

AD-A126 926

POTENTIALDYNAMIC POLARIZATION STUDIES OF AN A1-MG-LI  
ALLOY(U) RENSSELAER POLYTECHNIC INST TROY N Y DEPT OF  
MECHANICAL ENGINEERING R E RICKER ET AL. APR 83  
N00014-75-C-0466

1/1

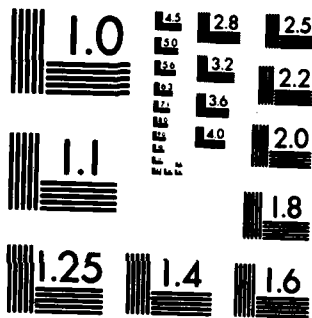
UNCLASSIFIED

F/G 7/4

NL



END  
DATE  
FILMED  
5 83  
DTIC



MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

POTENTIODYNAMIC POLARIZATION STUDIES OF AN Al-Mg-Li ALLOY

R. E. Ricker and D. J. Duquette  
Rensselaer Polytechnic Institute  
Materials Engineering Department  
Troy, New York 12181

April 1983

Technical Report to the Office of Naval Research

Contract No. N00014-67-A-0117-0012

No. N00014-75-C-0466, NR 036-093

Reproduction in whole or in part for any purpose of the U.S.  
Government is permitted. Distribution of this document is  
unlimited.

ADA 126926

FILE COPY

DTIC  
ELECTE  
APR 19 1983  
S A D

88 04 19 000

**Security Classification**

**DOCUMENT CONTROL DATA - R&D**

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

1. ORIGINATING ACTIVITY (Corporate author) Rensselaer Polytechnic Institute Materials Engineering Department Troy, New York 12181		2a. REPORT SECURITY CLASSIFICATION Unclassified	
		2b. GROUP AD-4126926	
3. REPORT TITLE  POTENTIODYNAMIC POLARIZATION STUDIES OF AN Al-Mg-Li ALLOY			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)  Technical Report			
5. AUTHOR(S) (Last name, first name, initial)  Ricker, R. E. Duquette, D. J.			
6. REPORT DATE April 1983		7a. TOTAL NO. OF PAGES 15	7b. NO. OF REFS 14
8a. CONTRACT OR GRANT NO. #N00014-75-C-0466, NR036-093		8b. ORIGINATOR'S REPORT NUMBER(S)	
b. PROJECT NO.			
c.		8c. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.			
10. AVAILABILITY/LIMITATION NOTICES Distribution of this document is unlimited.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY OFFICE OF NAVAL RESEARCH	
13. ABSTRACT <p>Potentiodynamic polarization tests were compared for an Al-Mg-Li alloy and a 7000 series alloy (7050). Tests were performed in various concentrations of sodium chloride, sodium sulfate and sodium nitrate solutions as functions of scan rate, pH, temperature, and degree of aeration. The lithium containing alloy exhibited significantly more active corrosion potentials in neutral and acidic solutions while the pitting potentials were essentially the same for the two alloys.</p>			

**Security Classification**

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Pitting Corrosion Aluminum Lithium Alloy Corrosion General Corrosion						

**INSTRUCTIONS**

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.
- 2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.
- 2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.
3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.
4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.
5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.
6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.
- 7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.
- 7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.
- 8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.
- 8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.
- 9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.
- 9b. **OTHER REPORT NUMBER(S):** If the report has been used on any other report numbers (either by the originator or by the sponsor), also enter this number(s).
10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those

imposed by security classification, using standard statements such as:

- (1) "Qualified requesters may obtain copies of this report from DDC."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through \_\_\_\_\_."
- (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through \_\_\_\_\_."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through \_\_\_\_\_."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.
12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.
13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet should be attached.  
  
It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (R).  
  
There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.
14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical content. The assignment of links, roles, and weights is optional.

POTENTIODYNAMIC POLARIZATION STUDIES OF AN Al-Mg-Li ALLOY

R. E. Ricker and D. J. Duquette  
Materials Research Center  
Rensselaer Polytechnic Institute  
Troy, New York 12181

Potentiodynamic polarization tests were compared for an Al-Mg-Li alloy and a 7000 series alloy (7050). Tests were performed in various concentrations of sodium chloride, sodium sulfate and sodium nitrate solutions as functions of scan rate, pH, temperature, and degree of aeration. The lithium containing alloy exhibited significantly more active corrosion potentials in neutral and acidic solutions while the pitting potentials were essentially the same for the two alloys.



Accession No.	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Distribution/	
Availability Codes	
Dist.	Special

## Introduction

Lithium containing alloys of aluminum are promising alternatives to either existing alloys or composites. The combined reduction in density and increases in strength and elastic modulus has attracted much interest in this system. However, most of the alloys developed to date have not been placed in service due to poor fracture toughness. If alloys are developed with improved fracture toughness, then the corrosion behavior of these alloys will be of great interest.

Aluminum is an active metal ( $E^\circ=1.71$  V vs. she) and derives its corrosion resistance from an adherent continuous passive film of oxides or hydroxides (1). As a result, the corrosion behavior of aluminum and its alloys is completely determined by the stability of this layer and the rate at which it reforms when ruptured (2).

Lithium is a very active element ( $E^\circ=3.05$  V vs. she) and therefore could have dramatic effects on the corrosion properties of an alloy even in small concentrations. Niskanen et. al. studied the effect of heat treatment and microstructure on the corrosion of various Al-Li-X alloys (3,4). They found that overaging, resulting in the precipitation of the equilibrium phase AlLi, had a deleterious effect on the corrosion properties of the alloys studied. However, in the Al-Li-Mg alloys the formation of  $Al_2MgLi$  prevented the formation of the anodic AlLi phase and resulted in improved corrosion properties. A similar study on an Al-Li-Cu-Mg alloy also showed no deleterious effect of overaging (5).

This program was undertaken to determine the corrosion properties of an Al-Mg-Li alloy in a variety of environments under a variety of environmental and electrochemical conditions and to compare the behavior of the lithium containing alloy to the behavior of a normal 7000 series alloy (7050).

## Materials and Procedures

Two alloys were chosen for this study. The first was an Al-Mg-Li alloy and the second was an alloy of the 7000 series (7050). The lithium containing alloy was supplied by the Naval Air Development Center, Warminster PA and the 7050 alloy was supplied by Alcoa Pittsburg PA. The compositions of the alloys are shown in table I.

Cylindrical samples were machined from each of the alloys. The samples were then ground with successively finer grades of silicon carbide papers to 600 grit and then polished with 9 micron diamond paste. Samples were reconditioned after each test machining off the exposed surface and then repeating the procedure above to produce a fresh surface for each test.

Tests were performed in a standard glass polarization cell with the sample mounted on a steel rod encased in glass and sealed with a teflon gasket as shown in figure 1 (6). Only the totally immersed sample, teflon gasket and glass made contact with the solution. Potentials were measured with a Luggin capillary and a saturated calomel electrode and all reported voltages are verses the saturated calomel electrode (0.0 V

Table I. Chemical Analysis of Alloy Composition

<u>Element</u>	<u>7050 Alloy</u>	<u>Al-Mg-Li Alloy</u>
Mg	2.41	4.24
Zn	6.52	0.004
Li	- -	2.13
Cu	2.20	0.030
Zr	0.113	- -
Cr	0.029	<0.002
Fe	0.147	0.01
Si	0.109	0.10
Ti	0.050	<0.005
Al	Rem.	Rem.

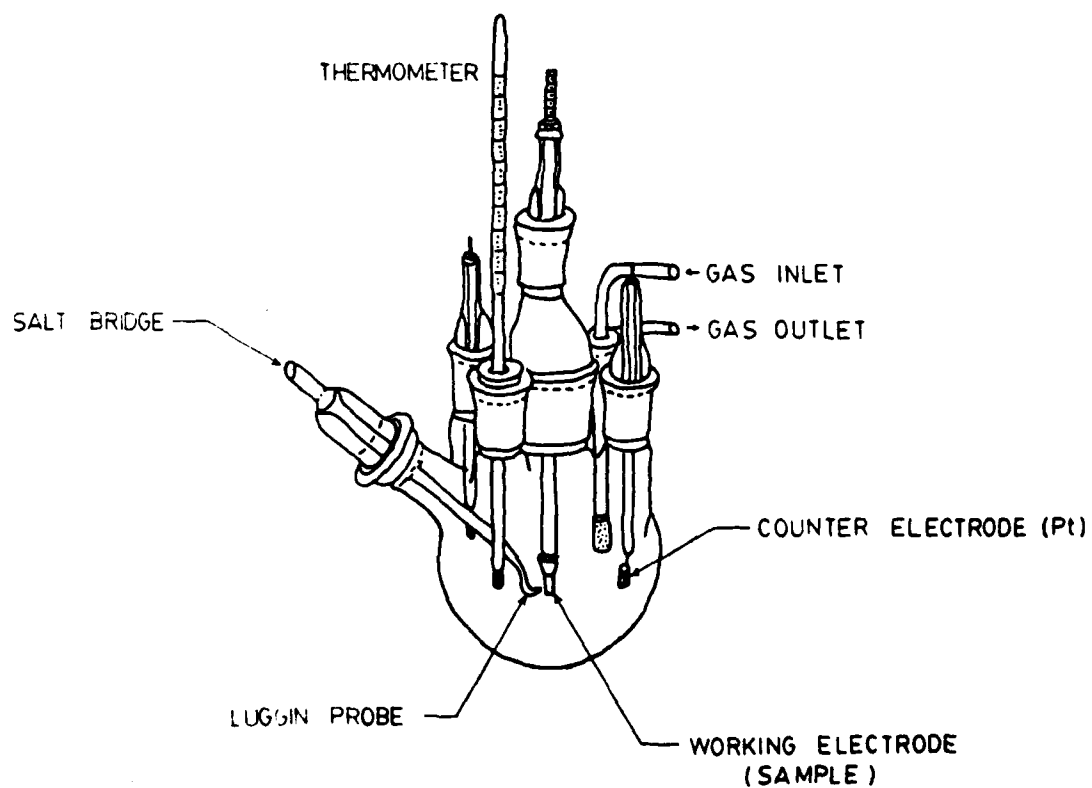


Figure 1. Diagram of a typical polarization cell.

vs. sce = 0.242 V vs. she). Temperatures were maintained constant utilizing a temperature bath filled with water into which the corrosion cell was immersed. The temperature of the solution in the cell was monitored with a standard laboratory thermometer.

All solutions were mixed, thoroughly deaerated and stored under nitrogen prior to use. The solutions were then deaerated with nitrogen or aerated with air for at least one hour prior to insertion of the sample. Bubbling of either nitrogen or air was continued for the duration of the tests to maintain conditions and to agitate the solutions.

The samples were inserted into the solutions for a period of 30 minutes to reach the steady state or free corrosion potential. Monitoring of the potential during this period and for longer durations indicated that this potential was reached in 10 to 20 minutes. A dynamic potential scan was started at a potential 100 mV active to the corrosion potential and continued to a potential sufficiently noble to cause pitting prior to reversing the scan. If pitting did not occur the scan was halted manually. The scans shown in the figures are active to noble potential scans. The reverse scans usually retraced the original scan.

## Results

### Scan Rate

Figure 2 shows the effect of scan rate on the measured pitting and corrosion potentials of the alloys. The slower scan rate resulted in reproducibly lower current densities at a given potential, indicating that the achievement of a steady state passive film is time dependent. That is, the steady state thickness of the passive layer increases with increasingly noble potentials and film growth is time dependent. However, figure 2 shows that the pitting potential is not significantly altered by the increased scan rate.

### Aeration

Aeration of the solutions reduced the passive current density and increased the free corrosion potential of the alloys in the environments tested. The pitting potentials are essentially unchanged. Figure 3 shows the effect of aeration on the Al-Mg-Li alloy in 0.5 N sodium chloride. In the 7050 alloy this resulted in pitting either during the 30 minute exposure before the test or on passing the zero potential during the scan. The Al-Mg-Li alloys free corrosion potential also increased but not enough to result in pitting. Table II lists the results of aeration tests compared to deaerated tests for sodium chloride solutions with varying pH.

### pH

Increasing the pH of the solution reduces the corrosion potential of both alloys while not significantly altering the pitting potential for a fixed chloride ion concentration and temperature. The free corrosion potential for the alloys in 0.5 N sodium chloride of pH 10, table II, are similar. They are

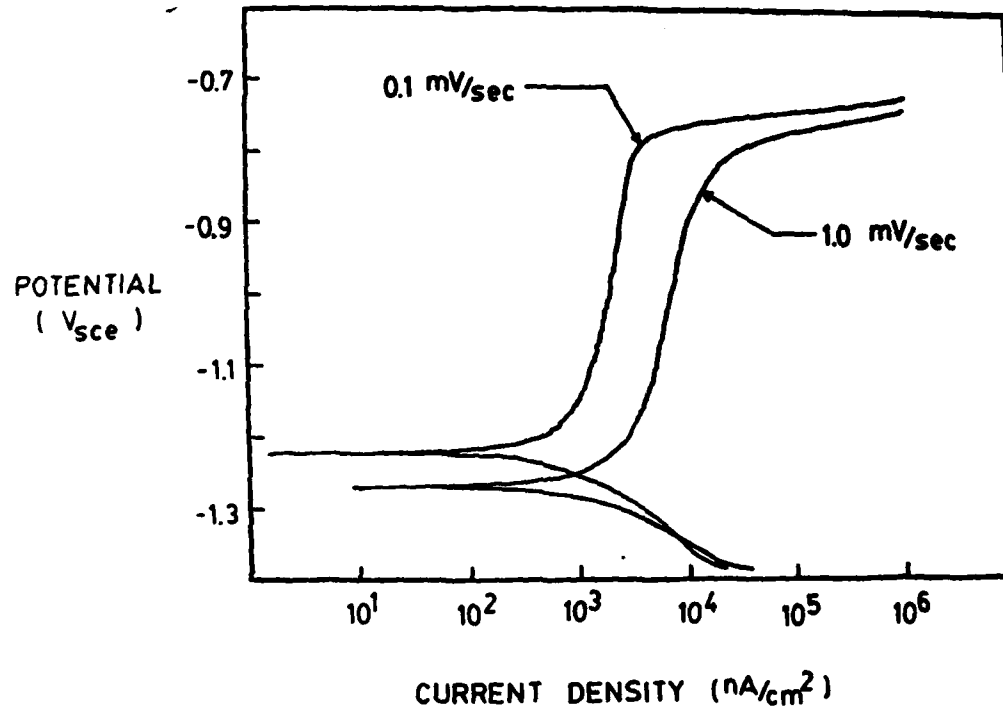


Figure 2. Effect of Potentiodynamic Scan Rate on the Polarization Behavior of the Al-Mg-Li Alloy in Deaerated 0.5 N Sodium Chloride at 23°C.

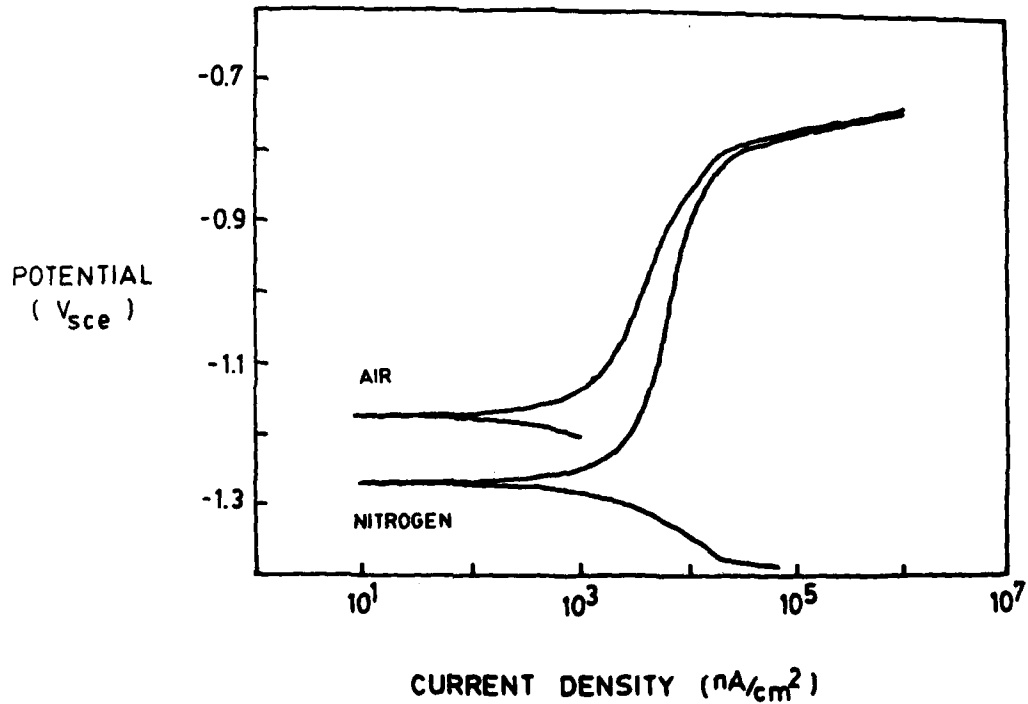


Figure 3. Effect of Solution Aeration on the Polarization Behavior of the Al-Mg-Li Alloy in 0.5 N Sodium Chloride at 23°C and 1 mV/sec scan rate.

Table II Effect of aeration and pH on the electrochemical behavior of aluminum alloy 7050 and an Al-Mg-Li alloy.

Alloy	Aeration	$E_{corr}^1$ (Vsce)	$E_{pit}^2$ (Vsce)	$\Delta E$	$I_{pass}^3$ ( $\mu A/cm^2$ )
(a) pH=2, 0.5 N sodium chloride					
7050	Nitrogen	-0.745	-0.738	+	- - -
	Air	-0.724	-0.709	*	- - -
Al-Mg-Li	Nitrogen	-1.052	-0.770	0.282	110
	Air	-0.798	-0.766	0.032	18
(b) Neutral pH, 0.5 N sodium chloride					
7050	Nitrogen	-0.728	-0.699	0.029	- - -
	Air	-0.726	-0.708	*	- - -
Al-Mg-Li	Nitrogen	-1.236	-0.805	0.431	7.3
	Air	-1.160	-0.789	0.371	4.4
(c) pH=10, 0.5 N sodium chloride					
7050	Nitrogen	-1.240	-0.712	0.528	4.3
Al-Mg-Li	Nitrogen	-1.342	-0.795	0.547	20
	Air	-1.364	-0.782	0.582	33

+ Occasionally pitting occurs immediately on passing the zero potential during the scan.

\* Pitting occurs immediately on passing the zero potential during the scan.

considerably different in neutral solutions and are closer again in aerated acidic solutions. Figure 4 shows the effect of varying the pH in 0.5 N sodium chloride solutions under deaerated and aerated conditions.

### Temperature

Increasing the temperature reduces the free corrosion potential and the pitting potential while increasing the passive current density. Figure 5 shows the effect of temperature on the polarization behavior of the alloys. In this figure, it can be seen that altering the temperature affected the alloys similarly, but that the pitting potential of the 7050 alloy shifted more as a function of temperature. Figure 6 shows the open circuit corrosion potential and pitting potential versus temperature for the alloys.

### Chloride Ion Concentration

Chloride ions or other ionic species in the environment can cause pitting of these as well as other alloys. Accordingly, the pitting potential of the alloys varies with the concentration or activity of the ionic species present. Figure 7 shows the effect of chloride ion concentration on the polarization behavior of the Al-Mg-Li alloy. In figure 8, the chloride ion activity is plotted against the pitting and corrosion potentials. For this figure, the activities were calculated from the concentrations using the activity coefficients of Latimer (7).

## Discussion

### Aeration

Increasing the oxygen content of the environment increases the oxygen in the passive film and increases the nobility of the sample. This reduces the corrosion rate, as indicated by the reduction in the passive current density, but it also increases the driving force for pitting. If the free corrosion potential reaches the critical pitting potential, pitting results. The 7050 alloy frequently pitted prior to initiation of a scan in aerated sodium chloride solutions. Since the free corrosion potential of the lithium containing alloy is more active, it did not pit in this situation.

### pH

Aluminum oxides are soluble in both high and low pH solutions (2,8). As a result, either increasing the pH or decreasing the pH increases the corrosion rate of both alloys. Foley et. al. studied the relative behavior of several anions toward the oxides of aluminum and the passive film on aluminum surfaces (8,9). They concluded that while halides were very detrimental, the most aggressive anion was the hydroxide ion. However, pit initiation is apparently pH independent.

### Temperature

Increasing the temperature decreased the pitting potentials. This means that the alloys are more resistant to

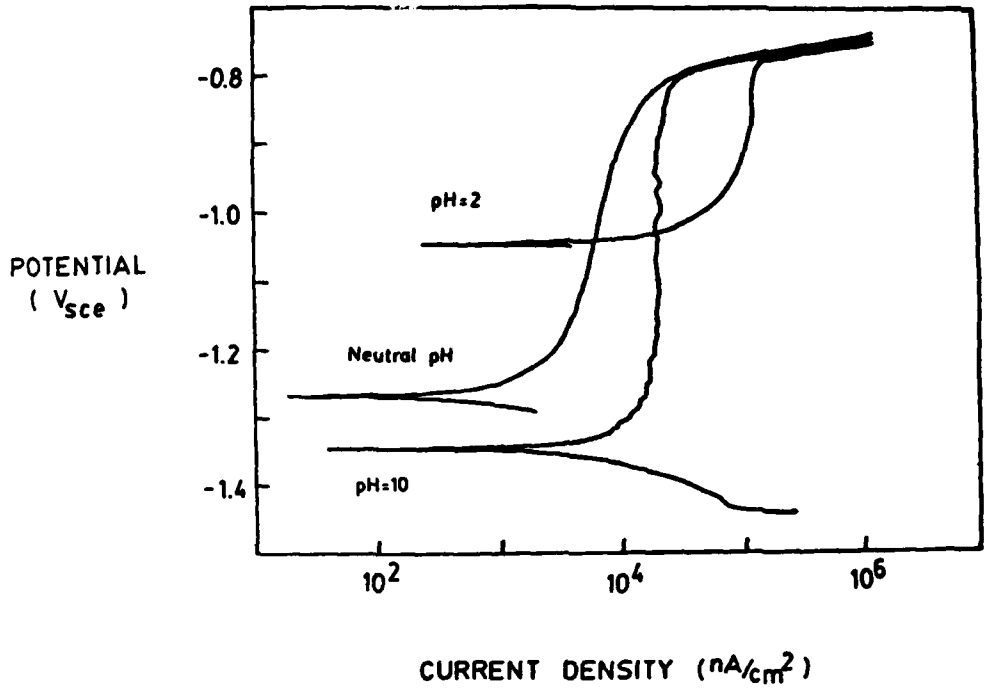


Figure 4A. Effect of pH on the Polarization Behavior of the Al-Mg-Li Alloy in Deaerated 0.5 N Sodium Chloride at 23°C and 1 mV/sec scan rate.

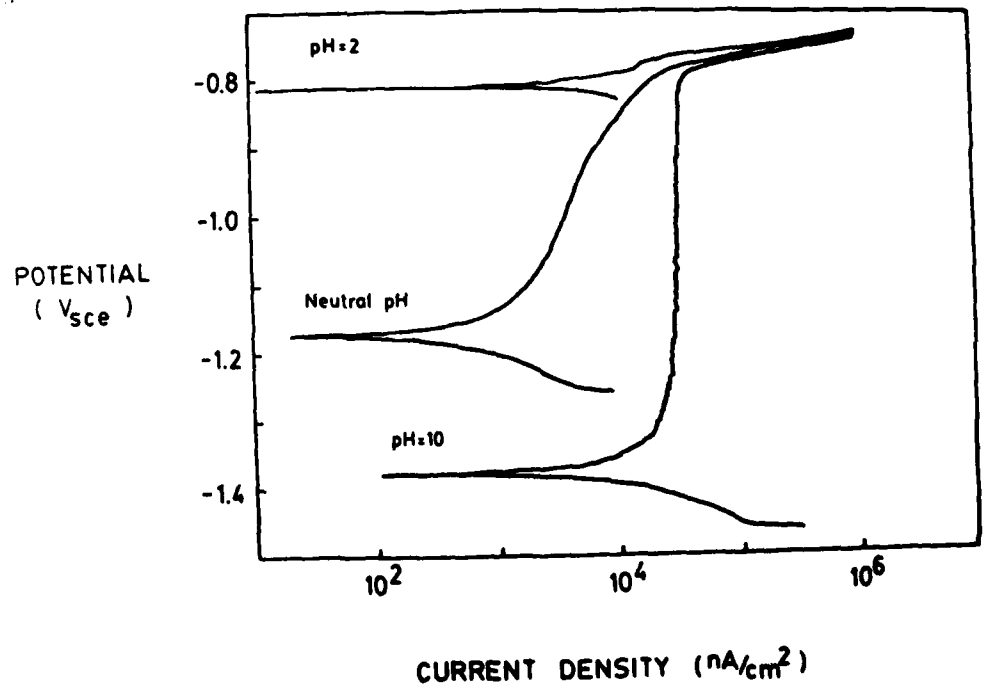


Figure 4B. Effect of pH on the Polarization Behavior of the Al-Mg-Li Alloy in Aerated 0.5 N Sodium Chloride at 23°C and 1 mV/sec scan rate.

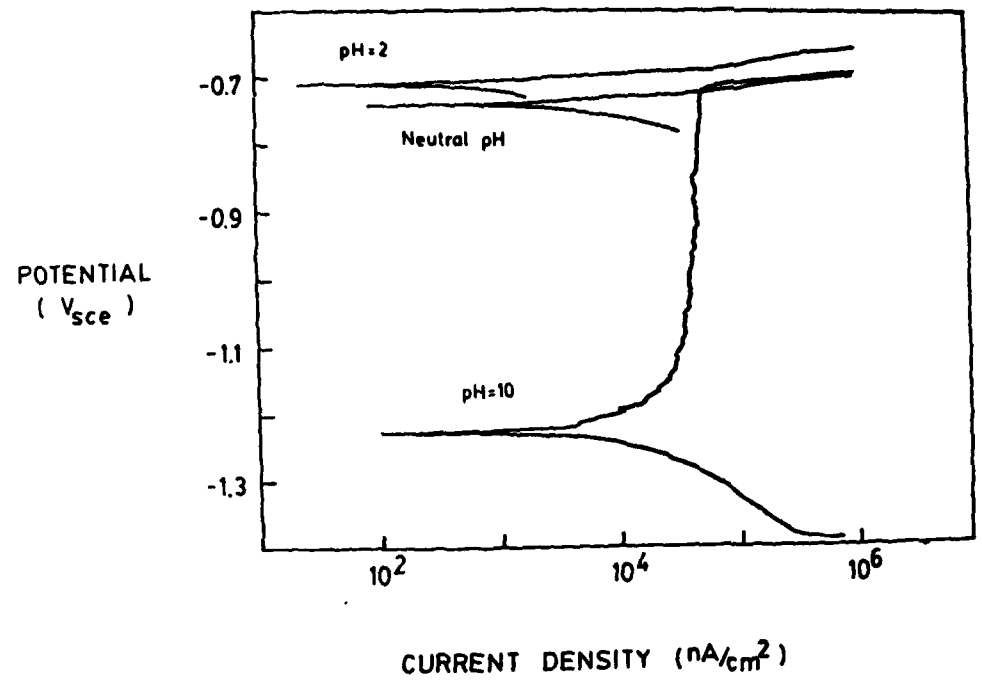


Figure 4C. Effect of pH on the Polarization Behavior of Alloy 7050 in Deaerated 0.5 N Sodium Chloride at 23°C and 1 mV/sec scan rate.

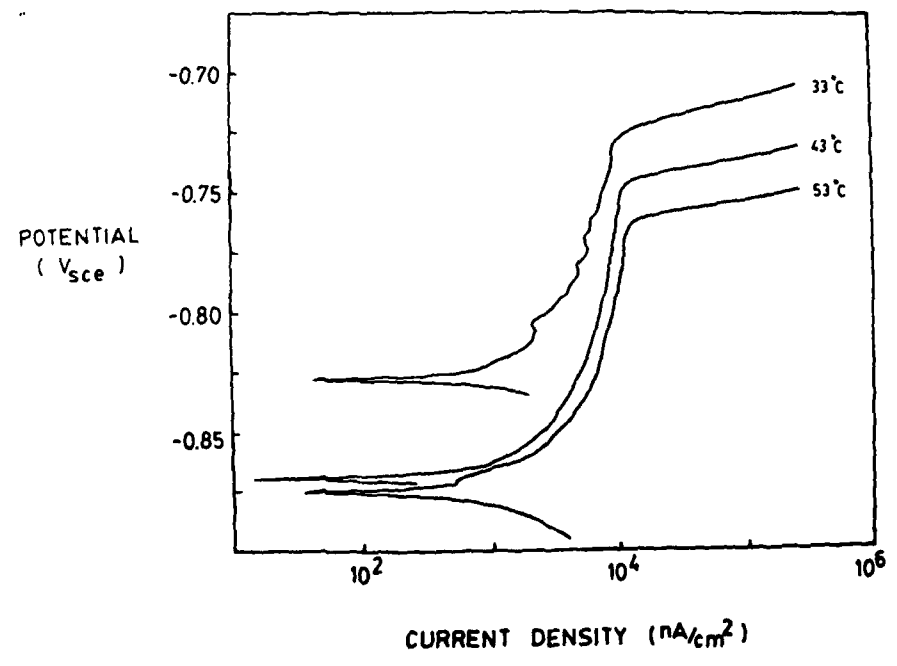


Figure 5A. Effect of Temperature on the Polarization Behavior of Alloy 7050 in Deaerated 0.5 N Sodium Chloride at 1 mV/sec scan rate.

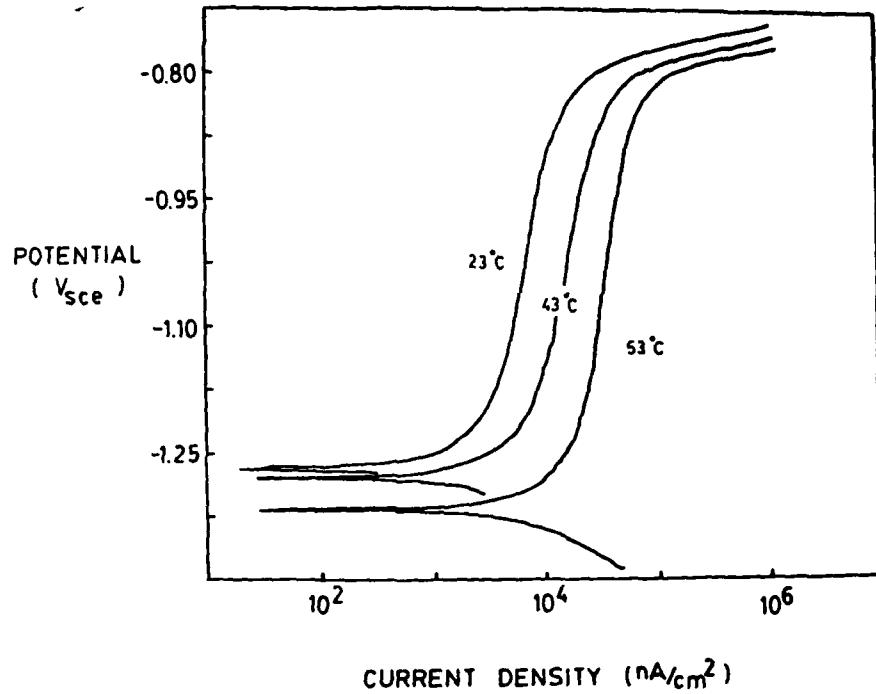


Figure 5B. Effect of Temperature on the Polarization Behavior of the Al-Mg-Li Alloy in Deaerated 0.5 N Sodium Chloride at 1 mV/sec scan rate.

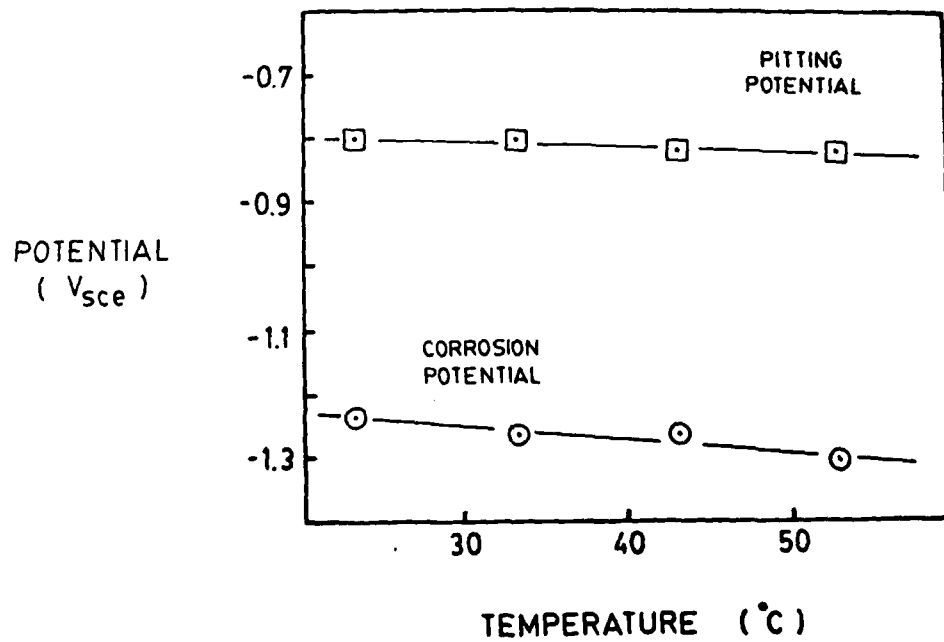


Figure 6A. Temperature versus the Corrosion and Pitting Potentials for the Al-Mg-Li Alloy in Deaerated 0.5 N Sodium Chloride.

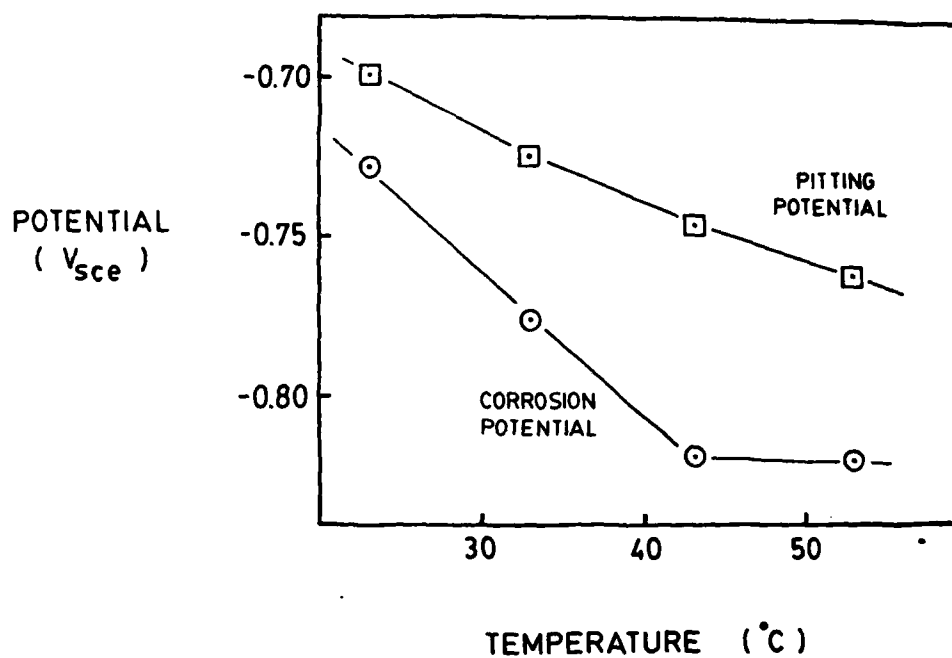


Figure 6B. Temperature versus the Corrosion and Pitting Potentials for Alloy 7050 in Deaerated 0.5 N Sodium Chloride.

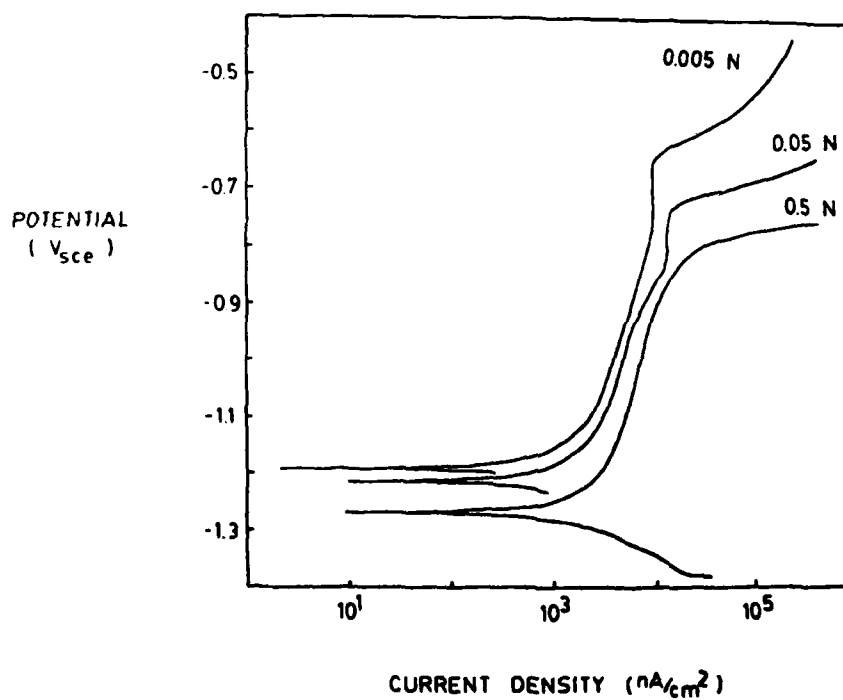


Figure 7A. Effect of Chloride Ion Concentration on the Polarization Behavior of the Al-Mg-Li Alloy in Deaerated Sodium Chloride at 23°C and 1 mV/sec scan rate.

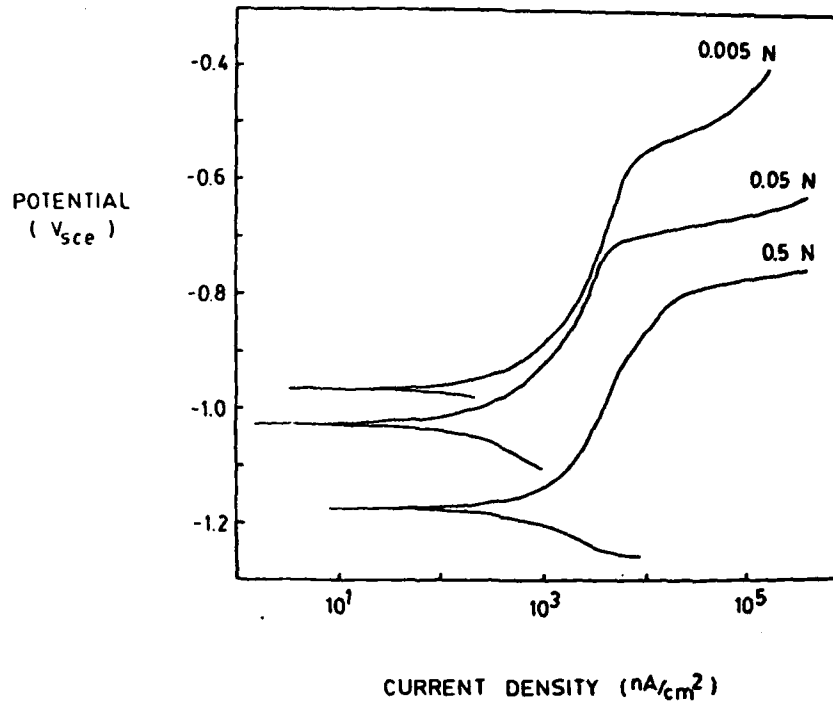


Figure 7B. Effect of Chloride Ion Concentration on the Polarization Behavior of the Al-Mg-Li Alloy in Aerated Sodium Chloride at 23°C and 1 mV/sec scan rate.

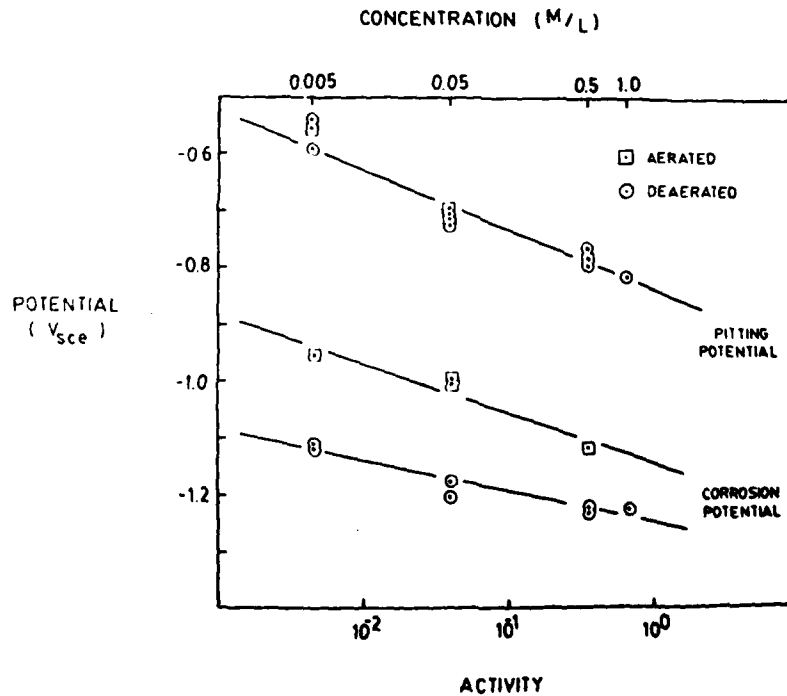


Figure 8. Chloride Ion Activity versus the Pitting and Corrosion Potentials of the Al-Mg-Li Alloy in Aerated and Deaerated Sodium Chloride Solutions at 23°C.

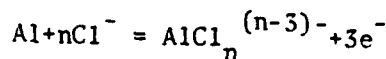
pitting at lower temperatures. Bohni and Uhlig (10) found little temperature effect on the pitting potentials of pure aluminum while other investigators report a similiar effect for pure aluminum to that reported here for the alloys (11,12). Bohni and Uhlig attributed the negligible temperature effect of aluminum to the absence of a temperature sensitive hydration and structure of the passive film. The observed potential shift with temperature of the 7050 is greater than for the Al-Mg-Li alloy. This suggests that either the scan rate-temperature dependence is different for the alloys or the temperature dependence of passive film hydration is different. It should be noted that the observed difference is in the range of reported differences by different investigators for pure aluminum (10-12).

Chloride Ion Concentration

The chloride ion concentration changes the pitting potential according to the relation:

$$E_p = E_p^0 + n \left( \frac{RT}{3F} \right) \ln [Cl^-]$$

Where "n" in the relationship is the stoichiometric factor or reaction order in the pitting reaction:



For the Al-Mg-Li alloy, the slope was found to be 106 mV/decade and the intercept was found to be at -843 mV. Stirrup et. al. found a slope of 100 mV/decade and an intercept of -757 mV for pure aluminum (11). Bohni and Uhlig found a slope of 124 mV/decade and an intercept of -746 mV for pure aluminum (10).

The more active intercept of the chloride activity vs. pitting potential line for the Al-Mg-Li alloy indicates that this alloy is more susceptible to pitting at all chloride concentrations than pure aluminum. Since the slopes for the alloy and pure aluminum are the same, then the pitting reaction is the same or of the same order. This indicates that the protective passive film on the lithium alloy is the same or at least similiar to the film on pure aluminum. The increased susceptibility to pitting may be due to either retardation of film repair kinetics or to an increase in the flaws in the film. This would also explain the shift in the free corrosion potential toward more active potentials.

Alloy Effect

For the Al-Mg-Li alloy compared to the 7050 alloy, the corrosion potential is usually more active and the pitting potential is also slightly less noble. Also, the passive current density at a given potential is higher. This indicates that the passive film on the lithium alloy is less protective.

The active shift in pitting potential indicates less resistance to pit initiation for the Al-Mg-Li alloy. The

difference between the intercept of the chloride ion activity verses pitting potential line, discussed above, for the Al-Mg-Li alloy and pure aluminum is about 100 mV. Thus, for a given electrochemical potential pits will initiate in the lithium alloy more readily than in pure aluminum or alloy 7050. However, the reduced free corrosion potential reduces the probability of pitting under free corrosion conditions. If the Al-Mg-Li alloy is galvanically coupled with either pure aluminum or alloy 7050, the Al-Mg-Li alloy would be expected to preferentially pit. The lithium in the alloy is not necessarily responsible for the shift in pitting potential. Bohni and Uhlig found that additions of either Mg or Mn shifted the pitting potential in the active direction for pure aluminum (10). Since the lithium alloy also contains more magnesium than the 7050 alloy, table I, the increased pitting susceptibility cannot be attributed to lithium alone.

The shift to more active corrosion potentials of lithium containing alloys has been shown to be primarily due to the addition of lithium, and results in increased free corrosion rates (3,4). However, the polarization behavior indicates that the free corrosion potentials are still in the passive regime and that the corrosion rates estimated from the curves are not significantly different compared to the accuracy of the techniques for estimating corrosion rates.

#### Conclusion

The corrosion behavior of the lithium containing alloy is different from that of alloy 7050. The Al-Mg-Li alloy is slightly more susceptible to pitting and general attack. The changes in pitting potential as a function of temperature and chloride ion activity are essentially the same as for pure aluminum. Therefore, the passive film protecting the lithium alloy at the pitting potential is essentially the same as the passive film on pure aluminum. The increased susceptibility may be due to either retardation of repassivation kinetics or due to imperfections in the passive layer.

#### Acknowledgement

The authors would like to acknowledge the support of the U. S. Office of Naval Research under contract no. N00014-75-C-0466.

References

1. H.P. Goddard, W.B. Jepson, M.R. Bothwell, and R.L. Kane, The Corrosion of Light Metals, John Wiley & Sons, Inc. New York (1967)
2. M. Pourbaix, Atlas of Electrochemical Equilibrium Diagrams in Aqueous Solutions, National Association of Corrosion Engineers, Houston, Texas (1974)
3. P. Niskanen, T.H. Sanders, Jr., M. Marek and J.G. Rinker, "The influence of Microstructure on the Corrosion of Al-Li, Al-Li-Mn, Al-Li-Mg and Al-Li-Cu Alloys in 3.5% NaCl Solutions" in Aluminum-Lithium Alloys, Edt. By T.H. Sanders Jr., and E.A. Starke Jr., TMS-AIME, Warrendale PA, (1981) Pg. 347
4. P. Niskanen, T.H. Sanders, Jr., J.G. Rinker and M. Marek, "Corrosion of Aluminum Alloys Containing Lithium", Corrosion Sci., 22 (4) p. 283, (1982) p. 283
5. M.J. Feeney, B.S. Project, Rensselaer Polytechnic Institute, Troy, New York (1982)
6. N.D. Green, Experimental Electrode Kinetics, Rensselaer Polytechnic Institute, Troy New York (1972)
7. W. Latimer, Oxidation Potentials, Prentice Hall, Englewood Cliffs, New Jersey (1952)
8. T.H. Nguyen and R.T. Foley, "The Chemical Nature of The Anion dependency of the Corrosion of Aluminum Corrosion III: Dissolution Mechanisms of Aluminum Oxide and Aluminum Powder in Various Electrolytes", J. Electrochemical Soc., 127 (1980) p. 2563
9. R.T. Foley and P.P. Trazaskoma, "The Chemical Nature of the Anion Dependency of the Corrosion of Aluminum Alloy 7075-T6" Corro 33, (12) (1977) p. 435
10. H. Bohni and H.H. Uhlig, "Environmental Factors Affecting the Critical Pitting Potential of Aluminum" J. Electrochemical Soc., 116 (7) (1969) p. 906-910
11. B.N. Stirrup, N.A. Hampson, I.S. Midgley, "Pit Formation in Relation to the Etching of Aluminum in Chloride Solutions", J. Applied Electrochemistry 5 (1975) p. 229-235
12. A. Broli and H. Holtan, "Use of Potentiokinetic Methods for The Determination of the Characteristic Potential for Pitting Corrosion of Aluminum in a Deaerated Solution of 3% NaCl", Corrosion Sci. , 13 (1973) p.237-246
13. S. Dallek and R.T. Foley, "Mechanism of Pit Initiation on Aluminum Alloy 7075", J. Electrochemical Soc. 123 (12) (1976) p.1775-1779
14. T.P. Hoar "The Production and Breakdown of the Passivity of Metals" Corrosion Sci. 7 (1967) p.341-355

