40)	24,000	241.2	(35)	61,000	206.7	(30)	106,000	206.7	(30)	63,000
241.2	(35)	78,000	206.7	(30)	191,000	137.8	(20)	560,000	137.8	(20)	282,000
241.2	(35)	58,000	206.7	(30)	323,000	137.8	(20)	452,000	137.8	(20)	265,000
206.7	(30)	142,000	189.5	(27.5)	474,000	103.4	(15)	1,296,000	103.4	(15)	725,000
206.7	(30)	692,000	189.5	(27.5)	256,000	103.4	(15)	1,333,000	103.4	(15)	667,000
189.5	(27.5)	81,000	189.5	(27.5)	N/A	68.9	(10)	5,618,000	68.9	(10)	1,923,000
189.5	(27.5)	4,909,000	158.5	(23)	3,538,000	68.9	(10)	5,671,000	68.9	(10)	2,099,000
189.5	(27.5)	303,000	158.5	(23)	976,000	46.2	(6.7)	29,889,000	46.2	(6.7)	9,076,000
192.9	(28)	235,000	137.8	(20)	1,901,000	46.2	(6.7)	23,428,000	46.2	(6.7)	10,463,000
192.9	(28)	196,000	137.8	(20)	6,164,000	32.4	(4.7)	75,555,000	32.4	(4.7)	21,048,000 (b)
172.3	(25)	195,000	124.0	(18)	10,605,000	32.4	(4.7)	107,360,000 (a)	32.4	(4.7)	13,118,000 (b)
172.3	(25)	446,000	124.0	(18)	13,130,000						
172.3	(25)	2,224,000	103.4	(15)	101,205,000 (a)						
158.5	(23)	561,000	103.4	(15)	110,372,000 (a)						
158.5	(23)	10,910,000									
158.5	(23)	19,390,000									
137.8	(20)	107,410,000 (a)									
137.8	(20)	102,429,000 (a)									

(a) TEST TERMINATED, SPECIMEN DID NOT FAIL

(b) LOWEST LIMIT OF MACHINE

TABLE 2. CORROSION FATIGUE OF 2219-T87 Al (CONVERSION COATED)

AIR			100 PPM NaCl			3.5% NaCl		
STRESS MPa	(KSI)	CYCLES	STRESS MPa	(KSI)	CYCLES	STRESS MPa	(KSI)	CYCLES
206.7	(30)	1,459,000	206.7	(30)	93,000	206.7	(30)	52,000
206.7	(30)	314,000	206.7	(30)	99,000	206.7	(30)	64,000
172.3	(25)	446,000	172.3	(25)	314,000	137.8	(20)	N/A
172.3	(25)	9,129,000	172.3	(25)	382,000	137.8	(20)	311,000
137.8	(20)	100,000,000 (a)	137.8	(20)	3,222,000	137.8	(20)	308,000
137.8	(20)	100,000,000 (a)	137.8	(20)	4,566,000	103.4	(15)	873,000
			103.4	(15)	9,122,000	103.4	(15)	858,000
			103.4	(15)	5,008,000	68.9	(10)	3,719,000
			68.9	(10)	5,255,000	68.9	(10)	3,378,000
			68.9	(10)	9,868,000	46.2	(6.7)	10,274,000
			46.2	(6.7)	106,275,000 (a)	46.2	(6.7)	17,484,000
			46.2	(6.7)	102,669,000 (a)	32.4	(4.7)	33,569,000 (b)
			32.4	(4.7)	102,670,000 (a)	32.4	(4.7)	32,241,000 (b)
			32.4	(4.7)	115,334,000 (a)			

(a) TEST TERMINATED, SPECIMEN DID NOT FAIL
(b) LOWEST LIMIT OF MACHINE

TABLE 3. CORROSION FATIGUE OF 2219-T87 Al (ANODIZED)

AIR			100 PPM NaCl			3.5% NaCl		
STRESS MPa	(KSI)	CYCLES	STRESS MPa	(KSI)	CYCLES	STRESS MPa	(KSI)	CYCLES
206.7	(30)	79,000	206.7	(30)	85,000	206.7	(30)	65,000
206.7	(30)	91,000	206.7	(30)	76,000	206.7	(30)	59,000
172.3	(25)	185,000	137.8	(20)	440,000	137.8	(20)	227,000
172.3	(25)	201,000	137.8	(20)	1,056,000	137.8	(20)	441,000
137.8	(20)	5,740,000	103.4	(15)	22,237,000	103.4	(15)	3,606,000
137.8	(20)	283,000	103.4	(15)	22,852,000	103.4	(15)	20,476,000
103.4	(15)	99,686,000 (a)	68.9	(10)	100,250,000 (a)	68.9	(10)	9,111,000
103.4	(15)	99,370,000 (a)	68.9	(10)	100,466,000 (a)	68.9	(10)	10,796,000
						46.2	(6.7)	32,342,000
						46.2	(6.7)	90,573,000
						32.4	(4.7)	63,581,000 (b)
						32.4	(4.7)	101,695,000 (a)

(a) TEST TERMINATED, SPECIMEN DID NOT FAIL
(b) LOWEST LIMIT OF MACHINE

TABLE 4. ESTIMATED CORROSION FATIGUE STRENGTH (CFS) OF 2219 Al

ENVIRONMENT	BARE ALUMINUM			CONVERSION COATED ALUMINUM			ANODIZED ALUMINUM		
	MPa	(KSI)	CFS/E. L. (a)	MPa	(KSI)	CFS/E. L. (a)	MPa	(KSI)	CFS/E. L. (a)
AIR	137.8	(20)	—	137.8	(20)	1.00	103.29	(15)	.749
DISTILLED H_2O	104.0	(15.1)	.755	—	—	—	—	—	—
100 PPM NaCl	31.0	(4.5)	.225	46.14	(6.7)	.335	68.9	(10.0)	.500
3.5% NaCl	19.97	(2.9)	.145	24.10	(3.5)	.175	30.29	(4.4)	.220

(a) RATIO OF CFS TO THE ENDURANCE LIMIT OF BARE AL. IN AIR

APPROVAL

CORROSION FATIGUE OF 2219-T87 ALUMINUM ALLOY

By Vernotto C. McMillan

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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