THE CHEMICAL NATURE OF ALUMINUM CORROSION. II.
ACTIVATION OF ALU--ETC(U)

K. SOTOUDEN, R. T. FOLEY, B. F. BROWN

NOV 79

F/D 11/46

UNCLASSIFIED

AMERICAN UNIV WASHINGTON DC DEPT OF CHEMISTRY

NO0016-75-C-0799

TL-10

CLASSIFIED

**SENSEIIIIIII

I//////. !**

END

This text is not legible due to the image being rotated 90 degrees clockwise. It appears to be a technical document discussing the chemical nature of aluminum corrosion, specifically focusing on the activation of aluminum.
The Chemical Nature of Aluminum Corrosion: I. Activation of Aluminum Surfaces by Aluminum Salts

Technical Report No. 10

By:
K. Sotoudeh, R.T. Foley and B.F. Brown

November 1979

To:
Office of Naval Research
Contract N00014-75-C-0799
NR 036-106

Reproduction in whole or in part is permitted for any purpose of the United States Government.

This work was sponsored by the Metallurgy and Ceramics Program of the Office of Naval Research.
The activation of aluminum surfaces (alloys 1199-H14 and 7075-T6) by solutions of Al(NO₃)₃, AlBr₃, AlCl₃, Al₂(SO₄)₃, Al(ClO₄)₃, AlI₃ and NaCl of various concentrations has been measured. Experiments were also conducted in saturated solutions of aluminum acetate, benzoate, phosphate, chromate and fluoride. The dissolution rate of the alloys varies considerably with the salt, the nitrate and iodide being most aggressive. The corrosion rate in sulfate solutions is much less than the rate in bromide, chloride, or perchlorate. The pH of the various salt solutions is not the determining parameter but for a given salt...
(AlCl₃) the corrosion rate increases with decrease in pH. The experiments definitely demonstrate that the activation effect is not restricted to aluminum chloride and suggests a strong chemical effect in the pitting and stress cracking mechanism.
Aluminum and its alloys are passive unless they are made active by either chemical environments or mechanical actions or by a combination of the two. Although water vapor has been shown in laboratory experiments to be capable of propagating stress corrosion cracks (which indicates a locally active state), it is known from both service experience and laboratory experiments on stress corrosion cracking (to be reported subsequently in this series) that there are effects involving ions other than those of water. It is also known from laboratory experiments that the corroding in localized forms of corrosion (such as pitting and stress corrosion cracking) is chemically different from the bulk environment, though whether this change is a cause or rather a result of the localized corrosion has not been established.

It is generally recognized that the pH of the solution in a growing pit on an aluminum alloy or in a crack on a stress-cracking specimen of an aluminum alloy is approximately 3.5 and there appears to be a relatively high concentration of Al$^{+++}$. Experiments by Rosenfeld and Marshakov$^1$, Brown, et al.$^2$, Marek, et al.$^3$, Davis$^4$, and Hagyard and Santhiapillai$^5$ support this conclusion. The analytical studies on the nature of local corroding agents by Brown, et al., by Marek, et al. and by Davis were conducted on small quantities of corroding, with attendant uncertainties, and they involved only chloride as
an anion (other than OH\(^-\)). Indeed, most of the experimental work in this field has been done in chloride solution and thus an attempt has been made to relate this corrosion to the hydrolysis of aluminum chloride. Almost without exception the thinking has been focused on aluminum chloride and as a result a complete understanding of the pitting mechanism or the stress cracking mechanism has not been realized. The fact is that, aluminum pits and cracks in a number of (non-chloride) environments.

The objective of this work was to measure the corrosion rate of aluminum alloy 1199 and alloy 7075 in various aluminum salt solutions to determine the ability of these various salts to activate the aluminum surface. The longer range intent is to relate this specific corrosion reaction to the initiation of pitting and the stress cracking process.

**EXPERIMENTAL**

The experimental work reported here consisted of immersion tests with two aluminum alloys, alloy 1199-H14 and alloy 7075-T6. Samples 38 x 26 x 0.81 mm were cleaned in the conventional manner. The strip was immersed in NaOH solution (5g/100ml) at 70\(^\circ\)-80\(^\circ\)C for one minute, rinsed thoroughly, dipped in HNO\(_3\) (1:3) for one minute at room temperature, and thoroughly rinsed in distilled water and acetone. Samples were immersed in triplicate in solutions of Al(NO\(_3\))\(_3\), AlBr\(_3\), AlCl\(_3\), Al\(_2\)(SO\(_4\))\(_3\), Al(ClO\(_4\))\(_3\), All\(_3\) and NaCl of various concentrations as well as in saturated solutions of aluminum acetate, aluminum benzoate, aluminum phosphate, aluminum chromate and aluminum fluoride. These samples were immersed for 7 to 9 day periods at room temperature, 23\(^\circ\) ± 2\(^\circ\)C. Following exposures, the corrosion products were removed with a stripping solution of 20 g of chromic acid and 32.25 ml of 85% phosphoric acid/liter. The weight loss reported was the difference
in weight of the sample before the test and that after the stripping. The latter was corrected with the weight loss of an uncorroded metal specimen in the stripping solution.

RESULTS

The weight losses for alloy 1199 immersed in 0.1M solutions of aluminum nitrate, bromide, chloride, sulfate, perchlorate and iodide are given in Table I. The activating effect of the nitrate and iodide is approximately three times that of the bromide, chloride and perchlorate, the sulfate one-half. This order is approximately followed in 0.2N solutions in a 7-day experiment reported in Table II. In neither set of experiments is there a correlation between corrosion rate and pH. The pH of these solutions fell in the 3.0-4.0 range with the exception of the aluminum perchlorate solution which had a pH of 2.6-2.7.

Dissolution rates for alloy 7075 in 0.5M solutions of the salts (Table III) were appreciably higher. Aluminum iodide produced a very high corrosion rate as did the nitrate and chloride solutions. The bromide and perchlorate effects were about about one-third of the latter and the sulfate solution an order of magnitude lower. Again, the pH of the solution was not a significant factor.

A number of aluminum salts, mainly those formed from weak acids, were used as saturated solutions. These included aluminum acetate, benzoate, phosphate, chromate, and fluoride.

The weight losses exhibited by samples of 1199 in these saturated solutions over a 7 to 9 day period are tabulated in Table IV. Chromate and phosphate solutions gave very little corrosion but the acetate and benzoate gave low but appreciable corrosion rates. The coupons immersed in aluminum
<table>
<thead>
<tr>
<th>Solution</th>
<th>Duration of Test (days)</th>
<th>pH</th>
<th>Loss in Weight Average (mg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al(NO₃)₃</td>
<td>7</td>
<td>3.30</td>
<td>1.69</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3.33</td>
<td>1.22</td>
</tr>
<tr>
<td>AlBr₃</td>
<td>7</td>
<td>3.76</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>3.64</td>
<td>0.79</td>
</tr>
<tr>
<td>AlCl₃</td>
<td>7</td>
<td>3.23</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>3.28</td>
<td>0.80</td>
</tr>
<tr>
<td>Al₂(SO₄)₃</td>
<td>7</td>
<td>3.40</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3.28</td>
<td>0.42</td>
</tr>
<tr>
<td>Al(ClO₄)₃</td>
<td>7</td>
<td>2.60</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>2.60</td>
<td>0.72</td>
</tr>
<tr>
<td>AlI₃</td>
<td>7</td>
<td>3.62</td>
<td>1.83</td>
</tr>
</tbody>
</table>
TABLE II

WEIGHT LOSS OF ALUMINUM ALLOY 1199 IN 0.2N SOLUTIONS OF VARIOUS ALUMINUM SALTS

<table>
<thead>
<tr>
<th>Solution</th>
<th>Duration of Test (days)</th>
<th>pH</th>
<th>Loss in Weight Average (mg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Al(NO}_3\text{)}_3$</td>
<td>7</td>
<td>3.32</td>
<td>1.79</td>
</tr>
<tr>
<td>$\text{AlBr}_3$</td>
<td>7</td>
<td>3.68</td>
<td>0.74</td>
</tr>
<tr>
<td>$\text{AlCl}_3$</td>
<td>7</td>
<td>3.26</td>
<td>0.53</td>
</tr>
<tr>
<td>$\text{Al}_2(\text{SO}_4\text{)}_3$</td>
<td>7</td>
<td>3.46</td>
<td>0.27</td>
</tr>
<tr>
<td>$\text{Al(ClO}_4\text{)}_3$</td>
<td>7</td>
<td>2.70</td>
<td>0.65</td>
</tr>
<tr>
<td>$\text{AlI}_3$</td>
<td>7</td>
<td>3.77</td>
<td>1.16</td>
</tr>
</tbody>
</table>
TABLE III

WEIGHT LOSS OF ALUMINUM ALLOY 7075 IN 0.5M SOLUTIONS OF ALUMINUM SALTS

<table>
<thead>
<tr>
<th>Solution</th>
<th>Duration of Test (days)</th>
<th>pH</th>
<th>Loss in Weight Average (mg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al(NO₃)₃</td>
<td>7</td>
<td>2.63</td>
<td>10.6</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>2.60</td>
<td>11.2</td>
</tr>
<tr>
<td>AlBr₃</td>
<td>7</td>
<td>3.36</td>
<td>3.04</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>2.94</td>
<td>7.07</td>
</tr>
<tr>
<td>AlCl₃</td>
<td>7</td>
<td>2.66</td>
<td>9.69</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>2.53</td>
<td>9.66</td>
</tr>
<tr>
<td>Al₂(SO₄)₃</td>
<td>7</td>
<td>2.90</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>2.81</td>
<td>0.97</td>
</tr>
<tr>
<td>Al(ClO₄)₃</td>
<td>7</td>
<td>1.32</td>
<td>3.17</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>1.10</td>
<td>4.82</td>
</tr>
<tr>
<td>AlI₃</td>
<td>7</td>
<td>3.49</td>
<td>44.9</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>3.30</td>
<td>51.6</td>
</tr>
<tr>
<td>Solution</td>
<td>Duration of Test (days)</td>
<td>pH</td>
<td>Loss in Weight Average (mg/cm²)</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------------</td>
<td>------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>( \text{Al(CH}_3\text{COO)}_3 )</td>
<td>7</td>
<td>4.78</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>4.92</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>4.53</td>
<td>0.16</td>
</tr>
<tr>
<td>( \text{Al(C}_6\text{H}_5\text{COO)}_3 )</td>
<td>7</td>
<td>3.32</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>3.31</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>3.54</td>
<td>0.17</td>
</tr>
<tr>
<td>( \text{AlPO}_4 )</td>
<td>7</td>
<td>3.00</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>2.84</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>3.39</td>
<td>0.01</td>
</tr>
<tr>
<td>( \text{Al(CrO}_4\text{)}_3 )</td>
<td>7</td>
<td>3.49</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3.12</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>3.37</td>
<td>0.005</td>
</tr>
<tr>
<td>( \text{AlF}_3 )</td>
<td>7</td>
<td>5.30</td>
<td>(+0.22)</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>5.05</td>
<td>(+0.23)</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>5.22</td>
<td>(+0.56)</td>
</tr>
</tbody>
</table>
fluoride solution gave a weight increase indicating that the standard stripping solution did not remove the precipitated corrosion product. Again, there was no correlation between the corrosion rate and pH of the solution. Similar results were obtained with alloy 7075 (Table V), with the exception that the rate in aluminum acetate solution at a pH, 4.7-4.9, was higher than the other solutions.

For a single salt, aluminum chloride, initially at 0.5N concentration, the corrosion rate varies with pH. This effect is shown in Table VI wherein the dissolution rate drops appreciably in going from a pH of 2.0 to 4.5.

The unexpected results obtained with aluminum nitrate, chloride, and sulfate suggested performing experiments wherein the salts were compared at approximately equivalent activity. The comparison, of necessity, was rather rough because the activity coefficients for these salts over a range of concentrations, particularly in dilute solutions, are not available. To approximate equivalent activities, solutions 0.69M in \( \text{Al}_2(\text{SO}_4)_3 \), 0.014M in \( \text{AlCl}_3 \), and 0.020M in \( \text{AlNO}_3 \) were compared. However, the order of activation was still the same for the three salts (Table VII).

**DISCUSSION**

The idea that aluminum surfaces may be activated by aluminum chloride has been advanced by several other investigators. The "autocatalytic" nature of aluminum pitting seems to have been first suggested by Edeleanu and Evans but explored in more detail by Hageyard and Santhiapillai. The latter investigators measured the pH and electrode potential inside an artificial pit on an aluminum electrode undergoing corrosion by short circuit to a graphite cathode in a solution 0.014M in chloride. The pH in the artificial pit ranged from a minimum of 3.18 to 3.8. The \( \text{AlCl}_3 \) concen-
<table>
<thead>
<tr>
<th>Solution</th>
<th>Duration of Test (days)</th>
<th>pH</th>
<th>Loss in Weight Average (mg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Al(CH}_3\text{COO)}_3$</td>
<td>7</td>
<td>4.67</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>4.92</td>
<td>0.42</td>
</tr>
<tr>
<td>$\text{Al(C}_6\text{H}_5\text{COO)}_3$</td>
<td>7</td>
<td>3.40</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>3.13</td>
<td>0.26</td>
</tr>
<tr>
<td>$\text{AlPO}_4$</td>
<td>7</td>
<td>3.11</td>
<td>0.075</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>2.84</td>
<td>0.11</td>
</tr>
<tr>
<td>$\text{Al(CrO}_4\text{)}_3$</td>
<td>7</td>
<td>3.52</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>3.12</td>
<td>0.005</td>
</tr>
<tr>
<td>$\text{AlF}_3$</td>
<td>7</td>
<td>4.90</td>
<td>(0.25)</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td></td>
<td>(0.24)</td>
</tr>
<tr>
<td>pH</td>
<td>Duration of Test (days)</td>
<td>Loss in Weight Average (mg/cm²)</td>
<td></td>
</tr>
<tr>
<td>----</td>
<td>------------------------</td>
<td>--------------------------------</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>7</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>7</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>7</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td>7</td>
<td>0.34</td>
<td></td>
</tr>
<tr>
<td>4.5</td>
<td>7</td>
<td>0.24</td>
<td></td>
</tr>
</tbody>
</table>
TABLE VII

WEIGHT LOSS OF ALUMINUM ALLOY 1199 IN SOLUTIONS OF APPROXIMATELY EQUIVALENT ACTIVITY

<table>
<thead>
<tr>
<th>Solution</th>
<th>Duration of Test (days)</th>
<th>Molarity</th>
<th>Loss in Weight Average (mg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al₂(SO₄)₃</td>
<td>7</td>
<td>0.69</td>
<td>0.20</td>
</tr>
<tr>
<td>AlCl₃</td>
<td>7</td>
<td>0.014</td>
<td>0.68</td>
</tr>
<tr>
<td>Al(NO₃)₃</td>
<td>7</td>
<td>0.020</td>
<td>0.85</td>
</tr>
</tbody>
</table>
tration at a pH of 3.2 conforms to 0.24 eq/l \( \text{AlCl}_3 \). They concluded that a NaCl solution did not activate the Al surface but highly basic \( \text{AlCl}_3 \) at the same pH (3.79) did. Solutions of \( \text{AlCl}_3 \) in concentrations of 0.1 and 1.0 eq/l activated Al in times decreasing with increased concentration while NaCl solutions at the same pH did not. Thus the "autocatalytic" nature of the process is not due to the pH or the \( \text{Cl}^- \) but the ability of the \( \text{AlCl}_3 \) solution to react with the oxide. The activation can be followed by the potential going negative, e.g. to -0.65 to -0.69 V (vs. Ag-AgCl reference) and the negative potential is due to the Al-\( \text{AlCl}_3 \) couple.

The present results support the concept that it is the nature of the aluminum salt rather than the pH of the solution produced by the hydrolysis of the aluminum cation. Thus, consistently aluminum sulfate solutions are non-corrosive and aluminum nitrate solutions accelerate corrosion. The results of these experiments emphasize the chemical nature of the process as opposed to strictly physical or electrochemical approaches. The results are inconsistent with some of the mechanisms proposed in the past particularly those that give to the chloride ion unique properties of adsorption and penetration of the oxide film.\(^7\)

This approach is also inconsistent with those models that put a heavy emphasis on flaws and dislocations in the film.\(^8\) Presumably, all of the samples of a given alloy would have the same surface structure.

These experiments definitely demonstrate that aluminum salts in the 3.0-4.0 pH range are accelerators for aluminum corrosion. This effect is not restricted to aluminum chloride solutions. Whether or not they are the accelerators for aluminum pitting and aluminum stress cracking for these processes occurring in neutral salt solutions remains to be demonstrated.
REFERENCES


## DISTRIBUTION LIST

<table>
<thead>
<tr>
<th>Organization</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defense Documentation Center</td>
<td>Naval Air Propulsion Test Center</td>
</tr>
<tr>
<td>Cameron Station</td>
<td>Trenton, NJ 08628</td>
</tr>
<tr>
<td>Alexandria, VA 22314</td>
<td>ATTN: Library</td>
</tr>
<tr>
<td>Office of Naval Research</td>
<td>Naval Construction Battalion</td>
</tr>
<tr>
<td>Department of the Navy</td>
<td>Civil Engineering Laboratory</td>
</tr>
<tr>
<td>800 N. Quincy Street</td>
<td>Port Hueneme, CA 93043</td>
</tr>
<tr>
<td>Arlington, VA 22217</td>
<td>ATTN: Materials Division</td>
</tr>
<tr>
<td>ATTN: Code 471</td>
<td>Naval Electronics Laboratory</td>
</tr>
<tr>
<td>Code 102</td>
<td>San Diego, CA 92152</td>
</tr>
<tr>
<td>Code 470</td>
<td>ATTN: Electron Materials Sciences Division</td>
</tr>
<tr>
<td>Commanding Officer</td>
<td>Naval Missile Center</td>
</tr>
<tr>
<td>Office of Naval Research</td>
<td>Materials Consultant</td>
</tr>
<tr>
<td>Branch Office</td>
<td>Code 3312-1</td>
</tr>
<tr>
<td>Building 114, Section D</td>
<td>Point Mugu, CA 92041</td>
</tr>
<tr>
<td>666 Summer Street</td>
<td>Commanding Officer</td>
</tr>
<tr>
<td>Boston, MA 02210</td>
<td>Naval Surface Weapons Center</td>
</tr>
<tr>
<td></td>
<td>White Oak Laboratory</td>
</tr>
<tr>
<td></td>
<td>Silver Spring, MD 20910</td>
</tr>
<tr>
<td></td>
<td>ATTN: Library</td>
</tr>
<tr>
<td>Commanding Officer</td>
<td>David W. Taylor Naval Ship Research and Development Center</td>
</tr>
<tr>
<td>Office of Naval Research</td>
<td>Materials Department</td>
</tr>
<tr>
<td>Branch Office</td>
<td>Annapolis, MD 21402</td>
</tr>
<tr>
<td>536 South Clark Street</td>
<td>Naval Undersea Center</td>
</tr>
<tr>
<td>Chicago, IL 60605</td>
<td>San Diego, CA 92132</td>
</tr>
<tr>
<td></td>
<td>ATTN: Library</td>
</tr>
<tr>
<td>Naval Research Laboratory</td>
<td>Naval Underwater System Center</td>
</tr>
<tr>
<td>Washington, DC 20375</td>
<td>Newport, RI 02840</td>
</tr>
<tr>
<td>ATTN: Codes 6000</td>
<td>ATTN: Library</td>
</tr>
<tr>
<td>6000</td>
<td>Naval Weapons Center</td>
</tr>
<tr>
<td>6100</td>
<td>China Lake, CA 93555</td>
</tr>
<tr>
<td>6300</td>
<td>ATTN: Library</td>
</tr>
<tr>
<td>6400</td>
<td>Naval Postgraduate School</td>
</tr>
<tr>
<td>2627</td>
<td>Monterey, CA 93940</td>
</tr>
<tr>
<td>Naval Air Development Center</td>
<td>ATTN: Mechanical Engineering Department</td>
</tr>
<tr>
<td>Code 392</td>
<td></td>
</tr>
<tr>
<td>Warminster, PA 18964</td>
<td></td>
</tr>
<tr>
<td>ATTN: Mr. F. S. Williams</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Organization

Naval Air Systems Command
Washington, DC 20360
ATTN: Codes 52031
      52032

Naval Sea System Command
Washington, DC 20362
ATTN: Code 03

Naval Facilities Engineering Command
Alexandria, VA 22331
ATTN: Code 03

Scientific Advisor
Commandant of the Marine Corps
Washington, DC 20380
ATTN: Code AX

Naval Ship Engineering Center
Department of the Navy
Washington, DC 20360
ATTN: Code 6101

Army Research Office
P.O. Box 12211
Triangle Park, NC 27709
ATTN: Metallurgy & Ceramics Program

Army Materials and Mechanics Research Center
Worthington, MA 02172
ATTN: Research Programs Office

Air Force Office of Scientific Research
Bldg. 410
Boiling Air Force Base
Washington, DC 20332
ATTN: Chemical Science Directorate
     Electronics & Solid State Sciences Directorate

Air Force Materials Laboratory
Wright-Patterson AFB
Dayton, OH 45433

Library
Building 50, Rm 134
Lawrence Radiation Laboratory
Berkeley, CA

Organization

NASA Headquarters
Washington, DC 20546
ATTN: Code RRM

NASA
Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135
ATTN: Library

National Bureau of Standards
Washington, DC 20234
ATTN: Metallurgy Division
Inorganic Materials Div.

Director Applied Physics Laboratory
University of Washington
1013 Northeast Forthieth Street
Seattle, WA 98105

Defense Metals and Ceramics Information Center
Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201

Metals and Ceramics Division
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37380

Los Alamos Scientific Laboratory
P.O. Box 1663
Los Alamos, NM 87544
ATTN: Report Librarian

Argonne National Laboratory
Metallurgy Division
P.O. Box 229
Lemont, IL 60439

Brookhaven National Laboratory
Technical Information Division
Upton, Long Island
New York 11973
ATTN: Research Library

Office of Naval Research
Branch Office
1030 East Green Street
Pasadena, CA 91106
Dr. T. R. Beck
Electrochemical Technology Corporation
10035 31st Avenue, NE
Seattle, Washington 98125

Professor I. M. Bernstein
Carnegie-Mellon University
Schenley Park
Pittsburgh, Pennsylvania 15213

Professor H. K. Birnbaum
University of Illinois
Department of Metallurgy
Urbana, Illinois 61801

Dr. Otto Buck
Rockwell International
1049 Camino Dos Rios
P. O. Box 1085
Thousand Oaks, California 91360

Dr. David L. Davidson
Southwest Research Institute
8500 Culebra Road
P. O. Drawer 28510
San Antonio, Texas 78234

Dr. D. J. Duquette
Department of Metallurgical Engineering
Rensselaer Polytechnic Institute
Troy, New York 12181

Professor R. T. Foley
The American University
Department of Chemistry
Washington, D. C. 20016

Mr. G. A. Gehring
Ocean City Research Corporation
Tennessee Avenue & Beach Thorofare
Ocean City, New Jersey 08226

Dr. J. A. S. Green
Martin Marietta Corporation
1450 South Rolling Road
Baltimore, Maryland 21227

Professor R. H. Heidersbach
University of Rhode Island
Department of Ocean Engineering
Kingston, Rhode Island 02881

Professor H. Herman
State University of New York
Material Sciences Division
Stony Brook, New York 11970

Professor J. P. Hirth
Ohio State University
Metallurgical Engineering
1314 Kinnear Road
Columbus, Ohio 43212

Dr. E. W. Johnson
Westinghouse Electric Corporation
Research and Development Center
1310 Beulah Road
Pittsburgh, Pennsylvania 15235

Professor R. M. Latanision
Massachusetts Institute of Technology
77 Massachusetts Avenue
Room E19-702
Cambridge, Massachusetts 02139

Dr. F. Mansfeld
Rockwell International Science Center
1049 Camino Dos Rios
P. O. Box 1085
Thousand Oaks, California 91360

Dr. Jeff Perkins
Naval Postgraduate School
Monterey, California 93940
Professor H. W. Pickering  
Pennsylvania State University  
Department of Material Sciences  
University Park, Pennsylvania 16802

Dr. E. A. Starke, Jr.  
Georgia Institute of Technology  
School of Chemical Engineering  
Atlanta, Georgia 30332

Dr. Barry C. Syrett  
Stanford Research Institute  
333 Ravenswood Avenue  
Menlo Park, California 94025

Dr. R. P. Wei  
Lehigh University  
Institute for Fracture and Solid Mechanics  
Bethlehem, Pennsylvania 18015

Professor H. G. E. Wilsdorf  
University of Virginia  
Department of Materials Science  
Charlottesville, Virginia 22903

Dr. Clive Clayton  
State University of New York  
Material Sciences Division  
Stony Brook, New York 11970