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NRL Report 6105

Corrosion of Metals in Tropical Environments

Part 6 - Aluminum and Magnesium

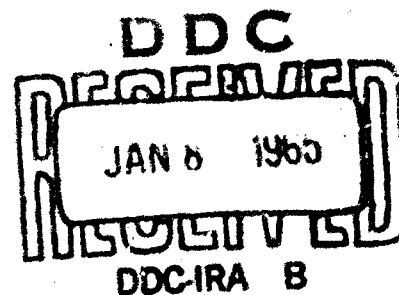
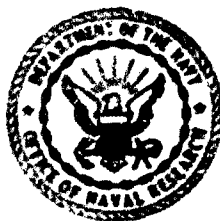
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PREVIOUS REPORTS IN THIS SERIES

"Corrosion of Metals in Tropical Environments, Part 1 - Test Methods Used and Results Obtained for Pure Metals and a Structural Steel," A.L. Alexander, B.W. Forgeson, H.W. Mundt, C.R. Southwell, and L.J. Thompson, NRL Report 4929, June 1957

"Corrosion of Metals in Tropical Environments, Part 2 - Atmospheric Corrosion of Ten Structural Steels," C.R. Southwell, B.W. Forgeson, and A.L. Alexander, NRL Report 5002, Dec. 1957

"Corrosion of Metals in Tropical Environments, Part 3 - Underwater Corrosion of Ten Structural Steels," B.W. Forgeson, C.R. Southwell, and A.L. Alexander, NRL Report 5153, Aug. 1958

"Corrosion of Metals in Tropical Environments, Part 4 - Wrought Iron," C.R. Southwell, B.W. Forgeson, and A.L. Alexander, NRL Report 5370, Oct. 1959

"Corrosion of Metals in Tropical Environments, Part 5 - Stainless Steel," A.L. Alexander, C.R. Southwell, and B.W. Forgeson, NRL Report 5517, Sept. 1960

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ABSTRACT

The corrosion resistance of three alloys of aluminum and two alloys of magnesium has been studied following exposure up to 16 years in five natural tropical environments. These include sea-water immersion, fresh-water immersion, and exposure to tidal sea water, a tropical marine atmosphere, and a tropical inland atmosphere. Aluminum 1100, aluminum alloy 6061-T, and magnesium alloy AZ31X were exposed to each of the environments listed. In addition, Alclad aluminum 2024-T and magnesium alloy AZ61X were exposed to the two tropical atmospheres. Weight loss, pitting, and change in tensile properties were measured to show the extent of corrosion for each of these materials. Aluminum alloys demonstrate extremely high resistance to each environment, with the exception of tropical fresh water, in which case serious pitting occurred. Alloy 6061-T demonstrated some superiority in all environments to aluminum 1100.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

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CORROSION OF METALS IN TROPICAL ENVIRONMENTS

PART 6 - ALUMINUM AND MAGNESIUM

INTRODUCTION

This report is the sixth in a series describing the results from a long-term study of the corrosion rates of 50 metals and alloys exposed to five local environments in tropical latitudes. Most metals were exposed for a total of 16 years. Sufficient replicates were included to allow pairs of each to be removed, studied, and evaluated at intervals of 1, 2, 4, 8, and 16 years. Other reports in this series (1-6) are based on eight-year data. This report is the first to include results for the full 16 years. Earlier reports will be updated to include all 16-year data.

In the present report, corrosion data are included for aluminum 6061-T and 1100, Alclad 2024-T, and magnesium AZ31X and AZ61X. Exposure of the magnesium samples was discontinued after eight years, since the specimens were sufficiently corroded that further measurements of damage would have been of little or no significance.

With the increasing use of the light-metal alloys, more attention is being focused on the natural corrosion characteristics of these metals. Early exposure studies with light metals (7,8) indicated rather poor resistance to marine environments. Subsequent investigations, including the newer alloys, along with some results from field use, have shown very high corrosion resistance in some instances. The present study of three aluminum and two magnesium alloys in five generally corrosive but hitherto uninvestigated natural environments should make a significant addition to the literature on the corrosion of light metals.

MATERIALS AND METHODS

Locations of the test sites are shown in Fig. 1. Samples exposed at mean tide and immersed were supported in their racks by ceramic insulators and suspended from special piers erected over selected areas of the test environments. Atmospheric exposure was made in two distinctly different tropical atmospheres; one is an unshaded seashore marine site, and the other is an unshaded ground-level inland site. The marine site is located on the roof of the Washington Hotel, Cristobal, Canal Zone, at 55 ft elevation and 300 ft from the Caribbean shore (Fig. 1a). The prevailing wind at this location is from the sea. The inland site is located near the Miraflores Locks on the Pacific side of the Canal Zone (Fig. 1b), where the prevailing wind is from the land. Two immersion locations were included, one in tropical fresh water in Gatun Lake, Canal Zone (Fig. 1c), and the other in tropical Pacific Ocean water at Fort Amador, Canal Zone (Fig. 1d). In addition, specimens were exposed to mean tide at Fort Amador, where the average tidal range is 13 ft.

Chemical analyses and physical properties of the metals are presented in Tables 1 and 2. The immersed specimens, exposed as 1/4-in.-thick plates, were similar in composition and properties to the atmospheric samples of the same metal, which were exposed as 1/16-in.-thick sheets; however, some difference between the two exists, so the separate listings shown in the tables of chemical and mechanical properties are warranted.

Weight loss and dimensional changes were determined by standard procedures. Pit depths were measured from the original surface of the metal, where there was sufficient

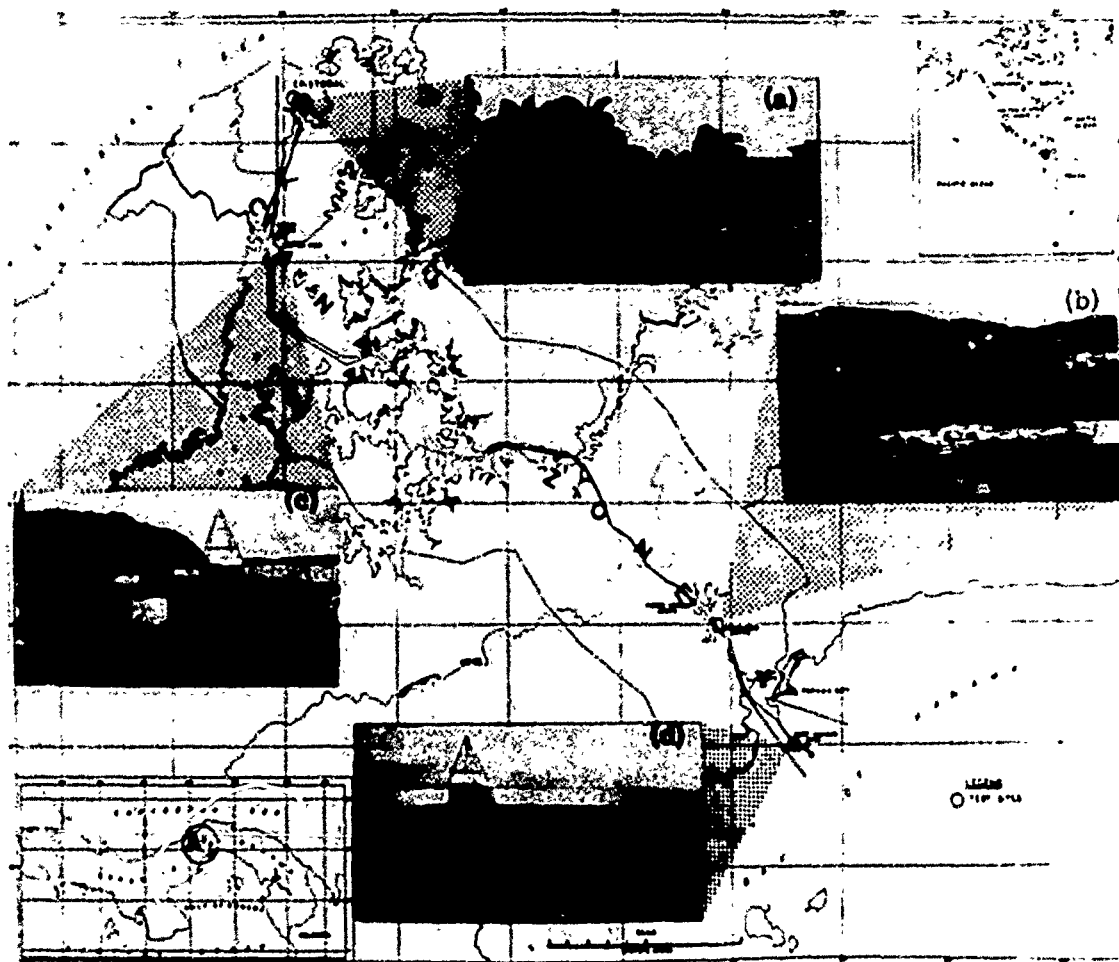


Fig. 1 - Location of test sites

original surface remaining; when all original metal surface was removed by general corrosion attack, the pit depth was measured from the corroded surface and then added to the measured loss to obtain the true depth of penetration. Loss in tensile strength was determined by comparing the average values from nine to 15 tensile tests of uncorroded metal with values derived from samples cut from the corroded plates. Tensile strengths were determined as prescribed by ASTM standard E8-52T. Complete descriptions of the test procedures and more information on the program background can be found in the first report of this series (1).

RESULTS

Table 3 lists the results obtained from the five light alloys under consideration. For the most part, the data are for 16 years' exposure in live tropical environments. The values are averages obtained from duplicate panels exposed to the indicated environments for periods of 1, 2, 4, 8, and 16 years. Weight loss is shown in grams/dm². Average penetration is presented in mils and for unit area is expressed as volume loss calculated from weight loss and specific gravity. Comparisons made between metals of differing densities are more realistic when expressed as loss in volume rather than weight. Pitting is tabulated along with eight-year data on loss in tensile strength and type of visible corrosion attack. While volume loss is perhaps the single most important factor in following the progression of corrosion and in evaluating the merits of a particular metal, other factors are important in broadening the evaluation and giving a more complete picture of the behavior of a metal in a specific environment.

Table 1
Chemical Composition of Test Metals

Exposure	Metal	Specifications	Proximate Chemical Composition (% by wt.)									
			Mn	Si	Sr	Ni	Cu	Fe	Zn	Al	Mg	Ti
Submerged	Aluminum 6061-T	QQ-A-327 Condition T	0.01	0.55	C.30	-	0.23	0.15	0.015	97.91 (a)	0.80	0.05
	Aluminum 1100	QQ-A-561, Type 3 Plate Finish	0.015	0.16	-	-	0.18	0.47	0.16	99.01 (a)	-	-
	Magnesium AZ31X	ASTM B-90-41T Type 18X, Condition A	0.38	0.004	-	-	0.02	0.001	1.25	2.90	95.44 (a)	-
	Aluminum 6061-T	QQ-A-327 Condition T	0.053	0.57	0.25	-	0.26	0.30	0.003	97.64 (a)	0.87	0.05
Atmospheric	Aluminum 1100	QQ-A-561, Type 1 Half-hard	0.01	0.18	-	-	0.20	0.75	0.005	98.85 (a)	0.003	-
	Alclad 2024-T	QQ-A-362 Condition T	0.45	0.14	0.025	-	4.15	0.57	0.031	92.96 (a)	1.72	-
	Magnesium AZ31X	ASTM B-90-41T Type 18X Condition A	0.24	0.029	-	0.001	0.01	0.003	1.51	3.01	98.21 (a)	-
	Magnesium AZ61X	ASTM B-90-41T Type 8X Condition A	0.29	0.026	-	0.001	-	0.003	0.47	6.86	99.21 (a)	-

Note: Value (a) obtained by difference.

Table 2
Physical Properties of Test Metals

Exposure	Metal	Density (g/cc)	Tensile (psi)			Elongation % in 2-in. Gage Length	Brinell Hardness
			Yield Strength 0.2% Offset	Ultimate Strength	Proportional Limit		
Submerged	Aluminum 6061-T	2.70	41,970	44,700	37,700	14	99
	Aluminum 1100	2.71	19,330	21,070	15,800	11	43
	Magnesium AZ31X	1.77	22,170	37,130	14,700	17	59
Atmospheric	Aluminum 6061-T	2.70	42,200	47,130	34,000	13	-
	Aluminum 1100	2.71	16,200	18,000	13,500	8	-
	Alclad 2024-T	-	53,770	67,700	50,600	17	-
	Magnesium AZ31X	1.77	25,530	39,070	15,200	21	-
	Magnesium AZ61X	1.80	28,300	42,630	15,700	17	-

Table 3
Comprehensive Evaluation of Corrosion Damage of Light Metals Exposed
in Five Tropical Environments in the Panama Canal Zone

Metal	Exposure	Weight Loss (g/dm ²)					Average Penetration (mils) (a)					Depth of Pitting (mils) (b)					Tensile Strength Loss (%) 8 yr (c)	Type of Corrosion Attack (d) 16 yr
		1 yr	2 yr	4 yr	8 yr	16 yr	1 yr	2 yr	4 yr	8 yr	16 yr	1 yr	2 yr	4 yr	8 yr	16 yr		
Aluminum 1100	Immersion Sea Water	0.19	0.27	0.45	0.42	0.67	0.28	0.39	0.66	0.61	0.97	9(13)	3(17)	7	11	17	2	J
	Mean Tide Fresh Water	0.04	0.08	0.17	0.22	0.37	0.06	0.11	0.25	0.31	0.53	11(9)	10	26	14	39	1	JQ
	Atmospheric Inland	0.28	0.65	0.95	1.61	3.47	0.41	0.95	1.37	2.34	5.04	24	29	38	61	98	4	QK
Aluminum 6061-T	Immersion Sea Water	0.006	0.024	0.008	0.013	0.075	0.01	0.04	0.01	0.02	0.11	N	N	N	N	N	0	A
	Mean Tide Fresh Water	0.002	0.017	0.000	0.024	0.052	0.00	0.03	0.00	0.03	0.08	N	N	N	N	N	0	AK
	Atmospheric Inland	0.19	0.33	0.39	0.50	0.63	0.28	0.48	0.56	0.73	0.91	N	N	11(10)	23	14	0	J
Aluminum 2024-T	Immersion Sea Water	0.03	0.05	0.07	0.09	0.20	0.04	0.07	0.10	0.13	0.29	N	N	N	N	17	0	J
	Mean Tide Fresh Water	0.06	0.16	0.31	0.53	1.03	0.08	0.23	0.45	0.77	1.50	14	21	33	59	96	1	QK
	Atmospheric Inland	0.021	0.037	0.051	0.018	0.077	0.03	0.06	0.08	0.03	0.11	N	N	N	N	N	1	AK
Aluminum 7075-T	Immersion Sea Water	0.010	0.028	0.007	0.008	0.058	0.02	0.04	0.01	0.01	0.09	N	N	N	N	N	1	AK
	Mean Tide Fresh Water	0.017	0.028	0.009	0.012	0.090	0.03	0.04	0.02	0.02	0.14	N	N	N	N	N	1	KA
	Atmospheric Inland	0.009	0.009	0.000	0.002	0.050	0.02	0.02	0.00	0.01	0.07	N	N	N	N	N	2	KA
Magnesium AZ31X (e)	Immersion Sea Water	3.24	8.69	6.84	13.77	-	7.21	19.32	15.21	30.62	-	193(7)	233	184	253(p)	-	-	-
	Mean Tide Fresh Water	6.04	8.90	17.55	17.60	-	13.44	19.78	39.03	39.14	-	102	143	196	251(p)	-	-	-
	Atmospheric Inland	1.73	2.45	3.44	5.48	-	3.84	5.45	7.64	12.18	-	N	N	35(1)	24	-	5	-
Magnesium AZ61X (f)	Immersion Sea Water	0.48	0.85	1.62	3.54	6.77	1.06	1.89	3.60	7.88	15.47	13(11)	11(10)	18(10)	20	22	4	AE
	Mean Tide Fresh Water	0.27	0.54	0.70	2.05	4.23	0.61	1.20	1.56	4.55	9.40	N	N	N	5(10)	15	5	A
	Atmospheric Inland	0.22	0.59	0.16	2.84	5.35	0.48	1.27	0.35	6.19	11.66	12(12)	14(10)	N	11	16	11	A

NOTES:

- Calculated from weight loss and specific gravity.
- Represents depth of penetration from original surface; N = no measurable pits; number in parentheses gives number of measurable pits when less than 20; and (p) denotes perforation.
- Percent change in tensile strength calculated on basis of 1/4-in.-thick metal and average of four tests for underwater specimens, and 1/16-in.-thick metal and average of three tests for atmospheric specimens.
- A - uniform attack, E - localized attack (uniform), J - marine fouling contact, K - no visible attack, Q - pitting attack (random). Complete description of corrosion types are presented in Ref. 2.
- Former ASTM designation - 8X.
- Former ASTM designation - 8X.
- Because of high rate of corrosion magnesium panels were exposed for only eight years in these environments.
- Panels too badly corroded to test.

Aluminum

The relative severity of the five test environments is shown in Fig. 2. Average penetration, as a function of time, is presented for commercially pure aluminum 1100. Fresh water was clearly the most destructive environment, causing five times the volume loss as that of sea water over the 16-year period. The damage experienced in this soft neutral lake water was due wholly to intense pitting attack distributed randomly throughout the exposed surface. All other environments were relatively innocuous, none causing average penetration greater than one mil during 16 years. In the sea, mean-tide elevation was the least severe, being only half as corrosive as continuous immersion. In short, commercially pure aluminum 1100 showed a rather high resistance to marine corrosion. The rate of corrosion at the mean-tide location was only three times as severe as the seashore atmospheric site, and the corrosion accruing in the atmosphere, at both marine and inland locations, was less than 0.1 mil at the end of 16 years.

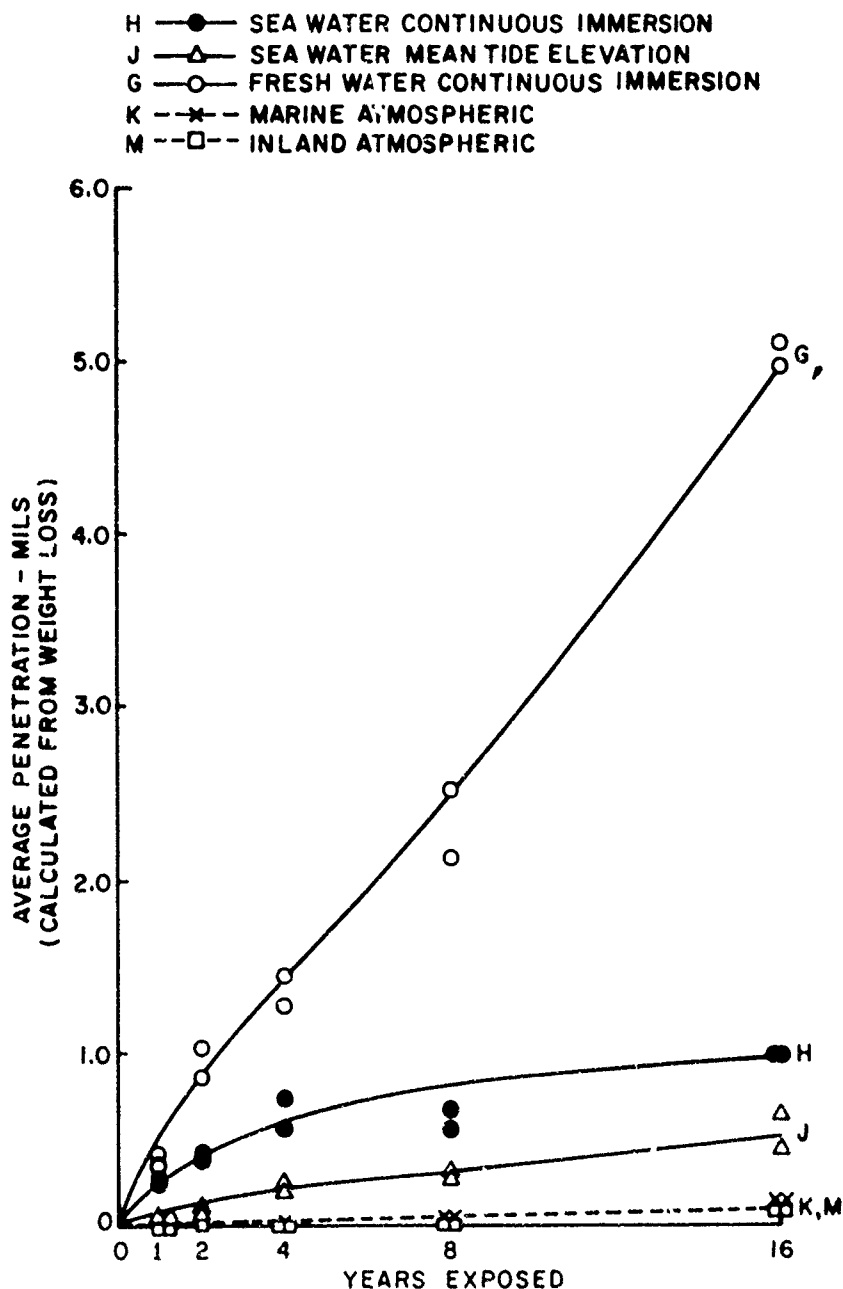


Fig. 2 - Sixteen-year corrosion curves of aluminum 1100

Three aluminum alloys were exposed in the two atmospheric environments (Fig. 3). There is no practical difference between the three aluminums, and all were highly resistant to these conditions. Because of the similar patterns and low corrosion rates, the resulting curves appear as bands rather than as clearly defined lines. Although the marine environment was slightly more severe than the inland atmosphere, it still caused only a maximum 0.15-mil average penetration after 16 years, while the greatest average penetration of any of the alloys at the inland site was only 0.09 mil. All aluminum panels retained much of their original finish and at most showed a slight surface etching. The high resistance of aluminum to both marine and inland atmospheric corrosion in temperate climates has been cited many times (9,10) and specifically for these three alloys. These results indicate that high resistance in tropical atmospheres can be expected also.

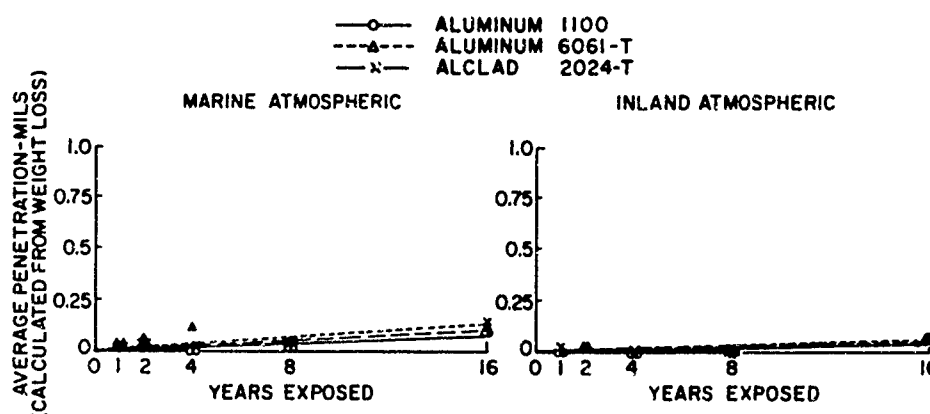


Fig. 3 - Corrosion of aluminum 1100, 6061-T, and Alclad 2024-T during 16 years of exposure in two tropical atmospheres

The corrosion rates of the widely used aluminum 6061-T alloy are shown in three tropical underwater environments in Fig. 4 and are compared with aluminum 1100. Continuous sea-water immersion proved to be almost equally corrosive to the two alloys, 1100 being only minutely higher. The data show that pitting of 6061-T was generally mild under tropical sea water; while it developed the deepest single pit (79 mils), it was slightly superior to 1100 when the 20 deepest pits were averaged.

The mean-tide location was the least corrosive to aluminum of all underwater environments studied. Again the 6061-T alloy was slightly superior, showing an average penetration considerably less than aluminum 1100 over the 16-year period. Both were quite resistant at this location, as the loss of 1100 amounted to only 0.5 mil after 16 years' exposure. Pitting, too, was slight on both aluminums at mean tide, with an average pit depth of only 17 mils at 16 years for type 6061-T and approximately double this depth for type 1100.

As shown earlier, the fresh water of Gatun Lake proved to be the most corrosive environment for aluminum. The difference in corrosion rates between 1100 and 6061-T was appreciable, with 6061-T corroding at approximately one-third the rate of 1100. Both metals sustained almost equivalent pitting attack in this location, as measured by pit depths. However, the number of pits was considerably higher on the type 1100 than on the 6061-T alloy. This difference in pitting density can be seen in Fig. 5, which compares the two aluminums after 16 years' exposure to fresh water.

A comparison of 6061-T in the three underwater locations shows this alloy to be most resistant to mean tide and least resistant to fresh water. The resistance to the two marine

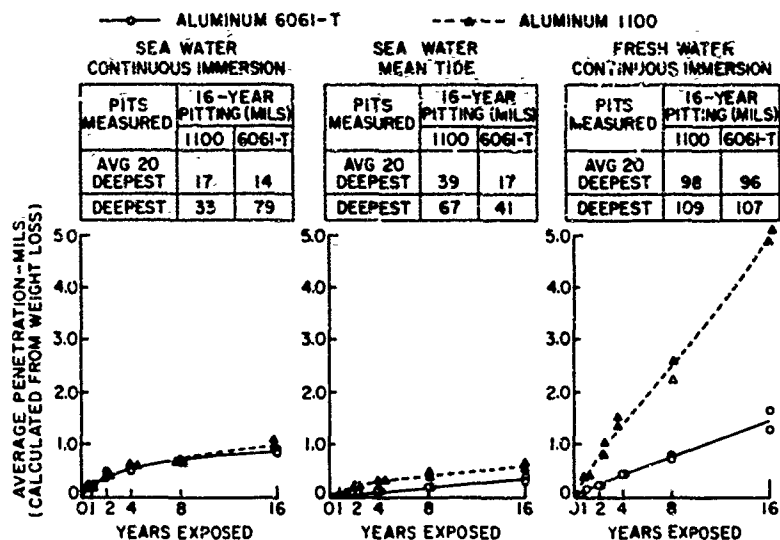


Fig. 4 - Comparison of aluminum alloy 6061-T with commercially pure aluminum 1100 for 16 years' exposure in three underwater environments

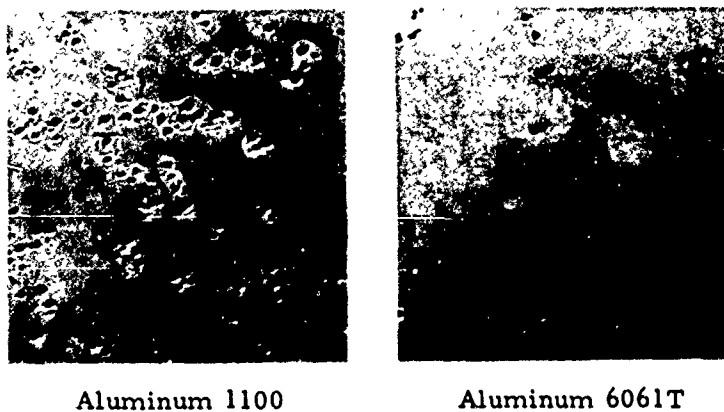


Fig. 5 - Comparison of the severity of pitting of two aluminum alloys after 16 years' exposure in tropical fresh water (1/4X)

locations was very good; the average penetration in sea water was only 1 mil after 16 years. It should be noted that in both the sea-water exposures the corrosion that did occur appeared to be initiated by fouling. Figure 6 shows the surface etching on an aluminum plate by fouling attachment. This etching practically covered the entire plate surfaces. The severe pitting observed in fresh water and shown in Fig. 5 can perhaps be attributed to the presence of trace amounts of heavy metal compounds, which are cited as promoting such localized attack (9).

Loss of tensile strength is a long-recognized criterion for evaluating the corrosion of aluminum. Tensile-strength data are presented as bar graphs in Fig. 7 for the three aluminum alloys after an eight-year exposure. Aluminum 1100 showed no loss in strength in the atmosphere after eight years, which is surprising in view of previously reported data for temperate climate exposures by Dix and Mears (10). The loss of one percent sustained by 6061-T is also lower than reported by Dix and Mears; on the other hand, the two-percent loss shown by Alclad 2024-T in the inland atmosphere is somewhat higher than



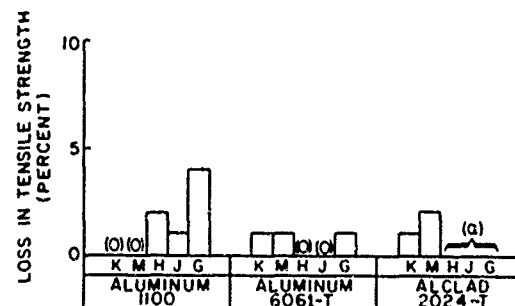
Fig. 6 - Close-up of the etching of aluminum 6061-T due to marine fouling after continuous immersion in tropical sea water for 16 years (3/2X)

K - MARINE ATMOSPHERIC
M - INLAND ATMOSPHERIC
H - SEA WATER CONTINUOUS IMMERSION
J - SEA WATER MEAN TIDE ELEVATION
G - FRESH WATER CONTINUOUS IMMERSION

NOTE:

(a) NO SAMPLES EXPOSED TO WATER

Fig. 7 - Loss in tensile strength of aluminum 1100, 6061-T, and Alclad 2024-T after eight years exposure in tropical environments



reported by these authors for this alloy in temperate climates. Underwater tensile data have not been so widely reported, and no comparable data from temperate latitudes were found. It is interesting to note, however, that the condition of the two alloys 1100 and 6061-T in the three underwater locations leads to the same conclusion, whether by weight-loss data or by loss in tensile strength, that 6061-T is somewhat the superior alloy in these environments.

Magnesium

Controlled-purity magnesium AZ31X containing 3-percent aluminum, formerly designated by ASTM as 18X, was exposed in all five environments for eight years. The marine and inland atmospheric studies of this metal were continued for the full 16-year period,

but because of the expected rapid corrosion of this alloy in sea water the immersion tests were planned for only eight years. Figure 8 presents penetration with time for AZ31X in the five environments over an eight-year period. In contrast to the aluminums the mean-tide environment, as might be expected, was the most aggressive for magnesium in several respects. The final average penetration at mean tide was 45 mils, or a 36-percent reduction of the original volume of the $9 \times 9 \times 1/4$ in. plates. This amounted to 1.5 times the volume loss found for panels continuously immersed in sea water and 3.7 times the volume loss in fresh water. An interesting note on the attack at mean tide was the heavy infestation of the panels by a stone-boring mollusk. These have been identified as belonging to the genus *Lithophaga*. There is some question concerning the mechanics of such an infestation as to whether the mollusk merely housed itself in an existing pit or actually mechanically or chemically created such a pit. Figure 9 shows duplicate AZ31X panels, one with the mollusks imbedded in the panel, and the other cleaned, showing the damage. The marine atmosphere proved some 1.7 times as corrosive as the inland site and two-thirds as corrosive as the fresh-water-immersion environment.

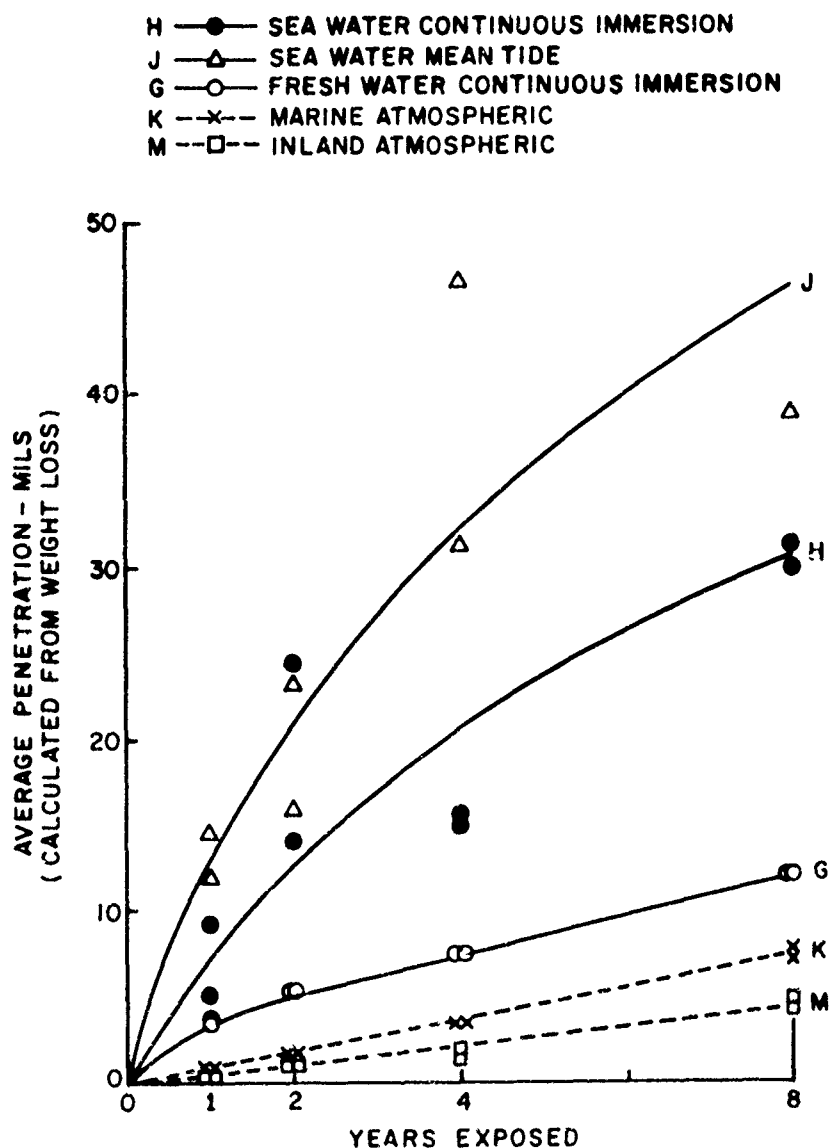


Fig. 8 - Corrosion of magnesium AZ31X for eight years' exposure in five tropical environments

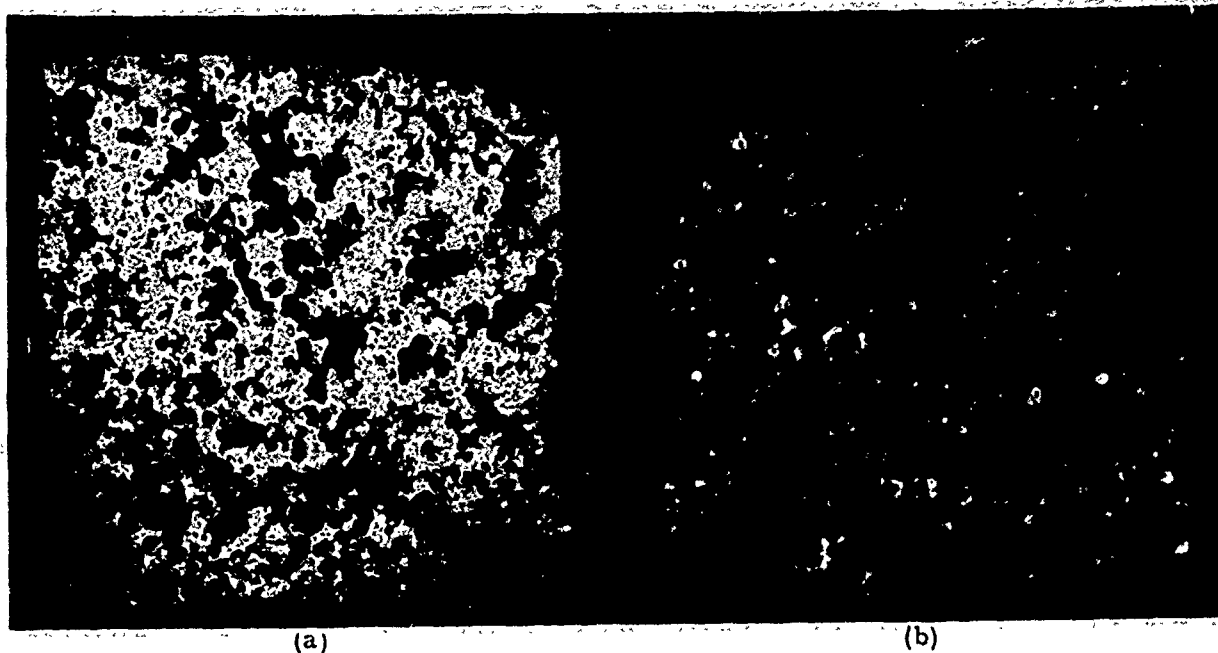


Fig. 9 - Attack of magnesium by *Lithophaga* during eight-year exposure
(a) Cleaned, (b) Uncleaned, organisms still in perforations

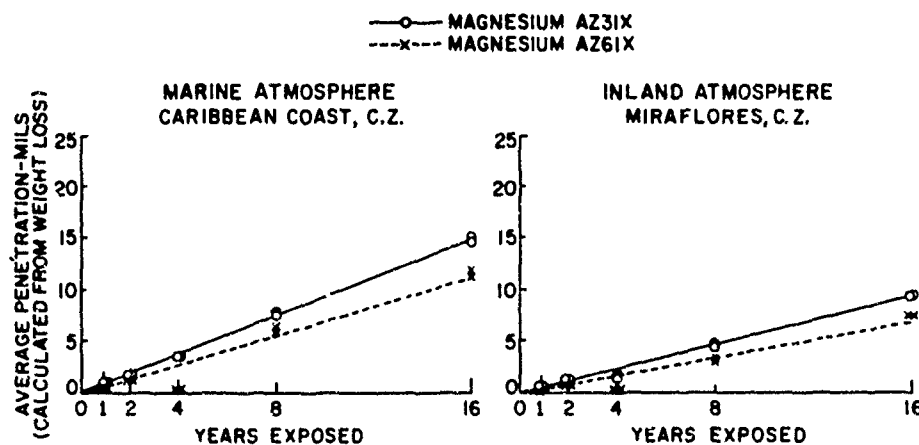


Fig. 10 - Atmospheric corrosion of magnesium AZ31X and AZ61X for 16-yr exposure in two tropical environments

In addition to the AZ31X, a 6-percent aluminum controlled-purity magnesium alloy, AZ61X, was exposed for the full 16 years in the two tropical atmospheres. A comparison of the effects on the two alloys is seen in Fig. 10. The marine atmosphere, as shown earlier for AZ31X, also is more severe for AZ61X. The AZ61X alloy, with higher aluminum content, was somewhat superior to AZ31X in both tropical atmospheres, on the basis of metal lost and depth of pitting.

The straight-line relation found for magnesium in tropical atmospheres gives constant corrosion rates that permit convenient comparison with corrosion rates found in temperate climates. The rate for AZ31X at the Cristobal Marine Site amounted to 0.94 mil per year. One- and three-year rates for this alloy reported from a marine atmosphere at Norfolk,

Virginia (11) were both 0.74 mil per year, while exposures made at Kure Beach, North Carolina (12) reported 0.40 mil per year for two years of exposure. Thus, as might be expected, the data indicate that the tropical environments cause an appreciably higher corrosion rate for magnesium than is found in temperate climates.

The perforated and extremely corroded condition of the magnesium panels for both sea-water environments was such that tensile tests would mean little or nothing. Therefore, only those specimens exposed to fresh water were evaluated as to tensile loss. A loss of 12 percent of the original tensile strength was observed, which agrees rather closely with the 10-percent reduction in thickness calculated from weight loss.

Tensile losses were measured for both magnesium alloys exposed in the two tropical atmospheres. The results of these tests following eight years exposure are shown in Fig. 11. Magnesium AZ31X proved very slightly superior to AZ61X in both atmospheres, based on these results, showing 0.9 the tensile-strength loss of the high aluminum alloy. The marine atmosphere was 1.4 times as corrosive as the inland site, as determined by tensile-strength measurements.

A comparison of the percent reduction in thickness with percent loss in tensile strength shows that AZ31X lost 25 percent in both thickness and tensile strength in the marine atmosphere, while losing 16 percent of its strength, as opposed to a 14-percent reduction in

K - MARINE ATMOSPHERIC
M - INLAND ATMOSPHERIC
H - SEA WATER CONTINUOUS IMMERSION
J - SEA WATER MEAN TIDE ELEVATION
G - FRESH WATER CONTINUOUS IMMERSION

NOTE:

- (a) NO SAMPLES EXPOSED TO WATER
(b) PANELS TOO BADLY CORRODED TO TEST

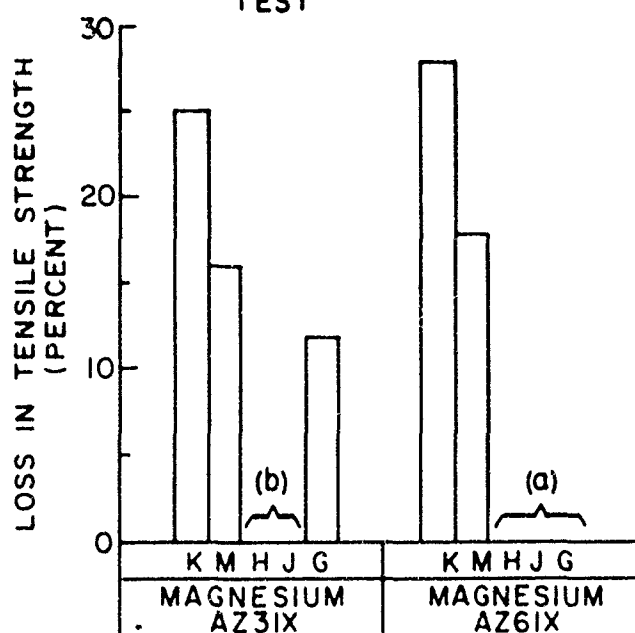


Fig. 11 - Loss in tensile strength of magnesium AZ31X and AZ61X after eight years' exposure in five tropical environments

thickness in the inland site. On the other hand, AZ61X, while losing 28 percent of its tensile strength, lost only 19 percent in thickness in the marine site, and in the inland location 18 percent in strength against 10 percent in thickness. The agreement in the case of AZ31X leads to the conclusion that effects other than weight loss are reflected in tensile losses for the higher aluminum AZ61X alloy.

With the exception of fresh-water exposure, magnesium did not show very high resistance to any tropical environment. In sea water it was rapidly perforated, and in the tropical atmospheres it showed a steady corrosion loss that after eight years approximated the losses found for structural steel.

CONCLUSIONS

1. Commercially pure aluminum 1100 and aluminum alloy 6061-T both proved quite resistant to corrosion in tropical sea water and in tropical atmospheres. Continuous immersion in sea water and alternate immersion at mean tide for 16 years caused only superficial etching around marine fouling, slight pitting, very little weight loss, and negligible change in tensile strength. In marine and inland atmospheres 16 years' exposure did little more than etch the surface of the panels.
2. Both aluminum 1100 and alloy 6061-T were deeply pitted in fresh water, which proved to be the most aggressive of the environments in which aluminum was studied.
3. Based on weight loss and depth of pitting, alloy 6061-T was equal to or slightly superior to commercially pure aluminum in all five environments. Tensile losses in the atmosphere were slightly greater for alloy 6061-T.
4. Alclad 2024-T proved to be equally as resistant as 6061-T and 1100 for 16 years in the two tropical atmospheres.
5. Controlled-purity magnesium alloys AZ31X and AZ61X showed rather poor resistance to tropical atmospheres, compared with their resistance to temperate climates. A steady corrosion rate of 0.94 mil per year was found for the former at the Caribbean coastal site, while 0.41 mil per year was reported from Kure Beach, North Carolina, and 0.71 mil per year for over-water tests at Norfolk, Virginia.
6. On the basis of weight loss and depth of pitting, magnesium alloy AZ61X containing 6-percent aluminum showed itself to be slightly superior in the tropical atmospheres to the 3-percent aluminum AZ31X. However, tensile loss slightly favored the 3-percent alloy.
7. Magnesium AZ31X was rapidly attacked in sea water, with deep pitting and perforation occurring within the first year of exposure. At mean tide perforation did not occur until the second year, but total metal lost was higher at all periods. Perhaps the most surprising fact about magnesium in sea water was that approximately two-thirds of the metal volume still remained after eight years of exposure.

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13 ABSTRACT The corrosion resistance of three alloys of aluminum and two alloys of magnesium has been studied following exposure up to 16 years in five natural tropical environments. These include sea-water immersion, fresh-water immersion, and exposure to tidal sea water, a tropical marine atmosphere, and a tropical inland atmosphere. Aluminum 1100, aluminum alloy 6061-T, and magnesium alloy AZ31X were exposed to each of the environments listed. In addition, Alclad aluminum 2024-T and magnesium alloy AZ61X were exposed to the two tropical atmospheres. Weight loss, pitting, and change in tensile properties were measured to show the extent of corrosion for each of these materials. Aluminum alloys demonstrate extremely high resistance to each environment, with the exception of tropical fresh water, in which case serious pitting occurred. Alloy 6061-T demonstrated some superiority in all environments to aluminum 1100.		

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