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AN IMPROVED STRESS CORROSION TEST MEDIUM FOR ALUMINUM ALLOYS

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TECHNICAL MEMORANDUM

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INTRODUCTION

Alternate immersion in 3.5 percent sodium chloride solution is the most widely used accelerated test method in the United States for evaluating the stress corrosion cracking (SCC) resistance of metal alloys, especially aluminum. Unfortunately, this solution when prepared with both high purity salt and water causes excessive pitting corrosion of the high strength aluminum alloys, and this interferes with SCC evaluation. Any media that causes pronounced pitting of the test specimen is undesirable because the tensile stresses at the tip of the pits are difficult, if not impossible, to calculate; and the net section stress is normally greater than the original applied stress.

A previous investigation was undertaken to find a test method that would discriminate among the aluminum alloys having low, intermediate, and high resistance to SCC and not be as corrosive as alternate immersion in salt water [1]. This test indicated that substitute ocean water per ASTM-D1141-52 was very discriminating and was considerably less aggressive to aluminum than salt water. The major problem with substitute ocean water, referred to hereafter as seawater, is that it is relatively expensive and difficult to prepare because it contains ten chemical compounds. Although alternate immersion in seawater is considered an effective SCC test method, a simpler and less expensive test that is discriminating in classifying the SCC resistance of aluminum alloys will be a definite asset.

EXPERIMENTAL PROCEDURE

The initial or screening test consisted of immersing 1 by 4 in. sheet specimens of 2219-T87 and 7075-T6 for 2 months in 450 ml of the solutions shown in Table 1. The test solutions consisted of various combinations of the chemical constituents in seawater and salt water with pH controlled in the range of 6.5 to 9.0. Similar sheet specimens were exposed by alternate immersion in salt water, seawater, a solution used by French investigators, and an aqueous solution of 3.5 percent sodium chloride and 0.52 percent magnesium chloride.

Stress corrosion tests of several aluminum alloys with varying resistance to SCC were conducted in the $NaCl\text{-}MgCl_2$ solution, the most promising medium based on the corrosion tests. Round tensile specimens taken from the short transverse grain direction of 2024-T4, 2024-T62, 7075-T651, and 7075-T7651 plate and 7075-T651 rod were strained to the desired stress, 140 MPa(20 ksi) to 310 MPa(45 ksi), by means of aluminum stressing jigs. After applying a protective coating to the jigs, the specimens were wiped with alcohol and exposed for a maximum of three months to alternate immersion in the $NaCl\text{-}MgCl_2$ solution, salt water, or seawater. The latter two solutions were used as a basis for comparison, with only limited tests conducted

TABLE 1 - COMPOSITION OF TEST SOLUTIONS

ALL CONCENTRATIONS IN PERCENT

No.	NaCl	$MgCl_2$	Na_2SO_4	$CaCl_2$	KCl	$NaHCO_3$	KBr	H_3BO_3	$SrCl_2$	NaF	Na_2HPO_4
1[a]	2.45	0.52	0.41	0.12	0.07	0.02	0.01	0.003	0.003	0.0003	
2	2.86	0.52	0.41			0.02		0.003			
3	2.86	0.52	0.41			0.02					
4	3.5	0.52				0.02		0.003			
5	3.5	0.52									
6	3.5		0.41			0.02					
7	3.5		0.41								
8	3.5					0.02					
9	3.5							0.003			
10[b]	3.5							1.25			0.19
11	3.5 (6.5pH)										
12	3.5 (7.0pH)										
13	3.5 (8.0pH)										
14	3.5 (9.0pH)										

NOTES: [a] Substitute ocean water per ASTM-D1141-52 without heavy metal salts.
[b] French Solution.

in salt water. A detailed description of test specimens, formula for calculating strain, and methods of loading and testing are given in Reference 2.

RESULTS AND DISCUSSION

The results obtained in the initial test, total immersion of sheet strips, were difficult to interpret because all the solutions caused pitting of one or both of the aluminum alloys (Table 2). The NaCl-$MgCl_2$ solution was chosen for additional investigation because it was one of the less corrosive solutions and was the easiest to prepare. The composition of the 3.5 percent NaCl-0.52 percent $MgCl_2$ solution used in the initial test was changed to 2.86 percent NaCl-0.52 percent $MgCl_2$ for all remaining tests to obtain a total chloride content similar to salt water and seawater. Sheet or rod specimens of 2024-T3, 2219-T87, and 7075-T6 were tested by alternate immersion in the NaCl-$MgCl_2$, French, salt, and seawater solutions because alternate immersion is the method normally used in laboratory SCC tests. The French solution was included in the test because it was one of the solutions used by the joint Aluminum Association - ASTM G1.06.91 Task Group in their investigation of a SCC test method for aluminum alloys. Based on exposure periods of 1, 2, and 3 months, the NaCl-$MgCl_2$ solution was found to compare favorably to seawater and was considerably less corrosive than salt water (Table 3). The French solution was as corrosive to aluminum as salt water and was dropped from the test program.

Stress corrosion tests were conducted in the NaCl-$MgCl_2$ solution, and the results compared very favorably with those obtained in salt water and seawater (Table 4). Failure of the low SCC resistant alloys, 2024-T4 and 7075-T651, occurred within 2 days in both the NaCl-$MgCl_2$ solution and seawater. These alloys were not tested in salt water because they are known to fail rapidly in this medium. The 7075-T7651 material, which reportedly possesses intermediate resistance to SCC, failed in all three media in a relatively short period. Agreement of test results was also obtained among the three media with 7075-T651 round bar stressed in the transverse grain direction, as opposed to the other plate materials which were stressed in the short transverse direction. As expected, the time to failure was longer for the 7075-T651 transverse specimens than that required for 7075-T651 short transverse specimens. The only indication of disagreement was the results of alloy 2024-T6 which is considered to have intermediate to high SCC resistance. No failure occurred in the NaCl-$MgCl_2$ solution within 90 days, but failures were encountered in both salt water and seawater. These failures occurred only after extended periods (>30 days), and all the failures in seawater were adjacent to or under the coating. Specimens of other test alloys failed in seawater adjacent to or under the coating, and specimens from the 7075-T651 round bar failed in this manner in both the NaCl-$MgCl_2$ solution and seawater. All failures associated with the coating occurred only after 12 or more days of exposure. There was no excessive pitting or other types of localized corrosion in the vicinity of the coating, and no other cause of failure was evident in this area.

TABLE 2 - CORROSION RESULTS - IMMERSION IN SALT WATER

	pH		Weight Loss (mg)		Visual Corrosion	
Soln *	Orig	Final	2219-T87	7075-T6	2219-T87	7075-T6
1	8.2	8.2	41	19	Scattered Pits	Few Shallow Pits
2	7.5	8.1	32	20	Scattered Pits	Few Shallow Pits
3	7.5	8.1	36	14	Scattered Pits	Few Shallow Pits
4	7.2	8.0	54	38	Scattered Pits	Few Shallow Pits
5	5.9	6.6	45	19	Scattered Pits	Edges etched
6	7.8	8.8	58	45	Scattered Pits	Edges etched
7	6.9	8.3	63	47	Scattered Pits	Edges etched
8	6.2	7.9	62	56	Scattered Pits	Edges etched
9	7.3	8.6	61	52	Scattered Pits	Edges etched
10	8.2	8.2	66	67	Scattered Pits	Many Shallow Pits
11	6.5	6.9	65	37	Many Shallow Pits	Edges etched
12	7.0	7.0	62	51	Many Shallow Pits	Edges etched
13	8.0	7.9	54	57	Many Shallow Pits	Edges etched
14	9.0	8.8	71	50	Many Shallow Pits	Edges etched

*Composition shown in Table 1.

TABLE 3 - CORROSION RESULTS - ALTERNATE IMMERSION

Solution	WEIGHT LOSS (mg) 2024-T3[c]	WEIGHT LOSS (mg) 2219-T87[b]	WEIGHT LOSS (mg) 7075-T6[b]	VISUAL CORROSION EVALUATION[a] 2024-T3[c]	VISUAL CORROSION EVALUATION[a] 2219-T87[b]	VISUAL CORROSION EVALUATION[a] 7075-T6[b]
1 MONTH EXPOSURE						
Seawater	17	39	6	Mild	Mild	Moderate
$NaCl-MgCl_2$	d	d	d	Mild	Mild	Mild
French Salt Water	343	679	329	Moderate	Moderate	Moderate
	321	744	579	Moderate	Moderate	Moderate
2 MONTHS EXPOSURE						
Seawater	49	28	6	Mild	Mild	Mild
$NaCl-MgCl_2$	57	97	151	Mild	Mild	Mild
French Salt Water	653	759	527	Moderate	Severe	Moderate
	432	928	617	Moderate	Severe	Moderate
3 MONTHS EXPOSURE						
Seawater	31	64	14	Mild	Mild	Mild
$NaCl-MgCl_2$	73	127	145	Mild	Mild	Mild
French Salt Water	935	1281	827	Severe	Severe	Severe
	480	1405	896	Severe	Severe	Severe

NOTE: [a] Corrosion classification was based primarily on pitting except that the 7075 T6 specimen suffered exfoliation in seawater and to a lesser extent in the French solution.

[b] 1 in. by 4 in. sheet specimens.

[c] 2.5 in. by 3/4 in. diameter bar.

[d] Weight loss not available.

TABLE 4 - STRESS CORROSION CRACKING RESULTS[a]

Material		Stress		$NaCl-MgCl_2$		Seawater		Salt Water	
Alloy	Form	MPA	ksi	Ratio	Days	Ratio	Days	Ratio	Days
2024-T4	Plate	140	20	5/5	2, 2, 5, 5, 6	5/5	2(4), 5		
2024-T6	Plate	310	45	0/4		3/5	36*, 36*, 34*	3/3	47, 48, 61
7075-T651	Plate	205	30	5/5	2(4), 12	5/5	2, 2, 5, 15*, 20*		
7075-T651	Bar	275	40	4/5	12*, 28*, 33* 43*	4/5	12, 15*, 15*, 40*	5/5	2(4), 15
7075-T7651	Plate	240	35	3/5	2, 5, 6	4/5	5, 7, 15*, 15*	4/5	2, 2, 5, 5

*Failed at edge or under coating.

Note: [a] Round tensile specimens exposed by alternate immersion to the indicated solutions until failure or a maximum of 90 days.

CONCLUSIONS

The results obtained in this investigation revealed that alternate immersion in an aqueous solution of 2.86 percent NaCl-0.52 percent $MgCl_2$ is an effective test method for evaluation of the SCC resistance of high strength aluminum alloys. The NaCl-$MgCl_2$ solution compares very favorably with seawater in corrosion compatibility and as a definitive medium for use in classifying the SCC resistance of aluminum alloys. In addition, the NaCl-$MgCl_2$ solution is easier to prepare and is less expensive than seawater. It is hoped that other investigators will evaluate the NaCl-$MgCl_2$ solution as a SCC test medium for aluminum alloys.

REFERENCES

1. Humphries, T. S. and Nelson, E. E.: Synthetic Seawater–An Improved Stress Corrosion Test Medium For Aluminum Alloys. NASA TM X-64733, March 21, 1973.

2. Humphries, T. S.: Procedures For Externally Loading And Corrosion Testing Stress Corrosion Specimens. NASA TM X-53483, June 29, 1966.

APPROVAL

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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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