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# CORROSION OF MATERIALS IN SURFACE SEAWATER AFTER 12 AND 18 MONTHS OF EXPOSURE

By

Fred M. Reinhart and James F. Jenkins

January 1972



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YF 38.535.005.01.004

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ABSTRACT

A total of 1150 specimens of 189 different alloys were completely immersed in surface seawater for 12 and 18 months to obtain data for comparison with deep ocean corrosion data.

Corrosion rates, types of corrosion and pit depths were determined.

Some highly alloyed nickel alloys, titanium alloys, silicon cast irons, specialty stainless steels, columbium, tantalum and a tantalum-tungsten alloy were uncorroded in seawater both at the surface and at depth.

The corrosion rates of the copper base alloys, nickel base alloys, steels, cast irons, lead, tin, lead-tin solder, molybdenum and tungsten decreased with the concentration of oxygen in seawater, i.e., the corrosion rates were lower at depth than at the surface. The corrosion rates of Ni-200, Ni-Cu 402, 406, 410, K-500 and 45-55, Ni-Cr-Fe X750, Ni-Mo2, all steels, grey cast iron and alloy cast irons decreased linearly with the concentration of oxygen in seawater.

The copper base alloys, steels, cast irons, molybdenum, tungsten, lead and lead-tin solder corroded uniformly both at the surface and at depth.

The aluminum alloys were attacked by pitting and crevice corrosion and seawater was more aggressive at depth than at the surface for such alloys. The effect of the concentration of oxygen in seawater on the corrosion of aluminum alloys was inconsistent.

The stainless steels were attacked by pitting, tunneling and crevice corrosion, except 309, 316L, 317, 329, 633, 20Cb-3 and Ni-Cr-Mo-Si. Surface seawater was more aggressive than seawater at depth in promoting these types of corrosion on the stainless steels.

PREFACE

The Naval Civil Engineering Laboratory has been conducting a research program to determine the effects of deep ocean environments on materials. It is expected that this research will establish the best materials to be used in deep ocean construction.

A Submersible Test Unit (STU) was designed, on which many test specimens can be mounted. The STU can be lowered to the ocean floor and remain there for long periods of exposure.

Thus far, exposures have been made at two deep-ocean test sites and at a surface seawater site in the Pacific Ocean. Seven STUs have been exposed and recovered. Test Site I (nominal depth of 6,000 feet) is approximately 81 nautical miles west-southwest of Port Hueneme, California, latitude 33°44'N and longitude 120°45'W. Test Site II (nominal depth of 2,500 feet) is 75 nautical miles west of Port Hueneme, California, latitude 34°06'N and longitude 120°42'W. A surface seawater exposure site (V) was established at Point Mugu, California, (latitude 34°06'N and longitude 119°07'W) to obtain surface immersion data for comparison purposes.

This report presents the results of the evaluation of the different alloys exposed at the surface immersion site for periods of 12 and 18 months.

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13. ABSTRACT


A total of 1150 specimens of 189 different alloys were completely immersed in surface seawater for 12 and 18 months to obtain data for comparison with deep ocean corrosion data.

Corrosion rates, types of corrosion and pit depths were determined.

Some highly alloyed nickel alloys, titanium alloys, silicon cast irons, specialty stainless steels, columbium, tantalum and a tantalum-tungsten alloy were uncorroded in seawater both at the surface and at depth.

The corrosion rates of the copper base alloys, nickel base alloys, steels, cast irons, lead, tin, lead-tin solder, molybdenum and tungsten decreased with the concentration of oxygen in seawater, i.e., the corrosion rates were lower at depth than at the surface. The corrosion rates of Ni-200, Ni-Cu 402, 410, K-500 and 45-55, Ni-Cr-Fe X750, Ni-Mo2, all steels, grey cast iron and alloy cast irons decreased linearly with the concentration of oxygen in seawater.

The copper base alloys, steels, cast irons, molybdenum, tungsten, lead and lead-tin solder corroded uniformly both at the surface and at depth.


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| | ROLE | WT | ROLE | WT | ROLE | WT |
| Corrosion | | | | | | |
| Metals | | | | | | |
| Alloys | | | | | | |
| Sea water | | | | | | |
| Shallow water | | | | | | |
| Nickel Alloys | | | | | | |
| Titanium Alloys | | | | | | |
| Silicon cast irons | | | | | | |
| Stainless steels | | | | | | |
| Columbium | | | | | | |
| Tantalum | | | | | | |
| Tantalum-tungsten alloy | | | | | | |
| Copper alloys | | | | | | |
| Lead | | | | | | |
| Tin | | | | | | |
| Lead-tin solder | | | | | | |
| Molybdenum | | | | | | |
| Tungsten | | | | | | |
| Steels | | | | | | |
| Cast iron | | | | | | |



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The aluminum alloys were attacked by pitting and crevice corrosion and seawater was more aggressive at depth than at the surface for such alloys. The effect of the concentration of oxygen in seawater on the corrosion of aluminum alloys was inconsistent.

The stainless steels were attacked by pitting, tunneling and crevice corrosion, except 309, 316L, 317, 329, 633, OCb-3 and Ni-Cr-Mo-Si. Surface seawater was more aggressive than seawater at depth in promoting these types of corrosion on the stainless steels.

## INTRODUCTION

The development of deep diving vehicles which can stay submerged for long periods of time has focused attention on the deep ocean as an operating environment. This has created a need for information concerning the behavior of both common and potential materials of construction at depths in the ocean.

To study the problems of construction in the deep ocean, project "Deep Ocean Studies" was established. Fundamental to the design, construction and operation of structures, and their related facilities, is information with regard to the deterioration of materials in deep ocean environments. This portion of the project is concerned with determining the effects of these environments on the corrosion of metals and alloys.

In order to determine the differences between the corrosiveness of seawater at depths and at the surface it is desirable to compare deep ocean corrosion data with surface immersion data. Since surface data was not available in the literature for many of the alloys exposed at depths in the Pacific Ocean, it was decided to establish a surface exposure site to obtain this information. Therefore, a third site, designated at Site V, was established at Point Mugu, California, latitude 34°06'N and longitude 119°07'W.

The locations of the three test sites, two deep ocean sites and the surface site, are shown in Figure 1. The specific geographical locations of the test sites and the average characteristics of the seawater at these sites are given in Table 1.

Reports pertaining to the performance of alloys in the deep ocean environments are given in References 1 through 9.

This report presents a discussion of the results obtained of the corrosion of various alloys exposed at the surface, Site V, for periods of 12 and 18 months.

## RESULTS AND DISCUSSIONS

The results presented and discussed herein also include the corrosion data for the alloys exposed at the surface for the International Nickel Company, Inc. Permission for their use has been granted by Dr. T. P. May, Reference 10.

The deep ocean data for depths of 2,500 and 6,000 feet after comparable periods of exposure are included for comparison purposes.

## ALUMINUM ALLOYS

The chemical compositions of the aluminum alloys are given in Table 2 and their corrosion rates and types of corrosion in Table 3. The variations of the corrosion rates and maximum pit depths of the alloys with depth and with oxygen content of seawater are shown graphically in Figures 2 through 9.

Aluminum alloys corrode chiefly by the pitting and crevice types in seawater, both of which are localized types, which means that the greater portion of the surface area of a specimen is unattacked. Therefore, corrosion rates calculated from weight losses and expressed as mils per year, which indicates uniform thinning of the material, are very misleading because they create an erroneous impression of the behavior of the material. In order to present a more realistic picture of the behavior of aluminum alloys, the maximum and average pit depths and the maximum depth of crevice corrosion are also reported.

In Figure 2 the corrosion rates of the aluminum alloys versus depth are shown. The variation of the oxygen content of seawater with depth is also shown in Figure 2. The corrosion rates of aluminum alloys 1100-H14, 5083-H113 and 3003-H14 increase progressively with depth. Those of the 6061-T6 and 2219-T81 alloys are greater at depth than at the surface but their increases are not progressive since their rates at the 2,500-foot depth are greater than those at the 6,000-foot depth. The corrosion rate of 2024-0 at the 6,000-foot depth was greater than at the surface, but at the 2,500-foot depth it was less than at the surface. The corrosion rate of 5086-H34 decreased slightly with depth. It is shown in Figure 2 that based on corrosion rates the corrosion of 5083-H113, 1100-H14 and 3003-H14 aluminum alloys are depth dependent.

The corrosion rates of aluminum alloys 2219-T81 and 6061-T6 increased with the decreasing concentration of oxygen in seawater while those of 5086-H34 decreased slightly as shown in Figure 3.

The corrosion rates of aluminum alloys 1100-H14, 3003-H14, 2024-0 and 5083-H113 are independent of the concentration of oxygen in seawater as shown in Figure 4. The corrosion rates of three of these alloys, 1100-H14, 3003-H14 and 5083-H113, were shown to be depth (pressure) dependent, Figure 2.

The maximum depths of pits of aluminum alloys 3003-H14, 2024-0 and 5083-H113 increased with depth (pressure), i.e., they were pressure dependent as shown in Figure 5. The maximum depths of pits of alloy 5086-H34 decreased with increase in depth. Although those of alloys 2219-T81 and 6061-T6 were deeper at a depth of 6,000 feet than at the surface, the depths of pits were at the maximums at the 2,500-foot depth, Figure 5.

The maximum depths of pits of aluminum alloys 2024-0, 2219-T81 and 6061-T6 increased as the concentration of oxygen in seawater decreased, while those of 5086-H34 decreased with the concentration of oxygen, Figure 6.

The maximum depths of pits in aluminum alloys 3003-H14 and 5083-H113 were independent of the concentration of oxygen in seawater, Figure 7. The maximum pit depths of these two alloys were depth (pressure) dependent as shown in Figure 5.

The corrosion rates of 6061-T6 and the 5000 series alloys (5083, 5086 and 5456) decreased with increasing time of exposure in surface seawater while their maximum pit depths increased with time of exposure as shown in Figure 8. The corrosion rates of alloys 3003-H14, Alclad 3003-H12 and 2219-T81 did not decrease constantly with increasing time of exposure in surface seawater; they decreased with time through 540 days of exposure and thereafter increased sharply as shown in Figure 9.

The depths of the maximum pits in alloy 2219-T81 increased with time of exposure, those in alloy 3003-H14 decreased initially and after 400 days increased rapidly, Figure 9. The depths of the maximum pits in Alclad 3003-H12 increased through the first 400 days of exposure and thereafter became constant with time. This constancy is explained by the fact that the sacrificial protective alloy layers on the Alclad 3003-H12 are corroded laterally, thus preventing pitting of the protected core alloy.

The corrosion rates as well as the maximum pit depths of 6061-T6 and 2219-T81 increased with decreasing concentration of oxygen in seawater, Figures 3 and 6. However, both the corrosion rates and maximum pit depths of 5086-H34 decreased with the concentration of oxygen in seawater. Although the maximum pit depths of 2024-0 increased with decreasing concentration of oxygen in seawater, Figure 6, its corrosion rate appears to be affected to a much lesser extent by changes in the concentration of oxygen in seawater, Figure 4. Neither the changes in the corrosion rates nor the maximum pit depths of aluminum alloys 3003-H14 and 5083-H113 appear to be dependent upon the changes in the concentration of oxygen in seawater as shown in Figures 4 and 7. They are generally greater at the lower concentrations of oxygen, although not progressively. The corrosion rates of aluminum alloys 1100-H14, 3003-H14 and 5083-H113 were depth (pressure) dependent in that they increased with depth, Figure 2, while those of 5086-H34 alloy decreased slightly with increasing depth. The corrosion rates of aluminum alloys 6061-T6, 2024-0 and 2219-T81 were not consistently influenced by depth, Figure 2. The maximum pit depths of four alloys, 5083-H113, 2024-0, 5086-H34 and 3003-H14 appear to have been affected by depth; those of 5083-H113, 2024-0 and 3003-H14 increased with depth while those of 5086-H34 decreased with increasing depth, Figure 5. The maximum pit depths of alloys 2219-T81 and 6061-T6 were not consistently affected by depth except that their maximum pit depths at a depth of 6,000 feet were deeper than at the surface. In general, the corrosion rates of the aluminum alloys decreased with increasing time of exposure in surface seawater while the maximum depths of the pits increased with time of exposure, Figures 8 and 9.

## COPPER ALLOYS

The chemical compositions of the copper alloys are given in Table 4 and their corrosion rates in Table 5. The effects of depth, concentration of oxygen in seawater and time on the corrosion rates are shown graphically in Figures 10 through 12.

Copper alloys corrode uniformly, hence corrosion rates calculated from weight losses and reported as mils per year reflect the true condition of the alloys. Therefore, corrosion rates for the copper alloys can be used reliably for design purposes. However, this does not apply to the copper base alloys which are susceptible to parting corrosion.

The variation of the corrosion rates of copper and the copper alloys with depth in the Pacific Ocean are shown in Figure 10. Since the corrosion rates of all the copper alloys, except those attacked by parting corrosion, were so comparable, the average values were plotted in Figure 10. The corrosion of copper was insensitive to depth as well as to the changes of concentration of oxygen in seawater at depth as shown in Figure 10. The oxygen concentration curve was included in Figure 10 to show its variation with depth and to show whether the corrosion rate curves were of comparable shape. The average corrosion rate curve for the copper alloys, although showing a slight decrease with depth, did not decrease gradually; hence it is more oxygen than depth dependent. The corrosion rates of only one alloy, Nickel-Silver #752, increased gradually with increasing depth, Figure 10; hence its corrosion is mostly depth dependent.

The corrosion of copper was independent of the concentration of oxygen in seawater as shown in Figure 11. However, the corrosion of the copper alloys decreased slightly with decreasing concentration of oxygen in seawater.

The corrosion rates of copper and the copper alloys decreased with increasing time of exposure in surface seawater as shown in Figure 12.

The following alloys were attacked by parting corrosion in seawater: commercial bronze, red brass, Muntz metal, manganese bronze A and nickel-manganese bronze, containing from 10 to 42 percent zinc, were dezincified; aluminum bronzes containing 5, 7, 10, 11 and 13 percent aluminum were dealuminified.

## NICKEL ALLOYS

The chemical compositions of the nickel and nickel alloys are given in Table 6 and their corrosion rates and types of corrosion in Table 7. The effects of depth, concentration of oxygen in seawater and time are shown graphically in Figures 13 to 19.

In stagnant seawater and underneath fouling many of the nickel alloys are attacked by pitting and crevice corrosion in addition to general surface attack. Under the same conditions some of the more highly alloyed nickel alloys are immune to corrosion, such as Ni-Cr-Fe 718, Ni-Cr-Mo 3 and 625, Ni-Mo-Cr "C", and Ni-Cr-Fe-Mo "F", "G" and "X". Ni-Co-Cr-Mo 700 alloy was attacked only by incipient crevice corrosion after 400 days of exposure at a depth of 2,500 feet.

The effect of depth on the corrosion of nickel alloys is shown in Figures 13, 14 and 15. The corrosion rates of alloys Ni-Cr-Fe 610 (cast) and 88 decreased with increasing depth, Figure 14. The corrosion rates of alloys Ni-Cu 400, Ni-Cr 75, 65-35 and 80-20, and Ni-Cr-Fe 600 and X750 decreased from the surface to the 2,500-foot depth and remained constant to the 6,000-foot depth, Figures 13, 14 and 15. All the other alloys except Ni-Sn-Zn 23 and Ni-Si D were more affected by the oxygen concentration than by depth. The corrosion rates of Ni-Sn-Zn 23 and Ni-Si D alloys were higher at the 6,000-foot depth than either at the surface or at the 2,500-foot depth, showing that neither depth nor oxygen were exerting the major influence on the corrosion of these two alloys.

The effect of the concentration of oxygen in seawater on the corrosion rates of nickel alloys is shown in Figures 16, 17 and 18. The corrosion rates of alloys electrolytic nickel, Ni-200, 201, 210, 211 and 301, Ni-Cu 402, 406, 410, K500, K505 and 45-55, Ni-Cr-Fe X750, Ni-Mo-Fe "B", Ni-Cr 80-20, and Ni-Mo 2 decreased with decreasing concentration of oxygen in seawater as shown in Figures 16, 17 and 18. The corrosion rates of some alloys decreased with the oxygen concentration to about 1.35 ml per liter and thereafter remained constant to 0.4 ml per liter - alloys Ni-Cu 400, Ni-Cr-Fe 600 and Ni-Cr 75. The corrosion of alloys Ni-Sn-Zn 23 and Ni-Si D are apprently not affected to any major extent by the concentration of oxygen in seawater, Figures 17 and 18.

The effect of time on the corrosion rates of some nickel alloys in surface seawater is shown in Figure 19. The corrosion rates of alloys Ni-200, Ni-Cu 400, Ni-Cr-Fe 600 and X750, and Ni-Fe-Cr 902 decreased with increasing time of exposure.

In general, pitting and crevice corrosion were more rapid in surface exposure than at depth.

Welding Ni-200 with electrode No. 141 and filler metal 61 resulted in corrosion of the weld bead material and/or in the adjacent heat affected zone.

There was no accelerated corrosion of Ni-Cu 400 alloy or of the weld beads when welded with electrodes 130 and 180; however, weld beads of filler metal 60 and electrode 190 were attacked locally.

The corrosion of Ni-Cu K500 alloy was not affected by welding with electrode 64 at the 2,500-foot depth, but the weld beads from electrodes 64 and 134 were attacked during 540 days of exposure at the surface and the weld bead of 134 electrode at the 2,500-foot depth.

The weld beads on Ni-Cr-Fe 600 alloy made from electrodes 132, 182, 62 and 82 were selectively attacked during exposure at the surface and at the 2,500-foot depth except the bead from electrode 182 at the 2,500-foot depth which was only uniformly etched.

The weld beads on Ni-Cr-Fe 718 alloy made from 718 electrodes were uncorroded.

The weld beads on Ni-Cr-Fe X750 alloy made from electrodes 69 and 718 were selectively corroded during exposure at the surface and at the 2,500-foot depth, except the bead made from electrode 69 at the 2,500-foot depth.

The weld beads on Ni-Cr-Mo 625 alloy made with 625 electrodes were uncorroded.

The weld beads on Ni-Fe-Cr 800 alloy made with electrodes 82 and 138 were selectively attacked during exposure at the surface and at the 2,500-foot depth.

The weld beads on Ni-Fe-Cr 825 alloy made with electrode 135 were selectively attacked while weld beads made with electrode 65 were unattacked at the 2,500-foot depth and only by incipient pitting at the surface.

STEELS

The chemical compositions of the steels are given in Table 8 and their corrosion rates and types of corrosion in Table 9. The effects of depth, concentration of oxygen in seawater and time are shown graphically in Figures 20 to 22.

Since the corrosion rates of the steels were nearly the same at any one depth, the average values for any one depth were averaged and plotted in Figures 20 to 22.

The effect of depth on the average corrosion rate of the steels is shown in Figure 20. The variation of the concentration of oxygen in seawater with depth is also plotted in Figure 20 for comparison purposes. The shapes of the curves for the steels and AISI 1010 steel show that the corrosion rates are not depth (pressure) dependent. The shapes of those curves are practically the same as the shape of the oxygen curve, indicating that the concentration of oxygen exerts a major influence on the corrosion of steels in seawater.

The effect of the concentration of oxygen in seawater on the corrosion rates of steels is shown in Figure 21. The curve for the average corrosion rates of all the steels is a straight line, indicating that the corrosion rates of steels in seawater are proportional to the oxygen concentration.

The corrosion rate of AISI 1010 steel and the averages of the corrosion rates of all the carbon and low alloy steels after one year of exposure versus the oxygen content and the temperature of seawater were analyzed using the technique of linear regression analysis. By this technique a relationship between oxygen content, temperature and corrosion rate was obtained for both the average of all carbon and low alloy steels and for AISI 1010 steel. The derived formulae are:

$$\text{Corrosion Rate (MPY)} = 0.84 + 1.0\ (O_2) + 0.014\ (T)$$

(avg of carbon and
low alloy steels)

$$\text{Corrosion Rate (MPY)} = 0.19 + 1.1\ (O_2) + 0.1\ (T)$$

(AISI 1010)

The corrosion rates are in mils per year (MPY), the oxygen content of seawater in milliliters per liter (ml/l) and temperature in degrees Centigrade (°C).

These derived formulae illustrate two important points:

(1) The concentration of oxygen in seawater is a major variable and its effect on the corrosion rate of steel in seawater is linear.

(2) The temperature of the seawater has less effect on the corrosion of steel in seawater than the oxygen content and its effect is also linear.

These formulae, however, cannot be used to predict the corrosion rates of steels in seawater at other locations due to the influences of other variables such as time, currents, sediment effects, etc. For example, the above formulae are not satisfactory for predicting corrosion rates for steels in the Tongue-of-the-Ocean, Atlantic Ocean. Since they are not applicable, it is obvious that other variables in that location are different from those in the Pacific Ocean off the Channel Islands.

The effect of time of exposure in surface seawater on the average corrosion rates of steels is shown in Figure 22. The corrosion rates decrease parabolically with increasing time of exposure.

All the steels except AISI Type 502, in general, corroded uniformly except for some pitting in surface seawater which was caused by fouling. AISI Type 502, because it contained about 5 percent chromium, was pitted.

## CAST IRONS

The chemical compositions of the cast irons are given in Table 10 and their corrosion rates and types of corrosion in Table 11. The effects of depth, concentration of oxygen in seawater and time are shown graphically in Figures 23 to 25.

The effect of depth on the corrosion rates of the cast irons is shown in Figure 23. The shape of the corrosion rate curve for the alloy cast irons was very close to that of the oxygen curve and shows that the corrosion of the alloy cast irons is not depth dependent. The shapes of the curves for gray cast iron, the austenitic cast irons, and the silicon and silicon-molybdenum cast irons show that depth is not an important variable in their corrosion behavior.

The effect of the concentration of oxygen in seawater on the corrosion rates of cast irons is shown in Figure 24. The corrosion rates of gray cast iron and the alloy cast irons decreased practically linearly with the concentration of oxygen in seawater. The corrosion rates of the austenitic cast irons decreased with the concentration of oxygen in seawater while the silicon and silicon-molybdenum cast irons were uncorroded; hence were insensitive to the concentration of oxygen.

All the cast irons corroded uniformly except the silicon and silicon-molybdenum cast irons which were uncorroded.

The effect of time of exposure on the corrosion of cast irons during surface exposure in seawater is shown in Figure 25. Data were available for only two austenitic cast irons and their corrosion rates decreased asymptotically with increasing time of exposure. Their corrosion rates became practically constant at between 2 and 3 mils per year after about two years of exposure.

## STAINLESS STEELS

The chemical compositions of the stainless steels are given in Table 12 and their corrosion rates and types of corrosion in Tables 13 through 17. The effect of depth and the concentration of oxygen in seawater on the corrosion rates of stainless steels are shown graphically in Figures 26 through 31.

In general, stainless steels corrode chiefly by pitting and crevice corrosion in seawater. In these types of localized attack the majority of the surface area is unattacked so that corrosion rates calculated from weight losses are very misleading because they reflect a uniform thinning of the material. However, in spite of this, the corrosion rates of a number of the stainless steels were plotted versus depth and the concentration of oxygen in seawater to see if any information of value could be obtained.

The corrosion rates of the 200 and 400 Series stainless steels as affected by depth are shown in Figure 26. The corrosion rates of AISI 430 and 18Cr-14Mn-0.5N stainless steels decreased with increasing depth. The corrosion rates of AISI 201, 202, 410 and 446 were lower at depth than at the surface, but they did not decrease progressively with increasing depth.

The effects of changes in the oxygen concentration of seawater on the corrosion rates of the 200 and 400 Series stainless steels are shown in Figure 27. The corrosion rates of AISI 410 decreased linearly with the oxygen content while those for AISI 201, 202 and 446 were not uniformly decreased. The corrosion rates of AISI 430 and 18Cr-14Mn-0.5N stainless steels, although lower at the lower oxygen concentrations than at the highest oxygen concentration, were not uniformly affected by the oxygen concentration.

Examination of the pitting, tunneling and crevice corrosion data for these stainless steels in Tables 13 and 17 shows only a general relationship with corrosion rates. The types of corrosion were, in general, more severe or just as severe at the surface seawater (highest oxygen concentration) than at depths of 2,500 and 6,000 feet. However, it is more realistic to assess the performance of these stainless steels on their localized types of corrosion performance than upon calculated corrosion rates.

The corrosion rates of the 300 Series stainless steels as affected by depth are shown in Figure 28. Only the corrosion rates of the AISI 304 and 304L stainless steels decreased with increasing depth. The corrosion rates of AISI 301, 302, 316, 316 (sensitized), 330, 347, 304 (sensitized) and 325 stainless steels were lower at depth than at the surface, but they did not decrease progressively with increasing depth. In addition, the shape of the corrosion rate curve for AISI 325 was similar to the oxygen concentration curve.

The effect of changes in the concentration of oxygen in seawater on the corrosion rates of the 300 Series stainless steels are shown in Figure 29. The corrosion rates of the alloys shown in Figure 29 decreased with decreasing oxygen concentration, although not uniformly.

Examination of the pitting, tunneling and crevice types of corrosion in Table 14 for the alloys whose corrosion rates were plotted in Figures 28 and 29 shows that, in general, there is no definite correlation between their corrosion rates and the severity of these types of corrosion. For example, the corrosion rates of AISI 304L varied from 1.0 to 0.4 to <0.1 MPY at the three depths, while pitting corrosion was to perforation (115 mils) in all exposures while crevice and tunneling corrosion was more severe at the 6,000-foot depth where the corrosion rate was the lowest (<0.1 MPY).

Oxygen and depth apparently had no effect on the corrosion of the following 300 Series stainless steels: AISI 309, 310, 311, 316L, 317, 321 (slightly affected) and 329.

The effect of depth on the corrosion rates of some of the 600 Series precipitation hardening stainless steels is shown in Figure 30. The corrosion rate of 631-TH1050 and 635 decreased with increasing depth of seawater. The corrosion rates of 630-H925 and 632-RH1100 were lower at depth than at the surface but they did not decrease progressively with increasing depth.

The effect of changes in the concentration of oxygen in seawater on the corrosion rates of the 600 Series precipitation hardening stainless steels is shown in Figure 31. The corrosion rate of AISI 632-RH1100 decreased progressively with the oxygen content of seawater. The corrosion rates of AISI 630-H925, 631-TH1050 and 635, although lower at the lower oxygen concentrations than at the highest, did not decrease progressively with the oxygen concentration.

Here again, comparison of the corrosion rates with the severity of the pitting, tunneling and crevice types of corrosion (Table 6) showed no definite correlations.

The corrosion rates and types of corrosion of the miscellaneous cast and wrought stainless steels are given in Table 17. Except for the 18Cr-14Mn-0.5N which contained no nickel, the others contained greater percentages of chromium and nickel than the conventional stainless steels in addition to molybdenum and copper. The corrosion rates of these stainless steels were mostly less than 0.1 MPY and instances of pitting and crevice corrosion were few except for the 18Cr-15Mn-0.5N alloy. Significant pitting and crevice corrosion occurred during surface exposures of wrought alloy 20-Cb and cast alloy Ni-Cr-Cu-Mo #2.

## TITANIUM ALLOYS

The chemical compositions of the titanium alloys are given in Table 18 and their corrosion rates and types of corrosion in Table 19.

There was no corrosion of any of the alloys except the welded 13V-11Cr-3Al alloy. It was susceptible to stress corrosion cracking during surface exposures. Specimens were in two welded conditions, half were butt welded and a 3-inch diameter circular weld bead was placed on the other half of the specimens. The welded specimens were intentionally not stress relieved in order to retain the maximum internal welding stresses in the specimens during exposure. The stress corrosion cracks extended across the butt welds normal to the direction of the beads and developed within 398 days of exposure. The stress corrosion cracks in the specimens with the circular welds extended radially across the weld beads and they also developed within 398 days of exposure.

## MISCELLANEOUS ALLOYS

The chemical compositions of the miscellaneous alloys are given in Table 20 and their corrosion rates and types of corrosion in Table 21. The effect of depth, concentration of oxygen in seawater and time are shown in Figures 32 to 34.

Columbium, tantalum and tantalum alloy Ta60 were uncorroded during 763 days of exposure at the surface and 402 days of exposure at a depth of 2,500 feet.

The effect of depth on the corrosion rates of the miscellaneous alloys is shown in Figure 32. The corrosion rates of tin, molybdenum and tungsten decreased with increasing depth. The corrosion rates of lead and lead-tin solder were lower at depth than at the surface but did not decrease progressively with increasing depth. The corrosion rate of zinc, on the other hand, was much greater at the 6,000-foot depth than at either the surface or the 2,500-foot depth.

The effect of the concentration of oxygen in seawater on the corrosion rates of the miscellaneous alloys is shown in Figure 33. The corrosion rates of lead, tin, lead-tin solder, molybdenum and tungsten were lower at the lower oxygen concentrations than at the highest, but the decreases were not linear. Since there were only two points for the molybdenum and tungsten curves, there is no assurance that the curves would be linear with more points at intermediate oxygen concentrations. The corrosion rate for zinc was definitely not dependent upon the oxygen concentration of seawater; it was the same at the lowest as at the highest concentration of oxygen in seawater and twice as high at the intermediate oxygen concentration.

The effect of time of exposure at the surface on the corrosion rate of molybdenum and tungsten are shown in Figure 34. The corrosion rate of molybdenum decreased with increasing time of exposure while that of tungsten definitely increased.

## SUMMARY

The purpose of this investigation was to determine the effects of surface seawater on the corrosion of different types of alloys for comparison with their deep ocean corrosion behavior. To accomplish this 1,134 specimens of 189 different alloys were exposed 5 feet below the lowest tide level in the Pacific Ocean at Point Mugu, California (Site V, Figure 1) for from 366 to 763 days.

### Aluminum Alloys

In general the corrosion rates of the aluminum alloys were greater at depth than at the surface in the Pacific Ocean after one year of exposure, except for 5086-H34 whose corrosion rate was slightly lower.

The maximum pit depths of the aluminum alloys were greater at depth than at the surface, except for 5086-H34 whose maximum pit depths were less than at the surface.

The corrosion rate of 5086-H34 decreased slightly with the oxygen concentration of seawater, those of 2219-T81 and 6061-T6 increased with decreasing oxygen concentration and those of 1100-H14, 5083-H113 and 3003-H14 were higher at the lower oxygen concentrations, but not progressively. The corrosion rate of 2024-0 appears to be independent of the oxygen concentration of seawater.

The maximum pit depths of alloys 2024-0, 2219-T81 and 6061-T6 increased with decreasing concentration of oxygen in seawater, while those of 5086-H34 decreased with the oxygen concentration. The maximum pit depths of 3003-H14 were deeper at the lower oxygen concentrations, but not progressively. The maximum pit depths of 5083-H113 were apparently not dependent upon the oxygen concentration.

The corrosion rates of the 5000 Series aluminum alloys and 6061-T6 decreased with increasing time of exposure at the surface in the Pacific Ocean while their maximum pit depths increased. The corrosion rates of 2219-T81, 3003-H14 and Alclad 3003-H12 decreased with time of exposure at the surface through 540 days of exposure and thereafter, for some unknown reason, increased rapidly. Their maximum pit depths, in general, increased with time of exposure.

The aluminum alloys were attacked by pitting and crevice types of corrosion; hence, corrosion rates calculated from weight losses are unsuitable for assessing the corrosion behavior.

Crevice corrosion, in general, was more severe at depth than at the surface.

### Copper Alloys

The copper alloys, in general, corroded uniformly except for some isolated cases of pitting and cratering. Also, there was dezincification of Muntz metal and nickel-manganese bronze and dealuminification of the aluminum bronzes.

The corrosion rate of copper was essentially unaffected by depth and that of all the copper alloys was lower at depth than at the surface, but not progressively.

The corrosion rate of copper was unaffected by changes in the concentration of oxygen in seawater while the average rate of the copper alloys decreased with decreasing concentration of oxygen. The corrosion rate of Muntz metal, which also was dezincified, also decreased with the concentration of oxygen in seawater.

The corrosion rates of all the copper alloys decreased with increasing time of exposure at the surface except Muntz metal whose corrosion rate increased with time.

### Nickel Alloys

Fourteen (14) of the nickel base alloys were uncorroded: Ni-Cr-Fe 718, Ni-Cr-Mo 3, Ni-Cr-Mo 625, Ni-Fe-Cr 800, Ni-Fe-Cr 804, Ni-Fe-Cr 825, Ni-Fe-Cr 825 (sensitized), Ni-Fe-Cr 825Cb, Ni-Fe-Cr 901, Ni-Cr-Fe-Mo "F", Ni-Cr-Fe-Mo "G", Ni-Cr-Fe-Mo "X", Ni-Mo-Fe "B", and Ni-Mo-Cr "C".

The corrosion rates of the other nickel base alloys were higher at the surface than at depth. The corrosion rates of Ni-Cr-Fe 600 and Ni-Cr-Fe 88 decreased with increasing depth while those of the other alloys did not decrease progressively with depth.

Most of the alloys which were corroded were also attacked by crevice corrosion.

The corrosion rates of all except two nickel base alloys (Ni-Sn-Zn 23 and Ni-Si D) decreased with decreasing concentration of oxygen in seawater. The corrosion rates of Ni-Cr-Fe X750, Ni-Mo 2, Ni-200 and Ni-Cu 402, 406, 410, K500, K505 and 45-55 alloys decreased linearly with the concentration of oxygen in seawater.

The corrosion rates of Ni-200, Ni-Cu 400, Ni-Cr-Fe 600 and X750, and Ni-Fe-Cr 902 decreased with increasing time of exposure at the surface.

In general, pitting and crevice corrosion were more rapid in surface seawater exposure than at depth.

There was either no corrosion or uniform corrosion of weld beads and in the adjacent heat affected zones when Ni-Cu 400 alloy was welded with electrodes 130 and 180, Ni-Cr-Fe 718 with electrode 718, and Ni-Cr-Mo 625 with electrode 625.

There was selective corrosion, line corrosion or pitting of either the weld beads or in the adjacent heat affected zones or both when Ni-200 was welded with electrodes 61 and 141, Ni-Cu 400 with electrodes 60 and 190, Ni-Cu K500 with electrodes 64 and 134, Ni-Cr-Fe 600 with electrodes 62, 82, 132 and 182, Ni-Cr-Fe X750 with electrodes 69 and 718, Ni-Fe-Cr 800 with electrodes 82 and 138, and Ni-Fe-Cr 825 with electrodes 65 and 135.

## Steels

The steels were all corroded uniformly and their corrosion rates were comparable - carbon steels, low alloy-high strength steels, nickel steels, and the very high strength steels.

The corrosion rates of the steels were lower at depth than at the surface, but they did not decrease progressively with increasing depth; i.e., they were not depth dependent.

The average corrosion rates of all the steels decreased linearly with the concentration of oxygen in seawater.

The corrosion rates, the oxygen concentration and temperature of seawater were analyzed using linear regression analysis. The following relationships were obtained for AISI 1010 steel and the averages of the other steels:

$$\text{Corrosion Rate (MPY)} = 0.84 + 1.0\,(O_2) + 0.014\,(T)$$

(Avg of carbon and
low alloy steels)

$$\text{Corrosion Rate (MPY)} = 0.19 + 1.1\,(O_2) + 0.1\,(T)$$

(AISI 1010)

The corrosion rates are in mils per year (MPY), the oxygen content of seawater in milliliters per liter (ml/l) and temperature in degrees Centigrade (°C).

These derived formulae illustrate two important points:

(1) The concentration of oxygen in seawater is a major variable and its effect on the corrosion rate of steel in seawater is linear.

(2) The temperature of seawater has less effect on the corrosion of steel in seawater than the oxygen content and its effect is also linear.

These formulae, however, cannot be used to predict the corrosion rates of steels in seawater at other locations due to the influence of other variables such as time, currents, sediment effects, etc.

The corrosion rates of the steels decreased progressively with increasing time of exposure in surface seawater.

Cast Irons

Silicon and silicon-molybdenum cast irons were uncorroded in seawater at the surface and at depth in the Pacific Ocean after one year of exposure.

The corrosion rates of the other cast irons were lower at depth than at the surface, but were not depth dependent.

The corrosion rates of the alloy cast irons and gray cast iron decreased linearly with the concentration of oxygen in seawater and those of the austenitic cast irons progressively.

The corrosion rates of two austenitic cast irons, Type 4 and Type D-2C, decreased asymptotically with time of exposure at the surface in seawater.

Stainless Steels

The following stainless steels were attacked only by incipient crevice corrosion after one year of exposure in seawater: AISI Type 309, 316L, 317, 329 and 633, 20Cb3 and Ni-Cr-Mo-Si.

All the other stainless steels were attacked by pitting, tunneling and crevice corrosion in various degrees of severity.

In general, the miscellaneous wrought and cast stainless steels, except the 18C-14Mn-0.5N steel, were less severely attacked than the others.

Titanium Alloys

The titanium alloys, unwelded and welded, except the 13V-11Cr-3Al alloy, were uncorroded. Welded 13V-11Cr-3Al titanium alloy was susceptible to stress corrosion cracking when the welding stresses were not relieved by thermal treatment.

## Miscellaneous Alloys

Columbium, tantalum and tantalum-tungsten alloy Ta60 were uncorroded. However, magnesium alloy FS-1 was practically disintegrated after one year of exposure in seawater.

The corrosion of lead (antimonial chemical and tellurium), tin, zinc, lead-tin solder, molybdenum and tungsten were not depth dependent.

The corrosion rates of lead, tin, lead-tin solder, molybdenum and tungsten decreased with the concentration of oxygen in seawater while that of zinc was not dependent on the oxygen concentration.

The corrosion rate of molybdenum decreased with increasing time of exposure in seawater at the surface while that of tungsten increased.

# CONCLUSIONS

Seawater at depth in the Pacific Ocean at the NCEL test sites was more aggressive to aluminum alloys than was seawater at the surface after one year of exposure, except for 5086-H34 alloy whose corrosion rate was slightly lower at depth.

In general, the corrosion rates and maximum pit depths of the aluminum alloys increased with decreasing oxygen concentration of seawater.

Aluminum alloys, because their modes of corrosion are the localized pitting and crevice types, must be protected for seawater applications if reasonable service life is desired. In general, aluminum alloys could not be recommended for deep sea applications for periods longer than three years if protective maintenance cannot be performed.

In most cases the copper base alloys corroded either at the same rates or slightly slower rates at depth than at the surface in seawater. Copper base alloys which are susceptible to dezincification and dealuminification are not recommended for seawater service. The other copper alloys corroded uniformly and can be recommended for seawater service where their low corrosion rates can be tolerated.

The nickel base alloys which were not corroded in seawater can be recommended for seawater applications.

Nickel base alloys susceptible to crevice corrosion are not recommended for seawater applications unless satisfactory precautions can be taken to prevent this type of attack.

The use of welded nickel alloys for seawater applications can be recommended only for those alloys which are not preferentially attacked in either the weld beads or the adjacent heat affected zones or both.

Steels and cast irons, because they corrode uniformly, can be recommended for seawater applications and their reliability can be increased by the use of adequate protective measures.

The stainless steels, because of their susceptibility to crevice, pitting and tunnel corrosion, are not recommended for seawater applications. Alloys 309, 316L, 317, 329, 633, 20Cb-3 and Ni-Cr-Mo-Si could be used for limited applications of not more than one year if adequate protective measures are used.

Titanium alloys, except welded 13V-11Cr-3Al alloy, are recommended for seawater applications.

Columbium, tantalum and tantalum alloy Ta60 are recommended for seawater service where the expense can be justified.

Magnesium alloy FS-1 is unsatisfactory for seawater applications.

Molybdenum, tungsten and lead (chemical, antimonial and tellurium), because of their low uniform corrosion, can be recommended for seawater applications where their mechanical and physical properties fulfill the requirements.

Tin, zinc and lead-tin solder are not recommended for seawater service. Zinc of special purity, however, is used as sacrificial anodes to protect more noble alloys in many seawater applications.

Table 1. Exposure Site Locations and Sea Water Characteristics

| Site No. | Latitude N | Longitude W | Depth, Feet | Exposure, Days | Temp. °C | Oxygen ml/1(1) | Salinity ppt(2) | pH | Current, Knots, Avg. |
|---|---|---|---|---|---|---|---|---|---|
| I-1 | 33°46' | 120°37' | 5300 | 1064 | 2.6 | 1.2 | 34.51 | 7.5 | 0.03 |
| I-2 | 33°44' | 120°45' | 5640 | 751 | 2.3 | 1.3 | 34.51 | 7.6 | 0.03 |
| I-3 | 33°44' | 120°45' | 5640 | 123 | 2.3 | 1.3 | 34.51 | 7.6 | 0.03 |
| I-4 | 33°46' | 120°46' | 6780 | 403 | 2.2 | 1.6 | 34.40 | 7.7 | 0.03 |
| II-1 | 34°06' | 120°42' | 2340 | 137 | 5.0 | 0.4 | 34.36 | 7.5 | 0.06 |
| II-2 | 34°06' | 120°42' | 2370 | 402 | 5.0 | 0.4 | 34.36 | 7.5 | 0.06 |
| V | 34°06' | 119°07' | 5 | 181-763 | 12-19 | 3.9-6.6 | 33.51 | 8.1 | Variable |

1. ml/1 - milliliters per liter
2. ppt - parts per thousand

Table 2. Chemical Composition of Aluminum Alloys

| Material | Si | Fe | Cu | Mn | Mg | Cr | Ni | Zn | Ti | Al | Source[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1100 | - | - | - | - | - | - | - | - | - | 99.0 | INCO[10] |
| | - | - | 4.3 | 0.6 | 1.5 | - | | - | | Rem. | INCO[10] |
| 2024 | - | - | 4.3 | 0.6 | 1.5 | - | - | - | - | Rem. | INCO[10] |
| 2219-T81[1] | 0.20 | 0.30 | 6.3 | 0.30 | 0.02 | - | - | 0.10 | 0.06 | Rem. | NCEL |
| 3003 | 0.15 | 0.45 | 0.15 | 1.25 | - | - | - | 0.05 | - | Rem. | INCO[10] |
| 3003-H14 | 0.20 | 0.58 | 0.13 | 1.05 | <0.01 | <0.01 | <0.01 | <0.01 | - | Rem. | NCEL |
| Alclad 3003-H12 | | | | | | | | | | | |
| Core | 0.60 | 0.70 | 0.20 | 1.25 | - | - | - | 0.10 | - | Rem. | NCEL & |
| Cladding | 0.70 | (Si&Fe) | 0.10 | 0.10 | 0.10 | - | - | 1.0 | - | Rem. | INCO[10] |
| 5052 | - | - | - | - | 2.5 | 0.25 | - | - | - | Rem. | INCO[10] |
| 5083 | - | - | 0.15 | 0.6 | 4.5 | - | - | - | - | Rem. | INCO[10] |
| 5083-H113 | 0.40 | 0.40 | 0.10 | 0.65 | 4.5 | 0.15 | - | 0.25 | 0.15 | Rem. | NCEL |
| 5086 | - | - | - | 0.3 | 4.0 | 0.15 | - | - | - | Rem. | INCO[10] |
| 5086-H32 | 0.15 | 0.25 | 0.05 | 0.32 | 3.75 | 0.12 | - | 0.12 | 0.01 | Rem. | NCEL |
| 5086-H34 | 0.40 | 0.50 | 0.10 | 0.45 | 4.0 | 0.15 | - | 0.25 | 0.15 | Rem. | NCEL |
| 5454 | - | - | - | 0.03 | 1.0 | 0.02 | - | - | - | Rem. | INCO[10] |
| 5456-H321 | 0.40 | (Si&Fe) | 0.10 | 0.75 | 5.0 | 0.13 | - | 0.25 | 0.20 | Rem. | NCEL |
| 6061 | - | - | 0.25 | - | 1.0 | 0.28 | - | - | - | Rem. | INCO[10] |
| 6061-T6 | 0.60 | 0.70 | 0.27 | 0.15 | 1.0 | 0.25 | - | 0.25 | 0.15 | Rem. | NCEL |
| 7039-T64 | 0.30 | 0.40 | 0.10 | 0.25 | 2.8 | 0.20 | - | 4.0 | 0.10 | Rem. | NCEL |

1. Other elements present are: 0.10%V, 0.17% Zr.
2. Numbers refer to references at end of paper.

Table 3. Corrosion of Aluminum Alloys in Sea Water

| Alloy | Exposure | | Corrosion Rate, MPY(1) | Pit Depth, Mils | | Crevice Corrosion, Depth, Mils | Corrosion, Type(2) | Source(3) |
|---|---|---|---|---|---|---|---|---|
| | Days | Depth, Feet | | Max. | Avg. | | | |
| 1100-H14 | 366 | 5 | 0.6 | 13 | -- | 13 | P,C | INCO(10) |
| 1100-H14 | 402 | 2370 | 1.6 | -- | -- | 62(PR) | SC | INCO(10) |
| 1100-H14 | 403 | 6780 | 4.1 | -- | -- | 62(PR) | SC | INCO(10) |
| 2024-0 | 366 | 5 | 4.1 | 34 | -- | 34 | P,C | INCO(10) |
| 2024-0 | 402 | 2370 | 3.0 | 62(PR) | -- | 62(PR) | SP,SC | INCO(10) |
| 2024-0 | 403 | 6780 | 6.2 | 62(PR) | -- | -- | SP | INCO(10) |
| 2219-T81 | 398 | 5 | 2.5 | 26 | 24.2 | 0 | P | NCEL |
| 2219-T81 | 540 | 5 | 1.4 | 48 | 36 | 32 | C,P | NCEL |
| 2219-T81 | 588 | 5 | 4.4 | 62 | 49 | 43 | C,P,E | NCEL |
| 2219-T81 | 402 | 2370 | 4.5 | 78 | 58.3 | 69 | C,SE,SP,IG | NCEL |
| 2219-T81 | 403 | 6780 | 3.6 | 35 | 24.7 | 38 | C,E,G,P,IG | NCEL |
| 3003 | 366 | 5 | 0.6 | -- | -- | -- | IP | INCO(10) |
| 3003-H14 | 398 | 5 | 1.0 | 21 | 14.6 | 0 | P | NCEL |
| 3003-H14 | 540 | 5 | 0.3 | 34 | 34 | 75 | C,P | NCEL |
| 3003-H14 | 588 | 5 | 2.0 | 65 | 49 | 0 | P | NCEL |
| 3003 | 402 | 2370 | 1.1 | -- | -- | 40(PR) | SC | INCO(10) |
| 3003-H14 | 402 | 2370 | 1.4 | 91 | -- | 93 | P,C,SE | NCEL |
| 3003 | 403 | 6780 | 3.8 | -- | -- | 50(PR) | SC | INCO(10) |
| 3003-H14 | 403 | 6780 | 3.9 | 125(PR) | 82.2 | 66 | SP,SC | NCEL |
| Alclad 3003 | 366 | 5 | 0.5 | 2 | -- | -- | P | INCO(10) |
| Alclad 3003-H12 | 398 | 5 | 1.1 | 16 | 15.3 | 0 | P | NCEL |
| Alclad 3003-H12 | 540 | 5 | 0.3 | 16 | 8.6 | 0 | P | NCEL |
| Alclad 3003-H12 | 588 | 5 | 1.8 | 17 | 15.5 | 0 | P | NCEL |
| Alclad 3003 | 402 | 2370 | 1.6 | -- | -- | -- | (4) | INCO(10) |
| Alclad 3003-H12 | 402 | 2370 | 2.2 | 14 | 12.9 | 15 | P,C(5) | NCEL |
| Alclad 3003 | 403 | 6780 | 2.5 | -- | -- | -- | C | INCO(10) |
| Alclad 3003-H12 | 403 | 6780 | 0.4 | 14 | 13.0 | 14 | P,C,SLE | NCEL |

Table 3. (cont'd)

| Alloy | Exposure | | Corrosion Rate, MPY(1) | Pit Depth, Mils | | Crevice Corrosion, Depth, Mils | Corrosion, Type(2) | Source(3) |
|---|---|---|---|---|---|---|---|---|
| | Days | Depth, Feet | | Max. | Avg. | | | |
| 5052 | 366 | 5 | 0.6 | 5 | -- | 5 | P,C | INCO(10) |
| 5052 | 402 | 2370 | 0.4 | -- | -- | 20 | C | INCO(10) |
| 5052-H34 | 402 | 2370 | 0.2 | -- | -- | 34 | C,IP | NCEL |
| 5052 | 403 | 6780 | 4.5 | -- | -- | 62(PR) | SC | INCO(10) |
| 5083 | 366 | 5 | 0.6 | -- | -- | -- | ET | INCO(10) |
| 5083-H113 | 398 | 5 | 0.4 | -- | -- | -- | ET | NCEL |
| 5083-H113, Butt Weld | 398 | 5 | 0.5 | 34 | 32.8 | I | IC,P | NCEL |
| 5083 | 540 | 5 | 0.7 | 36 | 31.1 | 114 | C,P | NCEL |
| 5083-H113, Butt Weld | 540 | 5 | 0.3 | 4 | 3 | 0 | P | NCEL |
| 5083-H113 | 588 | 5 | 0.3 | 11 | 7 | I | IC,P | NCEL |
| 5083-H113, Butt Weld | 588 | 5 | 0.3 | 9 | 6.2 | 0 | P | NCEL |
| 5083 | 402 | 2370 | 1.0 | -- | -- | 31 | C | INCO(10) |
| 5083-H113 | 402 | 2370 | 0.6 | -- | -- | 52 | SC,IP | NCEL |
| 5083-H113, Butt Weld | 402 | 2370 | 0.8 | 58 | 42.1 | -- | E,P | NCEL |
| 5083-H113 | 403 | 6780 | 4.0 | 59 | 52.6 | -- | SE,P | NCEL |
| 5083-H113, Butt Weld | 403 | 6780 | 2.1 | 92 | 72.8 | -- | SLE,P | NCEL |
| 5086 | 366 | 5 | 0.5 | 5 | -- | 5 | P,C | INCO(10) |
| 5086-H32 | 398 | 5 | 0.4 | 20 | 14.5 | 0 | P | NCEL |
| 5086-H34 | 398 | 5 | 0.8 | 27 | 22.7 | I | IC,P | NCEL |
| 5086-H34 | 540 | 5 | 0.3 | 0 | 0 | I | IC,ET | NCEL |
| 5086-H32 | 588 | 5 | 0.2 | 26 | 22 | I | IC,P | NCEL |
| 5086-H34 | 588 | 5 | 1.6 | 47 | 43.6 | 43 | C,P | NCEL |
| 5086 | 402 | 2370 | 0.8 | -- | -- | 35(PR) | SC | INCO(10) |
| 5086-H34 | 402 | 2370 | 0.6 | -- | -- | 18 | C,IP | NCEL |
| 5086-H34 | 403 | 6780 | 0.6 | -- | -- | 53 | SC,IP | NCEL |
| 5454 | 366 | 5 | 0.5 | -- | -- | -- | ET | INCO(10) |
| 5454-H32, Butt Weld | 398 | 5 | 0.5 | 8 | 6.1 | 0 | P | NCEL |
| 5454-H32, Butt Weld | 540 | 5 | 0.3 | I | -- | 0 | IP | NCEL |
| 5454-H32, Butt Weld | 588 | 5 | 0.7 | 39 | 26.7 | 0 | P,P(W&HAZ) | NCEL |

## Table 3. (cont'd)

| Alloy | Exposure Days | Exposure Depth, Feet | Corrosion Rate, MPY (1) | Pit Depth, Mils Max. | Pit Depth, Mils Avg. | Crevice Corrosion Depth, Mils | Corrosion, Type (2) | Source (3) |
|---|---|---|---|---|---|---|---|---|
| 5454 | 402 | 2370 | 0.4 | -- | -- | 28 | C | INCO (10) |
| 5454-H32 | 402 | 2370 | 0.3 | -- | -- | 39 | C,IP | NCEL |
| 5454-H32, Butt Weld | 402 | 2370 | 0.6 | 42 | 34.5 | -- | P,PWA | NCEL |
| 5454-H32 | 403 | 6780 | 0.9 | 38 | 28.0 | -- | MOE,MOP | NCEL |
| 5454-H32, Butt Weld | 403 | 6780 | 1.7 | 64 | 46.4 | -- | E,P | NCEL |
| 5456-H321 | 398 | 5 | 0.6 | 16 | 10.5 | 0 | P | NCEL |
| 5456-H321 | 540 | 5 | 0.9 | 14 | 11.5 | 8 | C,P | NCEL |
| 5456-H321 | 402 | 2370 | 1.1 | 41 | 20.7 | 44 | C,E,P | NCEL |
| 5456-H32 | 402 | 2370 | 0.6 | -- | -- | 5 | C,E | NCEL |
| 5456-H321 | 403 | 6780 | 1.0 | -- | -- | 50 | SC,E,IP | NCEL |
| 5456-H343 | 403 | 6780 | 0.2 | -- | -- | 28 | C,IP | NCEL |
| 6061 | 366 | 5 | 0.9 | 11 | -- | 11 | C,P | INCO (10) |
| 6061-T6 | 398 | 5 | 0.7 | 16 | 14 | 0 | P,E | NCEL |
| 6061-T6 | 540 | 5 | 0.3 | 23 | 16.1 | I | IC,P | NCEL |
| 6061-T6 | 402 | 2370 | 1.2 | -- | -- | 32(PR) | C | INCO (10) |
| 6061-T6 | 402 | 2370 | 2.0 | 75 | 51.4 | 66 | C,P | NCEL |
| 6061-T6 | 403 | 6780 | 1.0 | 58 | 48.4 | 55 | C,P | NCEL |
| 7039-T6 | 398 | 5 | 1.1 | 22 | 16.3 | I | IC,P | NCEL |
| 7039-T6, Butt Weld | 398 | 5 | 0.5 | 0 | 0 | 0 | P(W&HAZ) | NCEL |
| 7039-T6 | 540 | 5 | 0.3 | 6 | 4.4 | 3 | C,P | NCEL |
| 7039-T6, Butt Weld | 540 | 5 | 0.3 | 18(HAZ) | 15 | I | IC,P(HAZ) | NCEL |
| 7039-T6, Butt Weld | 588 | 5 | 0.3 | 26(HAZ) | 17.9 | I | IC,P(HAZ) | NCEL |
| 7039-T6 | 402 | 2370 | -- | -- | -- | -- | EXXF | NCEL |
| 7039-T6 | 403 | 6780 | -- | -- | -- | -- | EXXF | NCEL |

Footnotes

1. MPY - Mils penetration per year calculated from weight loss.
2. Symbols for types of corrosion
   - C - Crevice
   - E - Edge
   - ET - Etched
   - EX - Extensive
   - G - General
   - I - Incipient
   - IG - Intergranular
   - MO - Moderate
   - P - Pitting
   - PR - Perforated
   - S - Severe
   - SL - Slight
   - WA - Weld attack
   - XF - Exfoliation
3. Numbers refer to references at end of paper
4. 60% of cladding gone
5. 20% of cladding gone and incipient pitting in denuded areas

Table 4. Chemical Composition of Copper Alloys.

| CDA No.[1] | Material | Cu | Zn | Sn | Ni | Al | Fe | Si | Pb | Other | Source[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 102 | Copper, O Free | 99.96 | -- | -- | -- | -- | -- | -- | -- | -- | NCEL |
| 102 | Copper, O Free | 99.9 | -- | -- | -- | -- | -- | -- | -- | -- | INCO[10] |
| 172 | Be-Cu | 97.80 | -- | -- | 0.05 | -- | -- | -- | -- | Be 1.90<br>Co 0.25 | NCEL |
| 825 | Be-Cu, chain, cast | 97.5 | -- | -- | -- | -- | -- | -- | -- | Be 2.0<br>Co 0.5 | NCEL |
| 220 | Commercial Bronze | 90 | 10 | -- | -- | -- | -- | -- | -- | -- | INCO[10] |
| 230 | Red Brass | 85 | 15 | -- | -- | -- | -- | -- | -- | -- | INCO[10] |
| 443 | Arsenical Admiralty | 71.19 | 27.77 | 1.00 | -- | -- | 0.01 | -- | -- | As-0.027 | NCEL |
| 443 | Arsenical Admiralty | 70.0 | 29.0 | 1.0 | -- | -- | -- | -- | -- | As-0.04 | INCO[10] |
| 270 | Yellow Brass | 65.0 | 35.0 | -- | -- | -- | -- | -- | -- | -- | INCO[10] |
| 280 | Muntz Metal | 60.69 | 39.29 | -- | -- | -- | <0.02 | -- | -- | -- | NCEL |
| 280 | Muntz Metal | 60.0 | 40.0 | -- | -- | -- | -- | -- | -- | -- | INCO[10] |
| 678 | Mn Bronze A | 56.0 | 42.0 | -- | -- | 1.0 | 1.0 | -- | -- | Mn-0.01 | INCO[10] |
| 868 | Ni-Mn Bronze, cast | 54.58 | 34.48 | 0.70 | 3.77 | 1.73 | 1.66 | -- | 0.02 | Mn-3.06 | NCEL |
| -- | Al Brass | 78.0 | 20.0 | -- | -- | 2.0 | -- | -- | -- | -- | INCO[10] |
| -- | Ni Brass | 50.0 | 40.0 | -- | 8.0 | -- | 2.0 | -- | -- | -- | INCO[10] |
| 905 | G Bronze, cast | 88.0 | 10.0 | 2.0 | -- | -- | -- | -- | -- | -- | INCO[10] |
| 903 | G Bronze, Modified, cast | 88.0 | 4.0 | 8.0 | -- | -- | -- | -- | -- | -- | INCO[10] |
| 922 | M Bronze, cast | 88.2 | 4.0 | 6.0 | -- | -- | -- | -- | 2.0 | -- | INCO[10] |
| -- | Leaded Tin Bronze, cast | 85.0 | 5.0 | 5.0 | -- | -- | -- | -- | 5.0 | -- | INCO[10] |
| 510 | Phosphor Bronze A | 94.64 | <0.10 | 4.94 | -- | -- | <0.05 | -- | -- | P-0.26 | NCEL |
| 510 | Phosphor Bronze A | 96.0 | -- | 4.0 | -- | -- | -- | -- | -- | P-0.25 | INCO[10] |
| 524 | Phosphor Bronze D | 90.00 | <0.10 | 9.23 | -- | -- | <0.05 | -- | -- | P-0.17 | NCEL |
| 606 | Al Bronze 5% | 95.0 | -- | -- | -- | 5.0 | -- | -- | -- | -- | INCO[10] |
| 614 | Al Bronze 7% | 90.11 | -- | 0.15 | -- | 6.59 | 3.15 | -- | <0.02 | -- | NCEL |
| 614 | Al Bronze 7% | 90.0 | -- | -- | -- | 7.0 | 3.0 | -- | -- | -- | INCO[10] |
| 953 | Al Bronze 10% cast | 89.0 | -- | -- | -- | 10.0 | 1.0 | -- | -- | -- | INCO[10] |
| 954 | Al Bronze 11%, cast | 86.0 | -- | -- | -- | 10.0 | 4.0 | -- | -- | -- | INCO[10] |
| -- | Al Bronze 13% cast | 83.0 | -- | -- | -- | 13.0 | 4.0 | -- | -- | -- | INCO[10] |
| -- | Ni-Al Bronze #2 | 80.0 | -- | -- | 5.0 | 10.0 | 4.0 | -- | -- | Mn-0.5 | INCO[10] |

Table 4. (cont'd)

| CDA No.[1] | Material | Cu | Zn | Sn | Ni | Al | Fe | Si | Pb | Other | Source[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 653 | Si Bronze 3% | 97.0 | -- | -- | -- | -- | -- | 3.0 | -- | -- | INCO(10) |
| 655 | Si Bronze A | 95.49 | -- | -- | -- | -- | <0.02 | 3.28 | -- | Mn-1.18 | NCEL |
| 655 | Si Bronze A | 95.0 | -- | -- | -- | -- | -- | 3.0 | -- | Mn-1.0 | INCO(10) |
| -- | Ni-Vee Bronze A cast | 88.0 | 5.0 | 2.0 | 5.0 | -- | -- | -- | -- | -- | INCO(10) |
| -- | Ni-Vee Bronze B, cast | 87.0 | 5.0 | 2.0 | 5.0 | -- | -- | 1.0 | -- | -- | INCO(10) |
| -- | Ni-Vee Bronze C. cast | 80.0 | 5.0 | 5.0 | 5.0 | -- | -- | 5.0 | -- | -- | INCO(10) |
| 706 | Cu-Ni 90-10 | 89.04 | -- | -- | 9.42 | -- | 1.16 | -- | -- | Mn-0.38 | NCEL |
| 706 | Cu-Ni, 90-10 | 89.0 | -- | -- | 10.0 | -- | 1.4 | -- | -- | Mn-0.5 | INCO(10) |
| 962 | Cu-Ni 90-10, cast | 86.0 | -- | -- | 11.0 | -- | 1.4 | -- | -- | Mn-1.3 | INCO(10) |
| 710 | Cu-Ni 80-20 | 78.62 | -- | -- | 20.41 | -- | 0.62 | -- | -- | Mn-0.35 | NCEL |
| 710 | Cu-Ni 80-20 | 80.0 | -- | -- | 20.0 | -- | 0.03 | -- | -- | Mn-0.2 | INCO(10) |
| 715 | Cu-Ni, 70-30 | 68.61 | -- | -- | 30.53 | -- | 0.53 | -- | -- | Mn-0.33 | NCEL |
| 715 | Cu-Ni, 70-30 | 69.0 | -- | -- | 30.0 | -- | 0.6 | -- | -- | Mn-0.4 | INCO(10) |
| 716 | Cu-Ni 70-30 | 64.02 | -- | -- | 29.95 | -- | 5.27 | -- | -- | Mn-0.75 | NCEL |
| -- | Cu-Ni, 55-45 | 54.0 | -- | -- | 45.0 | -- | 0.1 | -- | -- | Mn-1.0 | INCO(10) |
| -- | Cu-Ni-Zn-Pb | 62.0 | 8.0 | -- | 25.0 | -- | -- | -- | 5.0 | -- | INCO(10) |
| 752 | Nickel-Silver | 65.0 | 17.0 | -- | 18.0 | -- | -- | -- | -- | -- | INCO(10) |

1. Copper Development Association alloy number.
2. Numbers refer to references at end of paper.

Table 5. Corrosion of Copper Alloys in Sea Water

| Alloy | CDA (1) | Exposure Days | Exposure Depth, Feet | Corrosion Rate, MPY (2) | Corrosion Type (3) | Source (4) |
|---|---|---|---|---|---|---|
| Copper, O Free | | 366 | 5 | 1.2 | G | INCO (10) |
| Copper, O Free | | 398 | 5 | 1.1 | G,P(37m) | NCEL |
| Copper, O Free | | 540 | 5 | 0.9 | G,P(22m) | NCEL |
| Copper, O Free | 102 | 588 | 5 | 0.9 | G,P(20m) | NCEL |
| Copper, O Free | 102 | 402 | 2370 | 1.4 | U | INCO (10) |
| Copper, O Free | 102 | 402 | 2370 | 0.9 | U | NCEL |
| Copper, O Free | 102 | 403 | 6780 | 1.3 | U | INCO (10) |
| Copper, O Free | 102 | 403 | 6780 | 1.2 | U | NCEL |
| | | | | | | |
| Be-Cu | 172 | 364 | 5 | 1.1 | U | NCEL |
| Be-Cu | 172 | 723 | 5 | 0.8 | U | NCEL |
| Be-Cu | 172 | 763 | 5 | 0.8 | U | NCEL |
| Be-Cu | 172 | 402 | 2370 | 0.6 | U | NCEL |
| Be-Cu, MIG Weld | 172 | 364 | 5 | 1.0 | U | NCEL |
| Be-Cu, MIG Weld | 172 | 723 | 5 | 0.7 | U | NCEL |
| Be-Cu, MIG Weld | 172 | 763 | 5 | 0.8 | U | NCEL |
| Be-Cu, MIG Weld | 172 | 402 | 2370 | 0.5 | U | NCEL |
| Be-Cu, TIG Weld | 172 | 364 | 5 | 1.1 | U | NCEL |
| Be-Cu, TIG Weld | 172 | 723 | 5 | 0.7 | U | NCEL |
| Be-Cu, TIG Weld | 172 | 763 | 5 | 0.7 | U | NCEL |
| Be-Cu, TIG Weld | 172 | 402 | 2370 | 0.6 | ET | NCEL |
| Be-Cu, Chain, Cast | 825 | 364 | 5 | 1.0 | U | NCEL |
| Be-Cu, Chain, Cast | 825 | 723 | 5 | 0.8 | U | NCEL |
| Be-Cu, Chain, Cast | 825 | 763 | 5 | 0.8 | UP(30.5m),C(7m) | NCEL |
| Be-Cu, Chain, Cast | 825 | 402 | 2370 | 0.5 | U | NCEL |
| | | | | | | |
| Commercial Bronze | 220 | 366 | 5 | 1.1 | P(4m) | INCO (10) |
| Commercial Bronze | 220 | 402 | 2370 | 0.2 | SL DZ | INCO (10) |
| Commercial Bronze | 220 | 403 | 6780 | 0.6 | U | INCO (10) |
| | | | | | | |
| Red Brass | 230 | 366 | 5 | 1.2 | CR(6m) | INCO (10) |
| Red Brass | 230 | 402 | 2370 | 0.7 | U | INCO (10) |
| Red Brass | 230 | 403 | 6780 | 1.2 | SL DZ | INCO (10) |

Table 5. (cont'd)

| Alloy | CDA No.(1) | Exposure | | Corrosion Rate, MPY(2) | Corrosion Type(3) | Source(4) |
|---|---|---|---|---|---|---|
| | | Days | Depth, Feet | | | |
| Yellow Brass | 270 | 366 | 5 | 1.3 | U | INCO(10) |
| Yellow Brass | 270 | 402 | 2370 | 0.9 | U | INCO(10) |
| Yellow Brass | 270 | 403 | 6780 | 1.0 | U | INCO(10) |
| Muntz Metal | 280 | 366 | 5 | 3.7 | S DZ | INCO(10) |
| Muntz Metal | 280 | 398 | 5 | 3.1 | DZ,P(6m) | NCEL |
| Muntz Metal | 280 | 540 | 5 | 3.4 | DZ,IP | NCEL |
| Muntz Metal | 280 | 588 | 5 | 3.3 | DZ,IP | NCEL |
| Muntz Metal | 280 | 402 | 2370 | 0.7 | SL DZ | INCO(10) |
| Muntz Metal | 280 | 402 | 2370 | 0.7 | SL DZ | NCEL |
| Muntz Metal | 280 | 403 | 6780 | 3.3 | S DZ | INCO(10) |
| Muntz Metal | 280 | 403 | 6780 | 2.6 | SL DZ | NCEL |
| As Admiralty | 443 | 366 | 5 | 1.3 | U | INCO(10) |
| As Admiralty | 443 | 608 | 5 | 1.1 | U,IP | NCEL |
| As Admiralty | 443 | 402 | 2370 | 0.6 | U | INCO(10) |
| As Admiralty | 443 | 402 | 2370 | 0.6 | U | NCEL |
| As Admiralty | 443 | 403 | 6780 | 0.8 | U | INCO(10) |
| As Admiralty | 443 | 403 | 6780 | 0.7 | U | NCEL |
| Al Brass | | 366 | 5 | 0.4 | P P(4m) | INCO(10) |
| Al Brass | | 402 | 2370 | 0.3 | U | INCO(10) |
| Al Brass | | 403 | 6780 | 0.4 | U | INCO(10) |
| Ni Brass | | 366 | 5 | 0.9 | U | INCO(10) |
| Ni Brass | | 402 | 2370 | 0.7 | U | INCO(10) |
| Ni Brass | | 403 | 6780 | 1.3 | U | INCO(10) |
| Mn Bronze A | 678 | 366 | 5 | 1.9 | S DZ | INCO(10) |
| Mn Bronze A | 678 | 402 | 2370 | 0.8 | S DZ | INCO(10) |
| Mn Bronze A | 678 | 403 | 6730 | 2.7 | S DZ | INCO(10) |

Table 5. (cont'd)

| Alloy | CDA No.(1) | Exposure Days | Exposure Depth, Feet | Corrosion Rate MPY(2) | Corrosion Type(3) | Source(4) |
|---|---|---|---|---|---|---|
| Ni-Mn Bronze, Cast | 868 | 364 | 5 | .72 | U,DZ | NCEL |
| Ni-Mn Bronze, Cast | 868 | 723 | 5 | 2.9 | DZ | NCEL |
| Ni-Mn Bronze, Cast | 868 | 763 | 5 | 3.0 | DZ | NCEL |
| Ni-Mn Bronze, Cast | 868 | 402 | 2370 | 1.6 | SL DZ | NCEL |
| Ni-Mn Bronze, Cast | 868 | 403 | 6780 | 0.4 | MD DZ | NCEL |
| G Bronze | 905 | 366 | 5 | 1.2 | CR(9m) | INCO(10) |
| G Bronze | 905 | 402 | 2370 | 0.3 | U | INCO(10) |
| G Bronze | 905 | 403 | 6780 | 0.7 | U | INCO(10) |
| Modified G Bronze | 903 | 366 | 5 | 1.0 | CR(7m) | INCO(10) |
| Modified G Bronze | 903 | 402 | 2370 | 0.3 | U | INCO(10) |
| Modified G Bronze | 903 | 403 | 6780 | 0.4 | U | INCO(10) |
| M Bronze | 922 | 366 | 5 | 1.1 | CR(2m) | INCO(10) |
| M Bronze | 922 | 402 | 2370 | 0.3 | U | INCO(10) |
| M Bronze | 922 | 403 | 6780 | 0.4 | U | INCO(10) |
| Leaded Sn Bronze | | 366 | 5 | 1.3 | CR(5m) | INCO(10) |
| Leaded Sn Bronze | | 402 | 2370 | 0.5 | U | INCO(10) |
| Leaded Sn Bronze | | 403 | 6780 | 0.5 | U | INCO(10) |
| P Bronze A | 510 | 366 | 5 | 1.3 | CR(5m) | INCO(10) |
| P Bronze A | 510 | 588 | 5 | 1.3 | CR(15m), C(3m) | NCEL |
| P Bronze A | 510 | 608 | 5 | 1.1 | CR(15m) | NCEL |
| P Bronze A | 510 | 402 | 2370 | 0.2 | U | INCO(10) |
| P Bronze A | 510 | 402 | 2370 | 0.1 | ET | NCEL |
| P Bronze A | 510 | 403 | 6780 | 0.3 | U | INCO(10) |
| P Bronze A | 510 | 403 | 6780 | 0.2 | ET | NCEL |
| P Bronze D | 524 | 398 | 5 | 0.9 | CR(4m) | NCEL |
| P Bronze D | 524 | 540 | 5 | 0.7 | CR(2m) | NCEL |
| P Bronze D | 524 | 608 | 5 | 0.7 | CR(7m),C(5m) | NCEL |
| P Bronze D | 524 | 402 | 2370 | <0.1 | U | NCEL |
| P Bronze D | 524 | 403 | 6780 | 0.2 | ET | NCEL |

Table 5. (cont'd)

| Alloy | CDA No.(1) | Exposure Days | Exposure Depth, Feet | Corrosion Rate MPY(2) | Corrosion Type(3) | Source(4) |
|---|---|---|---|---|---|---|
| Al Bronze, 5% | 606 | 366 | 5 | 0.7 | G | INCO(10) |
| Al Bronze, 5% | 606 | 402 | 2370 | 0.2 | U | INCO(10) |
| Al Bronze, 5% | 606 | 403 | 6780 | 0.2 | SL DA | INCO(10) |
| Al Bronze, 7% | 614 | 366 | 5 | 0.6 | G | INCO(10) |
| Al Bronze, 7% | 614 | 588 | 5 | 0.9 | SL DA,CR(44mm), C(20m) | NCEL |
| Al Bronze, 7% | 614 | 402 | 2370 | 0.2 | ET | INCO(10) |
| Al Bronze, 7% | 614 | 402 | 2370 | 0.2 | U | NCEL |
| Al Bronze, 7% | 614 | 403 | 6780 | 0.2 | U | INCO(10) |
| Al Bronze, 7% | 614 | 403 | 6780 | 0.7 | SL DA; C(12m); P(12m,6.6a) | NCEL |
| Al Bronze, 10% | 953 | 366 | 5 | 1.3 | MO DA | INCO(10) |
| Al Bronze, 10% | 953 | 402 | 2370 | 0.3 | S DA | INCO(10) |
| Al Bronze, 10% | 953 | 403 | 6780 | 0.7 | MO DA | INCO(10) |
| Al Bronze, 11% | 954 | 366 | 5 | 1.1 | U | INCO(10) |
| Al Bronze, 11% | 954 | 402 | 2370 | 0.2 | MO DA | INCO(10) |
| Al Bronze, 11% | 954 | 403 | 6780 | 0.1 | SL DA | INCO(10) |
| Al Bronze, 13% | | 366 | 5 | 1.9 | S DA | INCO(10) |
| Al Bronze, 13% | | 402 | 2370 | 0.3 | MO DA | INCO(10) |
| Al Bronze, 13% | | 403 | 6780 | 0.6 | S DA | INCO(10) |
| Si Bronze, 3% | 653 | 366 | 5 | 1.1 | G | INCO(10) |
| Si Bronze, 3% | 653 | 402 | 2370 | 1.2 | U | INCO(10) |
| Si Bronze, 3% | 653 | 403 | 6780 | 1.2 | MO CO | INCO(10) |
| Si Bronze A | 655 | 366 | 5 | 1.2 | G | INCO(10) |
| Si Bronze A | 655 | 398 | 5 | 1.1 | G | NCEL |
| Si Bronze A | 655 | 540 | 5 | 2.5 | CR(30m),C(15m) | NCEL |
| Si Bronze A | 655 | 588 | 5 | 0.9 | CR(9m) | NCEL |
| Si Bronze A | 655 | 402 | 2370 | 0.8 | U | INCO(10) |
| Si Bronze A | 655 | 402 | 2370 | 1.0 | ET | NCEL |
| Si Bronze A | 655 | 403 | 6780 | 1.2 | U | INCO(10) |
| Si Bronze A | 655 | 403 | 6780 | 1.2 | U | NCEL |

Table 5. (cont'd)

| Alloy | CDA No.(1) | Exposure Days | Exposure Depth, Feet | Corrosion Rate, MPY(2) | Corrosion Type(3) | Source(4) |
|---|---|---|---|---|---|---|
| Ni-Al Bronze #2 | | 366 | 5 | 0.4 | U | INCO(10) |
| Ni-Al Bronze #2 | | 402 | 2370 | 0.2 | U | INCO(10) |
| Ni-Al Bronze #2 | | 403 | 6780 | 0.2 | IP | INCO(10) |
| Ni-Vee Bronze A | | 366 | 5 | 1.5 | CR (10m) | INCO(10) |
| Ni-Vee Bronze A | | 402 | 2370 | 0.4 | U | INCO(10) |
| Ni-Vee Bronze A | | 403 | 6780 | 0.6 | U | INCO(10) |
| Ni-Vee Bronze B | | 366 | 5 | 1.3 | CR (6m) | INCO(10) |
| Ni-Vee Bronze B | | 402 | 2370 | 1.2 | U | INCO(10) |
| Ni-Vee Bronze B | | 403 | 6780 | 0.5 | U | INCO(10) |
| Ni-Vee Bronze C | | 366 | 5 | 1.5 | CR (5m) | INCO(10) |
| Ni-Vee Bronze C | | 402 | 2370 | 0.6 | U | INCO(10) |
| Ni-Vee Bronze C | | 403 | 6780 | 0.8 | U | INCO(10) |
| Cu-Ni, 90-10 | 706 | 366 | 5 | 0.6 | U | INCO(10) |
| Cu-Ni, 90-10 | 706 | 608 | 5 | 0.5 | U | NCEL |
| Cu-Ni, 90-10 | 706 | 402 | 2370 | 0.8 | U | INCO(10) |
| Cu-Ni, 90-10 | 706 | 402 | 2370 | 0.6 | U | NCEL |
| Cu-Ni, 90-10 | 706 | 403 | 6780 | 0.6 | U | INCO(10) |
| Cu-Ni, 90-10 | 706 | 403 | 6780 | 0.8 | U | INCO(10) |
| Cu-Ni, 90-10, Cast | 962 | 366 | 5 | 0.9 | U | INCO(10) |
| Cu-Ni, 90-10, Cast | 962 | 402 | 2370 | 0.7 | U | INCO(10) |
| Cu-Ni, 80-20 | 710 | 366 | 5 | 1.9 | G | INCO(10) |
| Cu-Ni, 80-20 | 710 | 402 | 2370 | 1.1 | U | INCO(10) |
| Cu-Ni, 80-20 | 710 | 402 | 2370 | 0.6 | U | NCEL |
| Cu-Ni, 80-20 | 710 | 403 | 6780 | 1.5 | U | INCO(10) |
| Cu-Ni, 80-20 | 710 | 403 | 6780 | 1.2 | U | NCEL |

Table 5. (cont'd)

| Alloy | CDA No. (1) | Exposure Days | Exposure Depth, Feet | Corrosion Rate, MPY (2) | Corrosion Type (3) | Source (4) |
|---|---|---|---|---|---|---|
| Cu-Ni, 70-30, 0.5Fe | 715 | 366 | 5 | 0.4 | G | INCO [10] |
| Cu-Ni, 70-30, 0.5Fe | 715 | 398 | 5 | 0.4 | P(7m) | NCEL |
| Cu-Ni, 70-30, 0.5Fe | 715 | 608 | 5 | 0.3 | IP | NCEL |
| Cu-Ni, 70-30, 0.5Fe | 715 | 402 | 2370 | 0.6 | U | INCO [10] |
| Cu-Ni, 70-30, 0.5Fe | 715 | 402 | 2370 | 0.5 | U | NCEL |
| Cu-Ni, 70-30, 0.5Fe | 715 | 403 | 6780 | 1.2 | U | INCO [10] |
| Cu-Ni, 70-30, 0.5Fe | 715 | 403 | 6780 | 1.2 | U | NCEL |
| Cu-Ni, 70-30, 5Fe | 716 | 398 | 5 | 0.7 | CR(17m),U | NCEL |
| Cu-Ni, 70-30, 5Fe | 716 | 608 | 5 | 0.6 | C(13m)CR(18m) | NCEL |
| Cu-Ni, 70-30, 5Fe | 716 | 402 | 2370 | 0.1 | U | NCEL |
| Cu-Ni, 70-30, 5Fe | 716 | 403 | 6780 | 0.1 | ET | NCEL |
| Cu-Ni, 55-45 | | 366 | 5 | 1.2 | U | INCO [10] |
| Cu-Ni, 55-45 | | 402 | 2370 | 0.7 | U | INCO [10] |
| Cu-Ni, 55-45 | | 403 | 6780 | 1.2 | U | INCO [10] |
| Nickel-Silver | 752 | 366 | 5 | 0.7 | U | INCO [10] |
| Nickel-Silver | 752 | 402 | 2370 | 1.0 | U | INCO [10] |
| Nickel-Silver | 752 | 403 | 6780 | 1.4 | U | INCO [10] |
| Cu-Ni-Zn-Pb | | 366 | 5 | 0.7 | U | INCO [10] |
| Cu-Ni-Zn-Pb | | 402 | 2370 | 0.4 | U | INCO [10] |
| Cu-Ni-Zn-Pb | | 403 | 6780 | 0.8 | U | INCO [10] |

1. Copper Development Association Number
2. MPY - Mils penetration per year, calculated from weight loss
3. Type of corrosion symbols:

   C - Crevice; CO - Coppering, a selective attack where copper appears on the surface similar to dezincification

   CR - Crater like pits; DA - Dealuminification; DZ - Dezincification

   ET - Etched; G - General; I - Incipient

   MD - Medium; MO - Moderate; P - Pitting

   S - Severe; SL - Slight; U - Uniform

   Numbers indicate mils:

   i.e. 20 - 20 mils; 20m - 20 mils maximum; 5.4a - 5.4 mils average
4. Numbers refer to references at end of paper.

Table 6. Chemical Composition of Nickel Alloys.

| Material | Ni | C | Mn | Fe | S | Si | Cu | Cr | Ti | Mo | Other | Source[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electrolytic Ni | 99.97+Co | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | INCO[10] |
| Ni-200 | 99.50 | 0.05 | 0.29 | 0.04 | 0.006 | 0.07 | 0.02 | -- | -- | -- | -- | NCEL |
| Ni-200 | 99.5 | 0.06 | -- | -- | -- | -- | -- | -- | -- | -- | -- | INCO[10] |
| Ni-201 | 99.5 | 0.01 | -- | -- | -- | -- | -- | -- | -- | -- | -- | INCO[10] |
| Ni-211 | 95.0 | -- | 5.0 | -- | -- | -- | -- | -- | -- | -- | -- | INCO[10] |
| Ni-270 | 99.97 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | INCO[10] |
| Ni-210, cast | 95.6 | -- | 1.0 | -- | -- | 2.0 | -- | -- | -- | -- | -- | INCO[10] |
| Ni-301 | 94.0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | Al-4.5 | INCO[10] |
| Ni-Cu 400 | 65.17 | 0.11 | 1.06 | 0.90 | 0.007 | 0.10 | 32.62 | -- | -- | -- | -- | NCEL |
| Ni-Cu 400 | 66.00 | 0.12 | 0.90 | 1.35 | 0.005 | 0.15 | 31.50 | -- | -- | -- | -- | NCEL |
| Ni-Cu 400 | 66.00 | -- | 0.90 | 1.40 | -- | 0.20 | 32.00 | -- | -- | -- | -- | INCO[10] |
| Ni-Cu 402 | 58.00 | -- | 0.90 | 1.20 | -- | 0.10 | 40.00 | -- | -- | -- | -- | INCO[10] |
| Ni-Cu 406 | 84.00 | -- | 0.90 | 1.40 | -- | 0.20 | 13.00 | -- | -- | -- | -- | INCO[10] |
| Ni-Cu 410, cast | 66.00 | -- | 0.80 | 1.00 | -- | 1.60 | 31.00 | -- | -- | -- | -- | INCO[10] |
| Ni-Cu K-500 | 65.00 | 0.15 | 0.60 | 1.00 | 0.005 | 0.15 | 29.50 | -- | 0.50 | -- | Al-2.80 | NCEL |
| Ni-Cu K-500 | 65.00 | -- | 0.60 | 1.00 | -- | 0.20 | 30.00 | -- | -- | -- | Al-2.80 | INCO[10] |
| Ni-Cu 505, cast | 64.00 | -- | 0.80 | 2.00 | -- | 4.00 | 29.00 | -- | -- | -- | -- | INCO[10] |
| Ni-Cu 45-55 | 45.00 | -- | 1.00 | 0.10 | -- | -- | 54.00 | -- | -- | -- | -- | INCO[10] |
| Ni-Cr-Fe 600 | 76.00 | 0.04 | 0.20 | 7.20 | 0.007 | 0.20 | 0.10 | 15.8 | -- | -- | -- | NCEL |
| Ni-Cr-Fe 600 | 76.0 | -- | -- | 7.0 | -- | -- | -- | 16.0 | -- | -- | -- | INCO[10] |
| Ni-Cr-Fe 610, cast | 71.0 | -- | -- | 9.0 | -- | 2.0 | -- | 16.0 | -- | -- | -- | INCO[10] |
| Ni-Cr-Fe X750 | 73.0 | -- | -- | 7.0 | -- | -- | -- | 15.0 | 2.5 | -- | -- | INCO[10] |
| Ni-Cr-Fe 718 | 52.5 | 0.04 | 0.20 | 18.0 | 0.007 | 0.20 | 0.10 | 19.0 | 0.80 | 3.0 | Cb-5.2<br>Al-0.60 | NCEL |
| Ni-Cr-Fe 88 | 71.0 | -- | -- | 7.0 | -- | -- | -- | 10.0 | -- | -- | Sn-5.0<br>Bi-3.0 | INCO[10] |
| Ni-Cr-Mo 3 | 58.0 | -- | -- | 3.0 | -- | -- | -- | 19.0 | -- | 19.0 | -- | INCO[10] |
| Ni-Cr-Mo 625 | 63.0 | -- | -- | -- | -- | -- | -- | 22.0 | -- | 9.0 | -- | INCO[10] |
| Ni-Co-Cr-Mo 700 | 46.0 | -- | -- | 1.0 | -- | -- | -- | 15.0 | -- | 3.75 | Co-28.5<br>Al-3.0 | INCO[10] |
| Ni-Fe-Cr 800 | 32.0 | 0.04 | 0.74 | 46.0 | 0.007 | 0.35 | 0.30 | 20.5 | -- | -- | -- | NCEL |
| Ni-Fe-Cr 800 | 32.0 | -- | 1.0 | 46.0 | -- | -- | -- | 20.0 | -- | -- | -- | INCO[10] |
| Ni-Fe-Cr 804 | 43.0 | -- | -- | 25.0 | -- | -- | -- | 29.0 | -- | -- | -- | INCO[10] |

Table 6. (cont'd)

| Material | Ni | C | Mn | Fe | S | Si | Cu | Cr | Ti | Mo | Other | Source[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ni-Fe-Cr 825 | 41.12 | 0.05 | 0.82 | 30.86 | 0.01 | 0.31 | 1.61 | 21.12 | 1.00 | 2.94 | Al-0.14 | NCEL |
| Ni-Fe-Cr 825 | 42.0 | -- | -- | 30.0 | -- | -- | 2.0 | 22.0 | -- | 3.0 | -- | INCO(10) |
| Ni-Fe-Cr 825Cb | 42.0 | -- | -- | 30.0 | -- | -- | 2.0 | 22.0 | -- | 3.0 | -- | INCO(10) |
| Ni-Fe-Cr 901 | 43.0 | -- | -- | 34.0 | - | -- | -- | 14.0 | -- | -- | -- | INCO(10) |
| Ni-Fe-Cr 902 | 42.0 | 0.02 | 0.40 | 48.5 | 0.008 | 0.50 | 0.05 | 5.4 | 2.40 | -- | Al-0.65 | NCEL |
| Ni-Cr-Fe-Mo "F" | 46.0 | -- | -- | 21.0 | -- | -- | -- | 22.0 | -- | 7.0 | -- | INCO(10) |
| Ni-Cr-Fe-Mo "G" | 45.0 | -- | -- | 20.0 | -- | -- | 2.0 | 21.0 | -- | 7.0 | -- | INCO(10) |
| Ni-Cr-Fe-Mo "X" | 60.0 | -- | -- | 19.0 | -- | -- | -- | 22.0 | -- | 9.0 | -- | INCO(10) |
| Ni-Mo-Fe "B" | 60.0 | -- | -- | 5.0 | -- | -- | -- | -- | -- | 26.0 | -- | INCO(10) |
| Ni-Mo-Cr "C" | 55.68 | 0.05 | 0.52 | 6.32 | 0.009 | 0.62 | -- | 15.33 | -- | 16.71 | W-3.53<br>Co-0.96<br>V-0.26<br>P-0.010 | NCEL |
| Ni-Mo-Cr "C" | 60.0 | -- | -- | 5.0 | -- | -- | -- | 15.0 | -- | 16.0 | W-4.0 | INCO(10) |
| Ni-Sn-Zn 23 | 79.0 | -- | 2.0 | -- | -- | -- | -- | -- | -- | -- | Sn-8.0<br>Zn-7.0<br>Pb-4.0 | INCO(10) |
| Ni-Cr 65-35 | 65.0 | -- | -- | -- | -- | -- | -- | 35.0 | -- | -- | -- | INCO(10) |
| Ni-Cr 75 | 78.0 | -- | -- | -- | -- | -- | -- | 20.0 | -- | -- | -- | INCO(10) |
| Ni-Cr 80-20 | 80.0 | -- | -- | -- | -- | -- | -- | 20.0 | -- | -- | -- | INCO(10) |
| Ni-Mo 2 | 66.0 | -- | -- | 2.0 | -- | -- | -- | -- | -- | 30.0 | -- | INCO(10) |
| Ni-Si D | 86.0 | -- | -- | -- | -- | 10.0 | 3.0 | -- | -- | -- | -- | INCO(10) |
| Ni-Be | 97.5 | -- | -- | -- | -- | -- | -- | -- | 0.50 | -- | Be 1.95 | NCEL |

1. Numbers refer to references at end of paper.

Table 7. Corrosion of Nickel Alloys in Sea Water

| Alloy | Exposure | | Corrosion Rate, MPY(1) | Max. Pit Depth, Mils | Corrosion, Crevice, Depth, Mils | Corrosion Type(2) | Corrosion, Weld | Source(3) |
|---|---|---|---|---|---|---|---|---|
| | Days | Depth, Ft | | | | | | |
| Electrolytic Ni | 366 | 5 | 6.9 | 30(PR) | 30(PR) | C,P | -- | INCO(10) |
| Electrolytic Ni | 402 | 2370 | 0.6 | 0.0 | 50(PR) | C | -- | INCO(10) |
| Electrolytic Ni | 403 | 6780 | 1.1 | 0.0 | 20 | C | -- | INCO(10) |
| Ni-200 | 366 | 5 | 4.5 | 40(PR) | 40(PR) | C,P | -- | INCO(10) |
| Ni-200 | 398 | 5 | 1.9 | 125(PR) | 0 | P,T | -- | NCEL |
| Ni-200 | 402 | 2370 | 0.6 | 0.0 | 50(PR) | C | -- | INCO(10) |
| Ni-200 | 402 | 2370 | 0.6 | 0.0 | 3 | C,SET | -- | NCEL |
| Ni-200, Welded, Elect. 141 | 402 | 2370 | 0.8 | I | 0.0 | IP,ET | SP | NCEL |
| Ni-200, Welded, FM61 | 402 | 2370 | 0.6 | I | 0.0 | IP,ET | P(PR) | NCEL |
| Ni-200 | 403 | 6780 | 0.5 | 0.0 | 50(PR) | C | -- | INCO(10) |
| Ni-200 | 403 | 6780 | 1.6 | -- | 79 | C,T to PR (123) | -- | NCEL |
| Ni-200 | 540 | 5 | 1.5 | 125(PR) | 0 | P,T | | NCEL |
| Ni-200, Welded, FM61 | 540 | 5 | 1.9 | 125(PR) | 0 | P,T | WB(PR),HAZ (PR) | NCEL |
| Ni-200 | 588 | 5 | 1.5 | 125(PR) | 0 | P,T | | NCEL |
| Ni-201 | 366 | 5 | 3.6 | 50(PR) | 50(PR) | C,P | -- | INCO(10) |
| Ni-201 | 402 | 2370 | 0.6 | 50(PR) | 50(PR) | C,P | -- | INCO(10) |
| Ni-201 | 403 | 6780 | 0.6 | 50(PR) | 50(PR) | C,P | -- | INCO(10) |
| Ni-210, Cast | 366 | 5 | 3.4 | 68 | 32 | C,P | -- | INCO(10) |
| Ni-210, Cast | 402 | 2370 | 0.7 | 0.0 | 16 | C | | INCO(10) |
| Ni-210, Cast | 403 | 6780 | 5.7 | 0 | 70 | C | | INCO(10) |
| Ni-211 | 366 | 5 | 4.5 | 50(PR) | 50(PR) | C,P | | INCO(10) |
| Ni-211 | 402 | 2370 | 0.6 | 0 | 50(PR) | C | | INCO(10) |
| Ni-211 | 403 | 6780 | 0.7 | 50(PR) | 50(PR) | C,P | | INCO(10) |

Table 7. (cont'd)

| Alloy | Exposure Days | Exposure Depth, Ft | Corrosion Rate, MPY(1) | Max. Pit Depth, Mils | Corrosion, Crevice, Depth, Mils | Corrosion Type(2) | Corrosion, Weld | Source(3) |
|---|---|---|---|---|---|---|---|---|
| Ni-270 | 366 | 5 | 4.5 | 40(PR) | 40(PR) | C,P | -- | INCO(10) |
| Ni-270 | 402 | 2370 | 0.6 | 0 | 50(PR) | C | -- | INCO(10) |
| Ni-301 | 366 | 5 | 4.1 | 40(PR) | 40(PR) | C,P | -- | INCO(10) |
| Ni-301 | 402 | 2370 | 0.7 | 0 | 0 | SLE | -- | INCO(10) |
| Ni-301 | 403 | 6780 | 3.6 | 0 | 40(PR) | C | -- | INCO(10) |
| Ni-Cu 400 | 366 | 5 | 2.4 | 16 | 40(PR) | C,P | -- | INCO(10) |
| Ni-Cu 400 | 398 | 5 | 0.8 | 39 | 0 | P | -- | NCEL |
| Ni-Cu 400 | 402 | 2370 | 0.8 | 0 | 40(PR) | C | -- | INCO(10) |
| Ni-Cu 400 | 402 | 2370 | 0.4 | 20 | 0 | P | -- | NCEL |
| Ni-Cu 400, Welded, Elect. 130 | 402 | 2370 | 0.5 | I | 0 | IP | U | NCEL |
| Ni-Cu 400, Welded, Elect. 180 | 402 | 2370 | 0.5 | I | 0 | IP | U | NCEL |
| Ni-Cu 400, Welded FM60 | 402 | 2370 | 0.4 | I | 0 | IP | SP | NCEL |
| Ni-Cu 400 | 403 | 6780 | 0.8 | 0 | 40(PR) | C,U | -- | INCO(10) |
| Ni-Cu 400 | 403 | 6780 | 0.5 | 20 | 10 | C,P,E | -- | NCEL |
| Ni-Cu 400 | 540 | 5 | 0.9 | 17 | 0 | P,E | -- | NCEL |
| Ni-Cu 400, Welded, Elect. 190 | 540 | 5 | 1.2 | 28 | 0 | CR | WB(CR) | NCEL |
| Ni-Cu 400 | 588 | 5 | 0.8 | 29 | 0 | P | -- | NCEL |
| Ni-Cu 402 | 366 | 5 | 2.3 | 30(PR) | 30(PR) | C,P | -- | INCO(10) |
| Ni-Cu 402 | 402 | 2370 | 0.7 | 0 | 30(PR) | C | -- | INCO(10) |
| Ni-Cu 402 | 403 | 6780 | 0.7 | 0 | 0 | U | -- | INCO(10) |
| Ni-Cu 406 | 366 | 5 | 6.0 | 50(PR) | 50(PR) | C,P | -- | INCO(10) |
| Ni-Cu 406 | 402 | 2370 | 0.6 | 0 | 50(PR) | C | -- | INCO(10) |
| Ni-Cu 406 | 403 | 6780 | 0.5 | 0 | 50(PR) | C | -- | INCO(10) |

Table 7. (cont'd)

| Alloy | Exposure | | Corrosion Rate, MPY(1) | Max. Pit Depth, Mils | Corrosion, Crevice, Depth, Mils | Corrosion Type(2) | Corrosion, Weld | Source(3) |
|---|---|---|---|---|---|---|---|---|
| | Days | Depth, Ft | | | | | | |
| Ni-Cu 410, Cast | 366 | 5 | 3.1 | 19 | 30 | C,P | -- | INCO(10) |
| Ni-Cu 410, Cast | 402 | 2370 | 0.4 | 0 | 0 | G | -- | INCO(10) |
| Ni-Cu 410, Cast | 403 | 6780 | 1.1 | 0 | 0 | U | -- | INCO(10) |
| Ni-Cu K500 | 366 | 5 | 3.6 | 30(PR) | 30(PR) | C,P | -- | INCO(10) |
| Ni-Cu K500 | 402 | 2370 | 0.6 | 0 | 30(PR) | C | -- | INCO(10) |
| Ni-Cu K500 | 402 | 2370 | 0.6 | 38 | 46 | C,P | -- | NCEL |
| Ni-Cu K500, Welded, Elect. 134 | 402 | 2370 | 0.6 | 0 | 0 | NC | P(14 mils), EWB | NCEL |
| Ni-Cu K500, Welded, FM64 | 402 | 2370 | 0.5 | 21 | 0 | P | U | NCEL |
| Ni-Cu K500 | 403 | 6780 | 0.3 | 0 | 18 | C | -- | INCO(10) |
| Ni-Cu K500, Welded, Elect. 134 | 540 | 5 | 1.1 | 20 | 0 | P | WB(CR) | NCEL |
| Ni-Cu K500, Welded, FM64 | 540 | 5 | 0.9 | 13 | 0 | P | P(WB)(HAZ) | NCEL |
| Ni-CU 505, Cast | 366 | 5 | 1.1 | 13 | 0 | P | -- | INCO(10) |
| Ni-Cu 505, Cast | 402 | 2370 | 0.3 | 0 | 0 | G | -- | INCO(10) |
| Ni-Cu 505, Cast | 403 | 6780 | 2.0 | 0 | 0 | U | -- | INCO(10) |
| Ni-Cu 45-55 | 366 | 5 | 1.2 | 0 | 0 | U | -- | INCO(10) |
| Ni-Cu 45-55 | 402 | 2370 | 0.7 | 0 | 0 | U | -- | INCO(10) |
| Ni-Cu 45-55 | 403 | 6780 | 1.3 | 0 | 0 | U | -- | INCO(10) |
| Ni-Cr-Fe 600 | 366 | 5 | .6 | 50(PR) | 50(PR) | C,P | -- | INCO(10) |
| Ni-Cr-Fe 600 | 402 | 2370 | 0.1 | 0 | 28 | C | -- | INCO(10) |
| Ni-Cr-Fe 600 | 402 | 2370 | <0.1 | I | 0 | IP,SLET | -- | NCEL |
| Ni-Cr-Fe 600, Welded, Elect. 132 | 402 | 2370 | 0.3 | 0 | 0 | ET | WB(PR) | NCEL |

Table 7. (cont'd)

| Alloy | Exposure | | Corrosion Rate, MPY(1) | Max. Pit Depth, Mils | Corrosion, Crevice, Depth, Mils | Corrosion Type(2) | Corrosion, Weld | Source(3) |
|---|---|---|---|---|---|---|---|---|
| | Days | Depth, Ft | | | | | | |
| Ni-Cr-Fe 600, Welded, Elect. 182 | 402 | 2370 | <0.1 | 0 | 0 | ET | ET | NCEL |
| Ni-Cr-Fe 600, Welded, Elect. 62 | 402 | 2370 | 0.4 | 0 | 0 | NC | WB(PR),LC | NCEL |
| Ni-Cr-Fe 600 Welded, Elect. 82 | 402 | 2370 | 0.3 | 0 | 0 | NC | WB(PR),LC T(PR)HAZ | NCEL |
| Ni-Cr-Fe 600 | 403 | 6780 | 0.1 | 0 | 23 | C | -- | INCO(10) |
| Ni-Cr-Fe 600 | 540 | 5 | 0.5 | 67 | 0 | P | -- | NCEL |
| Ni-Cr-Fe 600, Welded, Elect. 132 | 540 | 5 | 0.9 | 60 | 0 | P | WB(PR),T | NCEL |
| Ni-Cr-Fe 600, Welded, Elect. 182 | 540 | 5 | 0.9 | 50 | 0 | P | WB(PR) | NCEL |
| Ni-Cr-Fe 600, Welded, Elect. 62 | 540 | 5 | 0.7 | 88 | 0 | P | WB(PR) (125m) | NCEL |
| Ni-Cr-Fe 600, Welded, Elect. 82 | 540 | 5 | 0.6 | 77 | 0 | P | P(WB) | NCEL |
| Ni-Cr-Fe 610, Cast | 366 | 5 | 1.3 | 55 | 24 | C,P | -- | INCO(10) |
| Ni-Cr-Fe 610, Cast | 402 | 2370 | 0.3 | 0 | 18 | C | -- | INCO(10) |
| Ni-Cr-Fe 610, Cast | 403 | 6780 | <0.1 | 0 | I | IC | -- | INCO(10) |
| Ni-Co-Cr-Mo 700 | 366 | 5 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Co-Cr-Mo 700 | 402 | 2370 | <0.1 | 0 | I | IC | -- | INCO(10) |
| Ni-Co-Cr-Mo 700 | 403 | 6780 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Cr-Fe 718 | 402 | 2370 | <0.1 | 0 | 0 | NC | -- | NCEL |
| Ni-Cr-Fe 718, Welded, Elect. 718 | 402 | 2370 | 0.0 | 0 | 0 | NC | NC | NCEL |
| Ni-Cr-Fe 718 | 540 | 5 | 0.0 | 0 | 0 | NC | -- | NCEL |
| Ni-Cr-Fe 718, Welded, Elect. 718 | 540 | 5 | 0.0 | 0 | 0 | NC | NC | NCEL |

Table 7. (cont'd)

| Alloy | Exposure | | Corrosion Rate, MPY(1) | Max. Pit Depth, Mils | Corrosion Crevice, Depth, Mils | Corrosion Type(2) | Corrosion, Weld | Source(3) |
|---|---|---|---|---|---|---|---|---|
| | Days | Depth, Ft | | | | | | |
| Ni-Cr-Fe X750 | 366 | 5 | 0.9 | 50(PR) | 50(PR) | C,P | -- | INCO(10) |
| Ni-Cr-Fe X750 | 402 | 2370 | 0.1 | 0 | 17 | C | -- | INCO(10) |
| Ni-Cr-Fe X750 | 402 | 2370 | 0.1 | 0 | 0 | T | -- | NCEL |
| Ni-Cr-Fe X750, Welded, Elect. 69 | 402 | 2370 | 0.3 | 0 | 0 | ET | 0 | NCEL |
| Ni-Cr-Fe X750 Welded, Elect. 718 | 402 | 2370 | 0.2 | 0 | 0 | NC | T(55)HAZ, PR edge WB | NCEL |
| Ni-Cr-Fe X750 | 403 | 6780 | 0.2 | 0 | 35(PR) | C | -- | INCO(10) |
| Ni-Cr-Fe X750 | 540 | 5 | 0.3 | 130(PR) | 130(PR) | C,P | -- | NCEL |
| Ni-Cr-Fe X750, Welded, Elect. 69 | 540 | 5 | 0.5 | 130(PR) | 0 | P | CR(WB&HAZ) | NCEL |
| Ni-Cr-Fe X750 Welded, Elect. 718 | 540 | 5 | 0.5 | 130(PR) | 130(PR) | C,P | CR(PR,HAZ) | NCEL |
| Ni-Cr-Fe 88 | 366 | 5 | 1.0 | 150 | 0 | P | -- | INCO(10) |
| Ni-Cr-Fe 88 | 402 | 2370 | 0.4 | 1 | 52 | C,IP | -- | INCO(10) |
| Ni-Cr-Fe 88 | 403 | 6780 | <0.1 | 0 | 5 | C | -- | INCO(10) |
| Ni-Cr-Mo 3 | 366 | 5 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Cr-Mo 3 | 402 | 2370 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Cr-Mo 3 | 403 | 6780 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Cr-Mo 625 | 366 | 5 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Cr-Mo 625 | 398 | 5 | 0.0 | 0 | 0 | NC | -- | NCEL |
| Ni-Cr-Mo 625, Welded, Elect. 625 | 398 | 5 | 0.0 | 0 | 0 | NC | -- | NCEL |
| Ni-Cr-Mo 625 | 402 | 2370 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Cr-Mo 625 | 402 | 2370 | <0.1 | 0 | 0 | NC | -- | NCEL |
| Ni-Cr-Mo 625 | 540 | 5 | 0.0 | 0 | 0 | NC | -- | NCEL |
| Ni-Cr-Mo 625, Welded, FM625 | 540 | 5 | 0.0 | 0 | 0 | NC | NC | NCEL |

Table 7. (cont'd)

| Alloy | Exposure Days | Exposure Depth, Ft | Corrosion Rate, MPY(1) | Max. Pit Depth, Mils | Corrosion, Crevice, Depth, Mils | Corrosion Type(2) | Corrosion, Weld | Source(3) |
|---|---|---|---|---|---|---|---|---|
| Ni-Cr-Mo 625, Welded, Elect. 625 | 540 | 5 | 0.0 | 0 | 0 | NC | NC | NCEL |
| Ni-Cr-Mo 625 | 588 | 5 | 0.0 | 0 | 0 | NC | | NCEL |
| Ni-Cr-Mo 625, Welded, Elect. 625 | 588 | 5 | 0.0 | 0 | 0 | NC | NC | NCEL |
| Ni-Fe-Cr 800 | 366 | 5 | <0.1 | 0 | I | IC | -- | INCO(10) |
| Ni-Fe-Cr 800 | 402 | 2370 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Fe-Cr 800 | 402 | 2370 | 0.0 | 0 | 0 | NC | -- | NCEL |
| Ni-Fe-Cr 800 Welded, Elect. 82 | 402 | 2370 | <0.1 | 0 | 0 | NC | E,PR,WB | NCEL |
| Ni-Fe-Cr 800, Welded, Elect. 138 | 402 | 2370 | <0.1 | 0 | 0 | NC | IC,E,WB | NCEL |
| Ni-Fe-Cr 800 | 403 | 6780 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Fe-Cr 800 | 540 | 5 | 0.3 | 128(PR) | 0 | P | -- | NCEL |
| Ni-Fe-Cr 800, Welded, Elect. 182 | 540 | 5 | 0.7 | 128(PR) | 0 | P | WB&HAZ(PR) | NCEL |
| Ni-Fe-Cr 800, Welded, FM82 | 540 | 5 | 0.4 | 128(PR) | 0 | P | T(WB&HAZ) | NCEL |
| Ni-Fe-Cr 804 | 366 | 5 | <0.1 | 0 | I | IC | -- | INCO(10) |
| Ni-Fe-Cr 804 | 402 | 2370 | <0.1 | 0 | I | IC | -- | INCO(10) |
| Ni-Fe-Cr 804 | 403 | 6780 | <0.1 | 0 | I | IC | -- | INCO(10) |
| Ni-Fe-Cr 825 | 366 | 5 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Fe-Cr 825 | 398 | 5 | <0.1 | 0 | 0 | NC | -- | NCEL |
| Ni-Fe-Cr 825 | 402 | 2370 | <0.1 | 0 | I | IC | -- | INCO(10) |
| Ni-Fe-Cr 825 | 402 | 2370 | <0.1 | 0 | 15 | C,ET | -- | NCEL |
| Ni-Fe-Cr 825, Welded, Elect. 135 | 402 | 2370 | <0.1 | 0 | 0 | NC | WB, one end | NCEL |
| Ni-Fe-Cr 825, Welded, Elect. 65 | 402 | 2370 | <0.1 | 0 | 0 | NC | NC | NCEL |
| Ni-Fe-Cr 825 | 403 | 6780 | <0.1 | 0 | I | IC | -- | INCO(10) |
| Ni-Fe-Cr 825 | 403 | 6780 | 0.0 | 0 | 0 | NC | -- | NCEL |
| Ni-Fe-Cr 825 | 540 | 5 | <0.1 | 43 | 24 | C,P | -- | NCEL |

Table 7. (cont'd)

| Alloy | Exposure Days | Exposure Depth, Ft | Corrosion Rate, MPY(1) | Max. Pit Depth, Mils | Corrosion, Crevice, Depth, Mils | Corrosion Type(2) | Corrosion, Weld | Source(3) |
|---|---|---|---|---|---|---|---|---|
| Ni-Fe-Cr 825, Welded, Elect. 135 | 540 | 5 | <0.1 | 6 | I | C,P | CR(HAZ) | NCEL |
| Ni-Fe-Cr 825, Welded, FM65 | 540 | 5 | 0.0 | 4 | 0 | P | IP(WB&HAZ) | NCEL |
| Ni-Fe-Cr 825 | 588 | 5 | <0.1 | 18 | 0 | P | -- | NCEL |
| Ni-Fe-Cr 825 | 608 | 5 | <0.1 | 54 | 0 | P | -- | NCEL |
| Ni-Fe-Cr 825S(4) | 366 | 5 | <0.1 | 0 | I | IC | -- | INCO(10) |
| Ni-Fe-Cr 825S | 402 | 2370 | <0.1 | I | I | IC,IP | -- | INCO(10) |
| Ni-Fe-Cr 825S | 403 | 6780 | <0.1 | o | I | IC | -- | INCO(10) |
| Ni-Fe-Cr 825Cb | 366 | 5 | <0.1 | 0 | I | IC | -- | INCO(10) |
| Ni-Fe-Cr 825Cb | 402 | 2370 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Fe-Cr 825Cb | 403 | 6780 | <0.1 | 0 | I | IC | -- | INCO(10) |
| Ni-Fe-Cr 901 | 366 | 5 | <0.1 | 0 | I | IC | -- | INCO(10) |
| Ni-Fe-Cr 901 | 402 | 2370 | <0.1 | 0 | I | IC | -- | INCO(10) |
| Ni-Fe-Cr 901 | 403 | 6780 | <0.1 | 0 | I | IC | -- | INCO(10) |
| Ni-Fe-Cr 902 | 364 | 5 | 2.5 | 0 | 41 | C | -- | NCEL |
| Ni-Fe-Cr 902 | 402 | 2370 | 1.4 | I | 35 | C,IP | -- | NCEL |
| Ni-Fe-Cr 902 | 723 | 5 | 1.7 | 0 | 40 | C | -- | NCEL |
| Ni-Fe-Cr 902 | 763 | 5 | 1.5 | 73 | 125(PR) | C,P | -- | NCEL |
| Ni-Cr-Fe-Mo F | 366 | 5 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Cr-Fe-Mo F | 402 | 2370 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Cr-Fe-Mo F | 403 | 6780 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Cr-Fe-Mo G | 366 | 5 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Cr-Fe-Mo G | 402 | 2370 | <0.1 | 0 | 0 | NC | -- | INCO(10) |

Table 7. (cont'd)

| Alloy | Exposure | | Corrosion Rate, MPY(1) | Max. Pit Depth, Mils | Corrosion, Crevice, Depth, Mils | Corrosion Type(2) | Corrosion, Weld | Source(3) |
|---|---|---|---|---|---|---|---|---|
| | Days | Depth, Ft | | | | | | |
| Ni-Cr-Fe-Mo X | 366 | 5 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Cr-Fe-Mo X | 402 | 2370 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Cr-Fe-Mo X | 403 | 6780 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Mo-Fe B | 366 | 5 | 6.4 | 0 | 0 | G | -- | INCO(10) |
| Ni-Mo-Fe B | 402 | 2370 | 1.2 | 0 | 0 | G | -- | INCO(10) |
| Ni-Mo-Fe B | 403 | 6780 | 4.0 | 0 | 0 | U | -- | INCO(10) |
| Ni-Mo-Cr C | 366 | 5 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Mo-Cr C | 398 | 5 | <0.1 | 0 | 0 | NC | -- | NCEL |
| Ni-Mo-Cr C | 402 | 2370 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Mo-Cr C | 402 | 2370 | 0.0 | 0 | 0 | NC | -- | NCEL |
| Ni-Mo-Cr C | 403 | 6780 | <0.1 | 0 | 0 | NC | -- | INCO(10) |
| Ni-Mo-Cr C | 403 | 6780 | 0.0 | 0 | 0 | NC | -- | NCEL |
| Ni-Mo-Cr C | 608 | 5 | 0.0 | 0 | 0 | NC | -- | NCEL |
| Ni-Sn-Zn 23 | 366 | 5 | 4.5 | 37 | 37 | C,P | -- | INCO(10) |
| Ni-Sn-Zn 23 | 402 | 2370 | 0.9 | 0 | 29 | C | -- | INCO(10) |
| Ni-Sn-Zn 23 | 403 | 6780 | 8.0 | 36 | 36 | C,P | -- | INCO(10) |
| Ni-Be | 364 | 5 | 5.4 | Ends-152 | 0 | P | -- | NCEL |
| Ni-Be | 402 | 2370 | 1.1 | Ends- 17 | 0 | P,ET | -- | NCEL |
| Ni-Be | 763 | 5 | 4.9 | Ends-345 | 0 | P,CR | -- | NCEL |
| | | | | Surf.- 43 | | | | |
| Ni-Cr 65-35 | 366 | 5 | 1.9 | 30(PR) | 30(PR) | C,P | -- | INCO(10) |
| Ni-Cr 65-35 | 402 | 2370 | 0.1 | 0 | 6 | C | -- | INCO(10) |
| Ni-Cr 65-35 | 403 | 6780 | <0.1 | 0 | 35(PR) | C | -- | INCO(10) |
| Ni-Cr 75 | 366 | 5 | 1.2 | 50(PR) | 50(PR) | C,P | -- | INCO(10) |
| Ni-Cr 75 | 402 | 2370 | 0.4 | 40(PR) | 40(PR) | C,P | -- | INCO(10) |
| Ni-Cr 75 | 403 | 6780 | 0.4 | 0 | 40(PR) | C | -- | INCO(10) |

Table 7. (cont'd)

| Alloy | Exposure Days | Exposure Depth, Ft | Corrosion Rate, MPY(1) | Max. Pit Depth, Mils | Corrosion, Crevice, Depth, Mils | Corrosion Type(2) | Corrosion, Weld | Source(3) |
|---|---|---|---|---|---|---|---|---|
| Ni-Cr 80-20 | 366 | 5 | 1.6 | 30(PR) | 30(PR) | C,P | -- | INCO(10) |
| Ni-Cr 80-20 | 402 | 2370 | 0.2 | 18 | 18 | C,P | -- | INCO(10) |
| Ni-Cr 80-20 | 403 | 6780 | 0.2 | 0 | 11 | C | -- | INCO(10) |
| Ni-Mo 2 | 366 | 5 | 4.7 | 12 | 0 | P | -- | INCO(10) |
| Ni-Mo 2 | 402 | 2370 | 1.6 | 0 | 0 | G | -- | INCO(10) |
| Ni-Mo 2 | 403 | 6780 | 2.2 | 0 | 0 | C | -- | INCO(10) |
| Ni-Si D | 366 | 5 | 1.9 | 37 | 33 | C,P | -- | INCO(10) |
| Ni-Si D | 402 | 2370 | 0.5 | 0 | 14 | C | -- | INCO(10) |
| Ni-Si D | 403 | 6780 | 2.4 | 5 | 5 | C,P | -- | INCO(10) |

1. MPY - Mils penetration per year calculated from weight loss
2. Symbols for types of corrosion:
   - C - Crevice
   - CR - Crater type pits
   - E - Edge
   - ET - Etched
   - G - General
   - HAZ - Heat affected zone along weld
   - I - Incipient
   - LC - Line corrosion at edge of weld bead
   - NC - No visible corrosion
   - P - Pitting
   - PR - Perforated
   - S - Severe
   - SL - Slight
   - T - Tunnel
   - U - Uniform
   - WB - Weld bead
3. Numbers refer to references at end of paper
4. S - Sensitized by heating for 1 hour at 1200°F, air cooling

Table 8. Chemical Composition of Irons and Steels

| Material | C | Mn | P | S | Si | Ni | Cr | Mo | V | Cu | Other | Source[3] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Armco Iron | -- | 0.02 | -- | -- | -- | -- | -- | -- | -- | -- | -- | INCO[10] |
| Wrought Iron | 0.02 | 0.06 | 0.13 | 0.01 | 0.13 | -- | -- | -- | -- | -- | 2.5 Slag | NCEL |
| AISI 1010 | 0.12 | 0.50 | 0.004 | 0.23 | 0.060 | -- | -- | -- | -- | -- | -- | NCEL |
| AISI 1010 | -- | 0.34 | 0.01 | -- | 0.02 | 0.02 | 0.02 | -- | -- | 0.03 | -- | INCO[10] |
| Copper Steel | -- | 0.40 | 0.01 | -- | 0.02 | 0.01 | 0.03 | -- | -- | 0.28 | -- | INCO[10] |
| ASTM A36 | 0.20 | 0.55 | 0.010 | 0.020 | 0.064 | -- | -- | -- | -- | -- | -- | NCEL |
| HSLA #1[1] | 0.18 | 0.86 | 0.014 | .023 | 0.28 | 0.65 | 0.64 | 0.18 | 0.047 | -- | B-0.1028<br>Ti-0.020 | NCEL |
| HSLA #2 | 0.12 | 0.30 | 0.015 | 0.025 | 0.27 | 2.34 | 1.25 | 0.20 | -- | 0.17 | -- | NCEL |
| HSLA #4 | -- | 0.36 | 0.08 | -- | 0.41 | 0.32 | 0.72 | -- | -- | 0.38 | -- | INCO[10] |
| HSLA #5 | 0.14 | 0.78 | 0.020 | 0.025 | 0.23 | 0.74 | 0.56 | 0.42 | 0.36 | 0.22 | B-0.0041 | NCEL |
| HSLA #5 | With mill scale | | | | | | | | | | | INCO[10] |
| HSLA #7 | -- | 0.43 | 0.12 | -- | 0.13 | 0.54 | -- | -- | -- | 1.0 | -- | INCO[10] |
| HSLA #10 | -- | 0.63 | 0.01 | -- | -- | 0.99 | -- | -- | -- | 1.42 | -- | INCO[10] |
| HSLA #12 | 0.14 | 0.26 | 0.011 | 0.009 | 0.27 | 2.60 | 1.55 | 0.46 | 0.02 | -- | -- | NCEL |
| HS #1[2] | 0.11 | 0.78 | 0.008 | 0.006 | 0.29 | 5.03 | 0.56 | 0.42 | 0.05 | -- | -- | NCEL |
| HS #2 | 0.002 | 0.018 | 0.004 | 0.005 | 0.05 | 12.20 | 5.07 | 3.12 | | -- | Ti-0.21<br>Al-0.25 | NCEL |
| HS #3 | 0.28 | 0.29 | 0.005 | 0.005 | 0.10 | 8.26 | 0.53 | 0.47 | -- | -- | Co-3.82<br>V-0.15 | NCEL |
| 18% Ni-Maraging | 0.62 | 0.10 | 0.005 | 0.007 | 0.14 | 17.92 | -- | 4.78 | -- | -- | Co-8.75<br>B-0.003<br>Ti-0.94<br>Al-0.17 | NCEL |
| 1.5% Ni | Not recorded | | | | | | | | | | | INCO[10] |
| 3.0% Ni | Not recorded | | | | | | | | | | | INCO[10] |
| 5.0% Ni | Not recorded | | | | | | | | | | | INCO[10] |
| 9.0% Ni | Not recorded | | | | | | | | | | | INCO[10] |
| AISI Type 502 | 0.06 | 0.48 | 0.020 | 0.010 | 0.33 | -- | 4.75 | 0.55 | -- | -- | -- | NCEL |
| AISI Type 502 | 0.06 | 0.5 | -- | -- | -- | 0.4 | 5.2 | 0.5 | -- | -- | -- | INCO[10] |

1. High-Strength-Low-Alloy Steel
2. High Strength Steel
3. Numbers indicate references at end of paper

Table 9. Corrosion of Steels in Sea Water

| Alloy | Exposure | | Corrosion Rate, MPY(1) | Pit Depth, Mils | | Crevice Corrosion, Depth, Mils | Corrosion, Type(2) | Source(3) |
|---|---|---|---|---|---|---|---|---|
| | Days | Depth, Feet | | Max. | Avg. | | | |
| Armco Iron | 366 | 5 | 7.1 | -- | -- | -- | G | INCO(10) |
| Armco Iron | 402 | 2370 | 1.4 | -- | -- | -- | G | INCO(10) |
| Armco Iron | 403 | 6780 | 1.5 | -- | -- | -- | U | INCO(10) |
| Wrought Iron | 364 | 5 | 4.8 | -- | -- | -- | G | NCEL |
| Wrought Iron | 402 | 2370 | 1.5 | -- | -- | -- | G | NCEL |
| Wrought Iron | 403 | 6780 | 1.4 | -- | -- | -- | U | NCEL |
| Wrought Iron | 723 | 5 | 4.0 | -- | -- | -- | G | NCEL |
| Wrought Iron | 763 | 5 | 4.8 | -- | -- | -- | G | NCEL |
| AISI 1010 | 398 | 5 | 8.2 | 24 | 18.8 | 0 | U,P | NCEL |
| AISI 1010 | 366 | 5 | 8.0 | -- | -- | -- | G | INCO(10) |
| AISI 1010 | 402 | 2370 | 1.2 | -- | -- | | U | NCEL |
| AISI 1010 | 402 | 2370 | 1.1 | -- | -- | -- | G | INCO(10) |
| AISI 1010 | 403 | 6780 | 1.5 | -- | -- | -- | U | NCEL |
| AISI 1010 | 403 | 6780 | 2.3 | -- | -- | -- | G | INCO(10) |
| AISI 1010 | 588 | 5 | 8.9 | 23 | 15 | 15 | C,P | NCEL |
| Copper Steel | 366 | 5 | 6.0 | -- | -- | -- | G | INCO(10) |
| Copper Steel | 402 | 2370 | 1.1 | -- | -- | -- | G | INCO(10) |
| Copper Steel | 403 | 6780 | 2.1 | -- | -- | -- | G | INCO(10) |
| ASTM A36 | 398 | 5 | 6.2 | 39 | 19.9 | I | P,IC | NCEL |
| ASTM A36 | 402 | 2370 | 1.3 | -- | -- | -- | U | NCEL |
| ASTM A36 | 403 | 6780 | 1.5 | -- | -- | -- | U | NCEL |
| ASTM A36 | 540 | 5 | 6.3 | 21 | 17 | 0 | G,P | NCEL |
| ASTM A36 | 588 | 5 | 5.8 | 21 | 17 | 0 | G,P | NCEL |
| HSLA No. 1(4) | 398 | 5 | 5.2 | 42 | 25 | 0 | G,C,P | NCEL |
| HSLA No. 1 | 402 | 2370 | 1.0 | -- | -- | -- | U | NCEL |
| HSLA No. 1 | 403 | 6780 | 2.0 | -- | -- | -- | U | NCEL |
| HSLA No. 1 | 588 | 5 | 4.7 | 36 | 27 | 21 | G,C,P | NCEL |

Table 9. (cont'd)

| Alloy | Exposure | | Corrosion Rate, MPY[1] | Pit Depth, Mils | | Crevice Corrosion, Depth, Mils | Corrosion Type[2] | Source[3] |
|---|---|---|---|---|---|---|---|---|
| | Days | Depth, Feet | | Max. | Avg. | | | |
| HSLA No. 2 | 398 | 5 | 4.5 | 17 | 15 | I | U, IC,P | NCEL |
| HSLA No. 2 | 402 | 2370 | 1.3 | -- | -- | -- | U | NCEL |
| HSLA No. 2 | 403 | 6780 | 2.1 | -- | -- | -- | U | NCEL |
| HSLA No. 2 | 540 | 5 | 4.4 | 28 | 23.4 | 0 | G,P | NCEL |
| HSLA No. 4 | 366 | 5 | 8.0 | -- | -- | -- | G | INCO[10] |
| HSLA No. 4 | 402 | 2370 | 1.1 | -- | -- | -- | G | NCEL |
| HSLA No. 4 | 402 | 2370 | 1.3 | -- | -- | -- | G | INCO[10] |
| HSLA No. 4 | 403 | 6780 | 3.3 | -- | -- | -- | U | NCEL |
| HSLA No. 4 | 403 | 6780 | 2.1 | -- | -- | -- | G | INCO[10] |
| HSLA No. 5 | 398 | 5 | 6.0 | 26 | 14.4 | I | G,IC,P | NCEL |
| HSLA No. 5 | 366 | 5 | 8.0 | -- | -- | -- | G | INCO[10] |
| HSLA No. 5 | 402 | 2370 | 1.1 | -- | -- | -- | U | NCEL |
| HSLA No. 5 | 402 | 2370 | 1.4 | -- | -- | -- | G | INCO[10] |
| HSLA No. 5 | 403 | 6780 | 2.7 | -- | -- | 2.6 | U,C | NCEL |
| HSLA No. 5 | 403 | 6780 | 7.4 | 3.0 | -- | -- | P,SE | INCO[10] |
| HSLA No. 5 | 540 | 5 | 5.4 | 17 | 14.1 | 0 | G,P,E | NCEL |
| HSLA No. 7 | 366 | 5 | 8.0 | -- | -- | -- | G | INCO[10] |
| HSLA No. 7 | 402 | 2370 | 1.4 | -- | -- | -- | G | INCO[10] |
| HSLA No. 7 | 403 | 6780 | 1.5 | -- | -- | -- | G | INCO[10] |
| HSLA No. 10 | 366 | 5 | 8.0 | -- | -- | -- | G | INCO[10] |
| HSLA No. 10 | 402 | 2370 | 1.5 | -- | -- | -- | G | INCO[10] |
| HSLA No. 10 | 403 | 6780 | 1.8 | -- | -- | -- | G | INCO[10] |
| HSLA No. 12 | 398 | 5 | 4.2 | 23 | 17.6 | 0 | G,P | NCEL |
| HSLA No. 12 | 540 | 5 | 4.9 | 29 | 23.4 | 0 | G,P,E | NCEL |
| HSLA No. 12 | 588 | 5 | 4.3 | 26 | 23.0 | - | G,P,E | NCEL |

Table 9. (cont'd)

| Alloy | Exposure | | Corrosion Rate, MPY(1) | Pit Depth, Mils | | Crevice Corrosion, Depth, Mils | Corrosion Type(2) | Source(3) |
|---|---|---|---|---|---|---|---|---|
| | Days | Depth, Feet | | Max. | Avg. | | | |
| HS No. 1(5) | 398 | 5 | 4.7 | 42 | 25 | 0 | G,P | NCEL |
| HS No. 1 | 540 | 5 | 4.5 | 15 | 10.6 | 0 | G,P | NCEL |
| HS No. 1 | 588 | 5 | 4.2 | 15 | 10.7 | 6 | G,C,P | NCEL |
| HS No. 2 | 398 | 5 | 3.5 | 30 | 28.9 | 0 | G,P | NCEL |
| HS No. 2 | 588 | 5 | 3.3 | 42 | 36.9 | 0 | G,P | NCEL |
| HS No. 3 | 398 | 5 | 5.0 | 15 | 12.6 | 0 | U,P | NCEL |
| HS No. 3 | 540 | 5 | 3.8 | 15 | 9.7 | 0 | G,P | NCEL |
| HS No. 3 | 588 | 5 | 4.6 | 18 | 12.7 | 0 | G,P | NCEL |
| 18% Mi, Maraging | 366 | 5 | 7.0 | -- | -- | -- | P | INCO(10) |
| 18% Mi, Maraging | 398 | 5 | 3.0 | 10 | 6.2 | 0 | U,P | NCEL |
| 18% Mi, Maraging | 402 | 2370 | 1.2 | -- | -- | -- | G | NCEL |
| 18% Mi, Maraging | 402 | 2370 | 0.8 | 0 | 0 | 0 | G | INCO(10) |
| 18% Mi, Maraging | 588 | 5 | 3.1 | 12 | 8.8 | 9.0 | G,C,P | NCEL |
| 18% Mi, Maraging(6) | 364 | 5 | 4.0 | 10 | 6.8 | 0 | P,G | NCEL |
| 18% Mi, Maraging | 402 | 2370 | 3.5 | 0 | 0 | 0 | G | NCEL |
| 18% Mi, Maraging | 723 | 5 | 3.5 | 10 | 7.7 | 0 | P,G | NCEL |
| 18% Mi, Maraging | 763 | 5 | 4.1 | 0 | 0 | 0 | G | NCEL |
| 18% Mi, Maraging(7) | 364 | 5 | 4.0 | 10 | 7.2 | 0 | P,WB(G) | NCEL |
| 18% Mi, Maraging | 402 | 2370 | 2.8 | 0 | 0 | 0 | G | NCEL |
| 18% Mi, Maraging | 723 | 5 | 3.3 | 10 | 6.9 | 0 | P,G(8) | NCEL |
| 18% Mi, Maraging | 763 | 5 | 3.9 | 0 | 0 | 0 | G | NCEL |
| 1.5 Ni Steel | 366 | 5 | 8.0 | -- | -- | -- | G | INCO(10) |
| 1.5 Ni Steel | 402 | 2370 | 1.5 | -- | -- | -- | U | INCO(10) |
| 1.5 Ni Steel | 403 | 6780 | 1.7 | -- | -- | -- | U | INCO(10) |
| 3 Ni Steel | 366 | 5 | 8.0 | -- | -- | -- | G | INCO(10) |
| 3 Ni Steel | 402 | 2370 | 1.3 | -- | -- | -- | G | INCO(10) |
| 3 Ni Steel | 403 | 6780 | 1.9 | -- | -- | 2.0 | C,G | INCO(10) |

Table 9. (cont'd)

| Alloy | Exposure Days | Exposure Depth, Feet | Corrosion Rate, MPY(1) | Pit Depth, Mils Max. | Pit Depth, Mils Avg. | Crevice Corrosion, Depth, Mils, | Corrosion, Type(2) | Source(3) |
|---|---|---|---|---|---|---|---|---|
| 5 Ni Steel | 366 | 5 | 7.0 | -- | -- | -- | G | INCO(10) |
| 5 Ni Steel | 402 | 2370 | 1.3 | -- | -- | -- | U | INCO(10) |
| 5 Ni Steel | 403 | 6780 | 2.8 | -- | -- | 6.0 | C,G | INCO(10) |
| 9 Ni Steel | 366 | 5 | 8.0 | -- | -- | -- | G | INCO(10) |
| 9 Ni Steel | 402 | 2370 | 1.6 | -- | -- | -- | G | INCO(10) |
| 9 Ni Steel | 403 | 6780 | 2.9 | -- | -- | 9.0 | C,G | INCO(10) |
| AISI Type 502 | 366 | 5 | 8.0 | -- | -- | -- | G | INCO(10) |
| AISI Type 502 | 398 | 5 | 4.4 | 30 | 25.6 | 0 | G,P | NCEL |
| AISI Type 502 | 402 | 2370 | 0.8 | 16 | -- | 16.0 | P,C | NCEL |
| AISI Type 502 | 402 | 2370 | 3.1 | PR | | PR | P,C | INCO(10) |
| AISI Type 502 | 403 | 6780 | 2.3 | 0 | -- | 22 | C | NCEL |
| AISI Type 502 | 403 | 6780 | 13.2 | 35 | -- | 35 | P,C,G | INCO(10) |
| AISI Type 502 | 540 | 5 | 4.1 | 24 | | 0 | G,C,P | NCEL |

1. MPY - Mils penetration per year calculated from weight loss
2. Symbols for types of corrosion:
   - C - Crevice S - Severe
   - E - Edge U - Uniform
   - G - General WB - Weld bead
   - I - Incipient P - Pitting
3. Numbers refer to references at end of paper
4. HSLA - High strength - low alloy steels
5. HS - High strength steels
6. Heat treated aged 900°F-3hrs-air cooled
7. Welded - welded after heat treatment in (6)
8. Outer edge of heat affected zone grooved

Table 10. Chemical Composition of Cast Irons.

| Material | C | Mn | Si | Ni | Cr | Mo | Cu | Source[1] |
|---|---|---|---|---|---|---|---|---|
| Nickel | -- | 0.68 | 2.47 | 1.56 | -- | -- | -- | INCO(10) |
| Ni-Cr #1 | -- | 0.73 | 1.64 | 1.66 | 0.60 | -- | -- | INCO(10) |
| Ni-Cr #2 | -- | 0.86 | 1.99 | 3.22 | 0.98 | -- | -- | INCO(10) |
| Ductile #1 | -- | 0.35 | 2.50 | 0.91 | -- | -- | -- | INCO(10) |
| Ductile #2 | -- | 0.34 | 2.24 | -- | -- | -- | -- | INCO(10) |
| Silicon | -- | -- | 14.5 | -- | -- | -- | -- | INCO(10) |
| Si-Mo | -- | -- | 14.0 | -- | -- | 3.0 | -- | INCO(10) |
| Austenitic, Type 1 | -- | 1.4 | 2.05 | 15.8 | 1.79 | -- | 6.71 | INCO(10) |
| Austenitic, Type 2 | -- | 1.01 | 2.29 | 18.2 | 2.04 | -- | -- | INCO(10) |
| Austenitic, Type 3 | -- | 0.6 | 1.15 | 28.4 | 2.87 | -- | -- | INCO(10) |
| Austenitic, Type 4 | -- | 0.56 | 5.34 | 29.7 | 4.97 | -- | -- | INCO(10) |
| Austenitic, Type 4 | 2.13 | 0.79 | 5.60 | 29.98 | 5.02 | -- | 0.16 | NCEL |
| Austenitic, Type D-2 | -- | 0.94 | 3.0 | 21.4 | 2.26 | -- | -- | INCO(10) |
| Austenitic, Type D-2b | -- | 0.96 | 2.0 | 20.8 | 3.19 | -- | -- | INCO(10) |
| Austenitic, Type D-2c | 2.45 | 2.12 | 2.38 | 22.34 | 0.08 | -- | -- | NCEL |
| Austenitic, Type D-3 | -- | 0.5 | 1.83 | 29.8 | 2.70 | -- | -- | INCO(10) |
| Austenitic, Hardenable | Not Recorded | | | | | | | INCO(10) |

1. Numbers refer to references at end of paper.

Table 11. Corrosion of Cast Irons in Sea Water

| Alloy | Exposure Days | Exposure Depth, Ft | Corrosion Rate, MPY[1] | Corrosion Type[2] | Source[3] |
|---|---|---|---|---|---|
| Gray | 366 | 5 | 2.6 | G | INCO (10) |
| Gray | 402 | 2370 | 1.7 | U | INCO (10) |
| Gray | 403 | 6780 | 1.8 | U | INCO (10) |
| Nickel | 366 | 5 | 7.6 | G | INCO (10) |
| Nickel | 402 | 2370 | 1.5 | U | INCO (10) |
| Nickel | 403 | 6780 | 2.9 | U | INCO (10) |
| Ni-Cr #1 | 366 | 5 | 5.2 | U | INCO (10) |
| Ni-Cr #1 | 402 | 2370 | 1.8 | U | INCO (10) |
| Ni-Cr #1 | 403 | 6780 | 1.7 | U | INCO (10) |
| Ni-Cr #2 | 366 | 5 | 4.9 | G | INCO (10) |
| Ni-Cr #2 | 402 | 2370 | 1.8 | U | INCO (10) |
| Ni-Cr #2 | 403 | 6780 | 1.8 | U | INCO (10) |
| Ductile #1 | 366 | 5 | 6.2 | CR(24m) | INCO (10) |
| Ductile #1 | 402 | 2370 | 1.9 | U | INCO (10) |
| Ductile #1 | 403 | 6780 | 3.4 | G | INCO (10) |
| Ductile #2 | 366 | 5 | 7.1 | G | INCO (10) |
| Ductile #2 | 402 | 2370 | 1.8 | U | INCO (10) |
| Ductile #2 | 403 | 6780 | 2.9 | G | INCO (10) |
| Silicon | 366 | 5 | <0.1 | ET | INCO (10) |
| Silicon | 402 | 2370 | <0.1 | NC | INCO (10) |
| Silicon | 403 | 6780 | <0.1 | NC | INCO (10) |
| Si-Mo | 366 | 5 | <0.1 | ET | INCO (10) |
| Si-Mo | 402 | 2370 | <0.1 | NC | INCO (10) |
| Si-Mo | 403 | 6780 | <0.1 | NC | INCO (10) |
| Austenitic, Type 1 | 366 | 5 | 2.7 | U | INCO (10) |
| Austenitic, Type 1 | 402 | 2370 | 1.5 | U | INCO (10) |
| Austenitic, Type 1 | 403 | 6780 | 1.0 | U | INCO (10) |
| Austenitic, Type 2 | 366 | 5 | 2.9 | U | INCO (10) |
| Austenitic, Type 2 | 402 | 2370 | 1.1 | U | INCO (10) |
| Austenitic, Type 2 | 403 | 6780 | 2.2 | U | INCO (10) |

Table 11. (cont'd)

| Alloy | Exposure | | Corrosion Rate, MPY[1] | Corrosion Type[2] | Source[3] |
|---|---|---|---|---|---|
| | Days | Depth, Ft | | | |
| Austenitic, Type 3 | 366 | 5 | 2.8 | U | INCO[10] |
| Austenitic, Type 3 | 402 | 2370 | 0.6 | U | INCO[10] |
| Austenitic, Type 3 | 403 | 6780 | 1.8 | U | INCO[10] |
| Austenitic, Type 4 | 366 | 5 | 2.4 | U | INCO[10] |
| Austenitic, Type 4 | 364 | 5 | 2.4 | G | NCEL |
| Austenitic, Type 4 | 402 | 2370 | 0.8 | U | INCO[10] |
| Austenitic, Type 4 | 402 | 2370 | 0.9 | G | NCEL |
| Austenitic, Type 4 | 403 | 6780 | 2.0 | U | INCO[10] |
| Austenitic, Type 4 | 723 | 5 | 2.0 | G | NCEL |
| Austenitic, Type 4 | 763 | 5 | 2.0 | G | NCEL |
| Austenitic, Type D-2 | 366 | 5 | 2.4 | G | INCO[10] |
| Austenitic, Type D-2 | 402 | 2370 | 1.1 | U | INCO[10] |
| Austenitic, Type D-2 | 403 | 6780 | 1.2 | U | INCO[10] |
| Austenitic, D-2B | 366 | 5 | 2.7 | G | INCO[10] |
| Austenitic, D-2B | 402 | 2370 | 0.9 | U | INCO[10] |
| Austenitic, D-2B | 403 | 6780 | 1.6 | U | INCO[10] |
| Austenitic, D-2C | 364 | 5 | 3.2 | G | NCEL |
| Austenitic, D-2C | 402 | 2370 | 1.8 | U | NCEL |
| Austenitic, D-2C | 723 | 5 | 3.1 | U | NCEL |
| Austenitic, D-2C | 763 | 5 | 2.8 | U | NCEL |
| Austenitic, D-3 | 366 | 5 | 3.2 | G | INCO[10] |
| Austenitic, D-3 | 402 | 2370 | 0.7 | U | INCO[10] |
| Austenitic, D-3 | 403 | 6780 | 2.7 | G | INCO[10] |
| Austenitic, Hardenable | 366 | 5 | 2.6 | U | INCO[10] |
| Austenitic, Hardenable | 402 | 2370 | 1.8 | U | INCO[10] |
| Austenitic, Hardenable | 403 | 6780 | 1.1 | U | INCO[10] |

1. MPY - Mils penetration per year calculated from weight loss
2. Symbols for types of corrosion:
   - CR - Crater type pits
   - ET - Etched
   - G - General
   - NC - No visible corrosion
   - U - Uniform
3. Numbers refer to references at end of paper

Table 12. Chemical Composition of Stainless Steels.

| Alloy | C | Mn | P | S | Si | Ni | Cr | Mo | Cu | Other | Source[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AISI Type 201 | 0.08 | 6.8 | -- | -- | -- | 4.0 | 17.1 | -- | -- | -- | INCO[10] |
| AISI Type 202 | 0.09 | 7.6 | -- | -- | -- | 4.5 | 17.8 | -- | -- | -- | INCO[10] |
| AISI Type 301 | 0.11 | 1.17 | 0.025 | 0.021 | 0.34 | 6.73 | 17.4 | -- | -- | -- | NCEL[10] |
| AISI Type 302 | 0.11 | 1.36 | -- | -- | -- | 9.9 | 17.3 | 0.12 | 0.26 | -- | INCO[10] |
| AISI Type 302 | 0.06 | 1.05 | 0.020 | 0.013 | 0.60 | 9.33 | 18.2 | -- | -- | -- | NCEL[10] |
| AISI Type 304 | 0.06 | 1.62 | -- | -- | -- | 9.5 | 18.2 | 0.34 | 0.16 | -- | INCO[10] |
| AISI Type 304 | 0.06 | 1.73 | 0.024 | 0.013 | 0.43 | 10.0 | 18.8 | -- | -- | -- | NCEL[10] |
| AISI Type 304 Sensitized[2] | 0.06 | 1.62 | -- | -- | -- | 9.5 | 18.2 | 0.34 | 0.16 | -- | INCO[10] |
| AISI Type 304 L | 0.02 | 1.45 | -- | -- | -- | 9.5 | 17.9 | -- | -- | -- | INCO[10] |
| AISI Type 304 L | 0.03 | 1.24 | 0.028 | 0.023 | 0.68 | 10.2 | 18.7 | -- | -- | -- | NCEL[10] |
| AISI Type 309 | 0.10 | 1.60 | -- | -- | -- | 12.7 | 23.3 | -- | -- | -- | INCO[10] |
| AISI Type 310 | 0.04 | 1.78 | -- | -- | -- | 20.9 | 25.3 | -- | -- | -- | INCO[10] |
| AISI Type 311 | 0.20 | 2.0 | -- | -- | -- | 25 | 19 | -- | -- | -- | INCO[10] |
| AISI Type 316 | 0.05 | 1.73 | -- | -- | -- | 13.2 | 17.2 | 2.60 | -- | -- | INCO[10] |
| AISI Type 316 | 0.06 | 1.61 | 0.021 | 0.016 | 0.40 | 13.6 | 18.3 | 2.41 | -- | -- | NCEL[10] |
| AISI Type 316 Sensitized[2] | 0.05 | 1.73 | -- | -- | -- | 13.2 | 17.2 | 2.60 | -- | -- | INCO[10] |
| AISI Type 316 L | 0.02 | 1.78 | -- | -- | -- | 13.6 | 17.7 | 2.15 | -- | -- | INCO[10] |
| AISI Type 316 L | 0.02 | 1.31 | 0.012 | 0.015 | 0.47 | 13.7 | 17.9 | 2.76 | -- | -- | NCEL[10] |
| AISI Type 317 | 0.05 | 1.61 | -- | -- | -- | 13.6 | 18.7 | 3.30 | -- | -- | INCO[10] |
| AISI Type 321 | 0.06 | 2.0 | -- | -- | -- | 10.5 | 18.5 | -- | -- | -- | INCO[10] |
| AISI Type 325 | 0.03 | 0.7 | -- | -- | -- | 23.5 | 9.0 | -- | -- | -- | INCO[10] |
| AISI Type 329 | 0.07 | 0.46 | -- | -- | -- | 4.4 | 27.0 | 1.40 | -- | -- | INCO[10] |
| AISI Type 330 | 0.20 | -- | -- | -- | -- | 34.5 | 15.0 | -- | -- | -- | INCO[10] |
| AISI Type 347 | 0.04 | 1.19 | -- | -- | -- | 11.3 | 18.1 | -- | -- | -- | INCO[10] |
| AISI Type 405 | 0.05 | 0.62 | 0.014 | 0.011 | 0.27 | -- | 14.5 | -- | -- | 0.27 Al | NCEL[10] |
| AISI Type 410 | 0.13 | 0.4 | -- | -- | -- | 0.2 | 12.1 | -- | -- | -- | INCO[10] |
| AISI Type 410 | 0.13 | 0.43 | 0.019 | 0.005 | 0.45 | 0.1 | 12.3 | -- | -- | -- | NCEL[10] |
| AISI Type 430 | 0.06 | 0.4 | -- | -- | -- | -- | 17.7 | -- | -- | -- | INCO[10] |
| AISI Type 446 | 0.15 | 0.8 | -- | -- | -- | 0.2 | 30.0 | -- | -- | -- | INCO[10] |
| 20 Cb | 0.04 | 0.79 | 0.018 | 0.004 | 0.67 | 28.38 | 19.8 | 2.06 | 3.11 | 0.77 Cb and Ta | NCEL[10] |
| 20 Cb-3 | -- | -- | -- | -- | -- | 34 | 20 | 2.3 | 3.4 | -- | INCO[10] |

Table 12. (cont'd)

| Alloy | C | Mn | P | S | Si | Ni | Cr | Mo | Cu | Other | Source[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ni-Cr-Cu-Mo #1 | -- | -- | -- | -- | -- | 30.0 | 20.0 | 2.5 | 4.0 | -- | INCO (10) |
| Ni-Cr-Cu-Mo #2 | -- | -- | -- | -- | -- | 30.0 | 20.0 | 2.5 | 3.5 | -- | INCO (10) |
| Ni-Cr-Mo | -- | -- | -- | -- | -- | 24.0 | 19.0 | 3.0 | -- | -- | INCO (10) |
| Ni-Cr-Mo-Si | -- | -- | -- | -- | 1.0 | 23.0 | 21.0 | 5.0 | -- | -- | INCO (10) |
| Ph14-8Mo-SRH950 | 0.037 | 0.36 | 0.004 | 0.002 | 0.34 | 8.12 | 14.21 | 2.25 | -- | 1.21 Al | NCEL |
| AISI Type 631-RH1050 | 0.071 | 0.48 | 0.017 | 0.018 | 0.42 | 7.42 | 17.12 | -- | -- | 1.19 Al | NCEL |
| AISI Type 631-TH1050 | 0.071 | 0.48 | 0.017 | 0.018 | 0.42 | 7.42 | 17.12 | -- | -- | 1.19 Al | NCEL |
| AISI Type 630-H925 | 0.031 | 0.24 | 0.017 | 0.011 | 0.59 | 4.17 | 15.29 | -- | 3.23 | 0.24 Cb | NCEL |
| 17Cr-14 Ni-Cu-Mo | -- | -- | -- | -- | -- | 14 | 16 | 2 | 3 | -- | INCO (10) |
| 18Cr-15Mn | -- | 15 | -- | -- | -- | 0.5 | 18 | -- | -- | -- | INCO (10) |
| AISI Type 633 | -- | -- | -- | -- | -- | 4 | 17 | 3 | -- | -- | INCO (10) |
| AISI Type 635 | 0.05 | 0.56 | 0.026 | 0.009 | 0.74 | 6.80 | 16.8 | -- | -- | 0.79 Ti | NCEL |
| AISI Type 632-RH1100 | 0.070 | 0.50 | -- | 0.016 | 0.28 | 7.19 | 15.05 | 2.19 | -- | 1.11 Al | NCEL |

1. Numbers refer to references at end of paper
2. Heated for one hour at 1200°F, air cooled

Table 13. Corrosion of 200 Series Stainless Steels in Sea Water

| Alloy(4) | Exposure Days | Exposure Depth, Ft | Corrosion Rate, MPY(1) | Max. Pit Depth, Mils | Corrosion, Crevice Depth, Mils | Corrosion Type(2) | Source(3) |
|---|---|---|---|---|---|---|---|
| 201 | 366 | 5 | 0.6 | -- | -- | SE | INCO(10) |
| 201 | 402 | 2370 | <0.1 | 0 | 1 | C | INCO(10) |
| 201 | 403 | 6780 | <0.1 | 0 | I | C | INCO(10) |
| 202 | 366 | 5 | 0.5 | 50(PR) | 50(PR) | C,P | INCO(10) |
| 202 | 402 | 2370 | <0.1 | 0 | 17 | C | INCO(10) |
| 202 | 403 | 6780 | <0.1 | 0 | I | C | INCO(10) |

1. MPY - Mils penetration per year calculated from weight loss
2. Symbols for types of corrosion:
   - C - Crevice
   - E - Edge
   - I - Incipient
   - P - Pitting
   - PR - Perforated
   - S - Severe
3. Numbers refer to references at end of paper

Table 14. Corrosion of 300 Series Stainless Steels in Sea Water

| Alloy[4] | Exposure Days | Exposure Depth, Ft | Corrosion Rate, MPY[1] | Max. Pit Depth, Mils | Corrosion, Crevice, Depth, Mils | Corrosion Tunnel, Max. Lgth, Mils | Corrosion Type[2] | Source[3] |
|---|---|---|---|---|---|---|---|---|
| 301 | 398 | 5 | 2.3 | 103(PR) | 0 | 1150 | T,P | NCEL |
| 301 | 402 | 2370 | 0.5 | 103(PR) | 0 | 2500 | T,P | NCEL |
| 301 | 403 | 6780 | 1.4 | 103(PR) | 15 | 2450 | C,T,P | NCEL |
| 301 | 588 | 5 | 1.7 | 103(PR) | 50 | 1500 | C,T,P | NCEL |
| 302 | 366 | 5 | <0.1 | I | I | -- | C,P | INCO[10] |
| 302 | 398 | 5 | 0.4 | 53(PR) | 53(PR) | 5400 | C,E,T,P | NCEL |
| 302 | 402 | 2370 | <0.1 | 0 | I | -- | C | INCO[10] |
| 302 | 402 | 2370 | <0.1 | 0 | 18 | 6000 | C,T | NCEL |
| 302 | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO[10] |
| 302 | 403 | 6780 | <0.1 | 0 | 18 | 0 | C | NCEL |
| 302 | 588 | 5 | 0.5 | 52(PR) | 52(PR) | 5500 | C,P,T | NCEL |
| 304 | 366 | 5 | 0.4 | 34 | 33 | -- | C,P | INCO[10] |
| 304 | 402 | 2370 | 0.4 | 210(PR) | 0 | 2000 | E,T,P | NCEL |
| 304 | 402 | 2370 | <0.1 | 0 | 13 | -- | C | INCO[10] |
| 304 | 403 | 6780 | 0.5 | 210(PR) | 0 | 2000 | E,T,P | NCEL |
| 304 | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO[10] |
| 304 | 540 | 5 | 0.7 | 42 | 103 | 183 | C,P,T | NCEL |
| 304 | 588 | 5 | 0.5 | 0 | 138 | 113 | C,T | NCEL |
| 304[5] | 366 | 5 | 1.2 | 50(PR) | 50(PR) | -- | C,P | INCO[10] |
| 304[5] | 402 | 2370 | 0.3 | 0 | 50(PR) | -- | C | INCO[10] |
| 304[5] | 403 | 6780 | 0.7 | 0 | 50(PR) | -- | C | INCO[10] |
| 304L | 366 | 5 | 0.5 | 50(PR) | 0 | -- | P | INCO[10] |
| 304L | 398 | 5 | 1.0 | 115(PR) | 0 | 1100 | E,T,P | NCEL |
| 304L | 402 | 2370 | <0.1 | 0 | I | -- | C | INCO[10] |
| 304L | 402 | 2370 | 0.4 | 115(PR) | 0 | 3000 | T,P | NCEL |
| 304L | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO[10] |
| 304L | 403 | 6780 | <0.1 | 115(PR) | 12 | 4850 | C,E,T,P | NCEL |
| 304L | 540 | 5 | 0.7 | 115(PR) | 115(PR) | 1500 | C,E,T,P | NCEL |
| 309 | 366 | 5 | <0.1 | 0 | I | -- | C | INCO[10] |
| 309 | 402 | 2370 | <0.1 | 0 | I | -- | C | INCO[10] |
| 309 | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO[10] |

Table 14. (cont'd)

| Alloy[4] | Exposure Days | Exposure Depth, Ft | Corrosion Rate, MPY[1] | Max. Pit Depth, Mils | Corrosion, Crevice, Depth, Mils | Corrosion Tunnel, Max. Lgth, Mils | Corrosion Type[2] | Source[3] |
|---|---|---|---|---|---|---|---|---|
| 310 | 366 | 5 | <0.1 | 0 | 50(PR) | -- | C | INCO[10] |
| 310 | 402 | 2370 | <0.1 | 0 | 14 | -- | C | INCO[10] |
| 310 | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO[10] |
| 311 | 366 | 5 | <0.1 | I | I | -- | C,P | INCO[10] |
| 311 | 402 | 2370 | <0.1 | 0 | 6 | -- | C | INCO[10] |
| 311 | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO[10] |
| 316 | 366 | 5 | <0.1 | 0 | 0 | -- | NC | INCO[10] |
| 316 | 398 | 5 | 0.4 | 154 | 20 | 1350 | C,E,T,P | NCEL |
| 316 | 402 | 2370 | <0.1 | 0 | I | -- | C | INCO[10] |
| 316 | 402 | 2370 | 0.1 | 230(PR) | 0 | 500 | E,T,P | NCEL |
| 316 | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO[10] |
| 316 | 403 | 6780 | <0.1 | 0 | 0 | 0 | NC | NCEL |
| 316 | 540 | 5 | 0.3 | 0 | 63 | 70 | C,T | NCEL |
| 316 | 588 | 5 | 0.2 | 0 | 130 | 1500(PR) | C,T | NCEL |
| 316[5] | 366 | 5 | 0.6 | 50(PR) | 50(PR) | -- | C,P | INCO[10] |
| 316[5] | 402 | 2370 | <0.1 | 0 | 8 | -- | C | INCO[10] |
| 316[5] | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO[10] |
| 316L | 366 | 5 | <0.1 | 0 | I | -- | C | INCO[10] |
| 316L | 398 | 5 | <0.1 | 0 | 0 | 0 | SLE | NCEL |
| 316L | 402 | 2370 | <0.1 | 0 | I | -- | C | INCO[10] |
| 316L | 402 | 2370 | <0.1 | 0 | 0 | 0 | NC | NCEL |
| 316L | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO[10] |
| 316L | 403 | 6780 | <0.1 | 0 | 0 | 0 | NC | NCEL |
| 317 | 366 | 5 | <0.1 | 0 | I | -- | C | INCO[10] |
| 317 | 402 | 2370 | <0.1 | 0 | I | -- | C | INCO[10] |
| 317 | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO[10] |
| 321 | 366 | 5 | <0.1 | 22 | 0 | -- | P | INCO[10] |
| 321 | 402 | 2370 | 0.2 | 0 | 30(PR) | -- | C | INCO[10] |
| 321 | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO[10] |

Table 14. (cont'd)

| Alloy (4) | Exposure | | Corrosion Rate, MPY (1) | Max. Pit Depth, Mils | Corrosion, Crevice, Depth, Mils | Corrosion Tunnel, Max. Lgth, Mils | Corrosion Type (2) | Source (3) |
|---|---|---|---|---|---|---|---|---|
| | Days | Depth, Ft | | | | | | |
| 325 | 366 | 5 | 6.3 | 16 | 12 | -- | C,P | INCO(10) |
| 325 | 402 | 2370 | 1.9 | 0 | 0 | -- | G | INCO(10) |
| 325 | 403 | 6780 | 4.6 | 14 | 0 | -- | P | INCO(10) |
| 329 | 366 | 5 | <0.1 | 0 | I | -- | C | INCO(10) |
| 329 | 402 | 2370 | <0.1 | 0 | 0 | -- | NC | INCO(10) |
| 329 | 403 | 6780 | <0.1 | 0 | 0 | -- | NC | INCO(10) |
| 330 | 366 | 5 | 0.4 | 50(PR) | 0 | -- | P | INCO(10) |
| 330 | 402 | 2370 | <0.1 | 0 | 30(PR) | -- | C | INCO(10) |
| 330 | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO(10) |
| 347 | 366 | 5 | 0.7 | 50(PR) | 50(PR) | -- | C,P | INCO(10) |
| 347 | 402 | 2370 | <0.1 | 0 | I | -- | C | INCO(10) |
| 347 | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO(10) |

1. MPY - Mils penetration in mils per year calculated from weight loss
2. Symobls for types of corrosion:
   - C - Crevice
   - E - Edge
   - G - General
   - NC - No visible corrosion
   - P - Pitting
   - PR - Perforated
   - SL - Slight
   - T - Tunnel
3. Numbers refer to references at end of paper
4. AISI Type
5. S - Sensitized by heating to 1200°F for 1 hour and cooling in air

Table 15. Corrosion of 400 Series Stainless Steels in Sea Water

| Alloy[4] | Exposure Days | Exposure Depth, Ft. | Corrosion Rate, MPY[1] | Max. Pit Depth, Mils | Corrosion, Crevice, Depth, Mils | Corrosion Tunnel, Max. Lgth, Mils | Corrosion Type[2] | Source[3] |
|---|---|---|---|---|---|---|---|---|
| 405 | 402 | 2370 | 1.8 | 40 | 15 | 0 | C,P | NCEL |
| 405 | 403 | 6780 | 3.9 | 0 | 0 | 2000(PR) | E,T | NCEL |
| 405 | 588 | 5 | 4.5 | 124 | 250(PR) | 0 | C,P | NCEL |
| 410 | 366 | 5 | 3.0 | 50(PR) | 50(PR) | -- | C,P | INCO[10] |
| 410 | 402 | 2370 | 0.8 | 50(PR) | 50(PR) | -- | C,P | INCO[10] |
| 410 | 402 | 2370 | 0.5 | 40(PR) | 40(PR) | 6400 | C,T,P | NCEL |
| 410 | 403 | 6780 | 1.9 | 50(PR) | 50(PR) | -- | C,P | INCO[10] |
| 410 | 403 | 6780 | 0.2 | 40(PR) | 40(PR) | 6000 | C,T,P | NCEL |
| 430 | 366 | 5 | 1.1 | 50(PR) | 50(PR) | -- | C,P | INCO[10] |
| 430 | 402 | 2370 | 0.8 | 30(PR) | 30(PR) | -- | C,P | INCO[10] |
| 430 | 402 | 2370 | 0.6 | 137(PR) | 20 | 6000 | C,ET,P | NCEL |
| 430 | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO[10] |
| 430 | 403 | 6780 | 0.2 | 137(PR) | 30 | 3750 | C,T,P | NCEL |
| 430 | 540 | 5 | 0.7 | 50(PR) | 50(PR) | 4450 | C,T,P | NCEL |
| 430 | 588 | 5 | 0.9 | 50(PR) | 50(PR) | 3900 | C,T,P | NCEL |
| 446 | 366 | 5 | 0.6 | 50(PR) | 50(PR) | -- | C,P | INCO[10] |
| 446 | 402 | 2370 | <0.1 | 0 | I | -- | C | INCO[10] |
| 446 | 403 | 6780 | <0.1 | 0 | 0 | -- | NC | INCO[10] |

1. MPY - Mils penetration per year calculated from weight loss
2. Symbols for types of corrosion:
   C - Crevice
   ET - Etched
   NC - No visible corrosion
   P - Pitting
   PR - Perforated
3. Numbers refer to references at end of paper

Table 16. Corrosion of 600 Series Precipitation Hardening Stainless Steels

| Alloy | Exposure Days | Exposure Depth, Ft | Corrosion Rate, MPY(1) | Max. Pit Depth, Mils | Corrosion, Crevice, Depth, Mils | Corrosion, Tunnel, Max. Lgth, Mils | Corrosion, Type(2) | Corrosion Weld(3) | Source(4) |
|---|---|---|---|---|---|---|---|---|---|
| AISI 630, H925(6) | 398 | 5 | 1.4 | 112(PR) | 112(PR) | 0 | C,E,P | T,PR(WB& HAZ) | NCEL |
| AISI 630, H925(6) | 402 | 2370 | <0.1 | 0 | 0 | 0 | NC | NC | NCEL |
| AISI 630, H925(6) | 403 | 6780 | <0.1 | 0 | 0 | 0 | NC | T,PR(WB) | NCEL |
| AISI 631, TH1050(5) | 398 | 5 | 1.9 | 125(PR) | 125(PR) | 2600 | C,T,P | SCC | NCEL |
| AISI 631, TH1050(5) | 402 | 2370 | 0.4 | 125(PR) | 0 | 3750 | E,T,P | IP | NCEL |
| AISI 631, TH1050(5) | 403 | 6780 | 0.2 | 0 | 0 | 1750 | E,T | NC | NCEL |
| AISI 632, RH1100(6) | 398 | 5 | 1.8 | 125(PR) | 125(PR) | 750 | C,T,P | NC | NCEL |
| AISI 632, RH1100(6) | 402 | 2370 | 0.7 | 125(PR) | 0 | 1000 | T,P | NC | NCEL |
| AISI 632, RH1100(6) | 403 | 6780 | 1.5 | 125(PR) | 125(PR) | 2000 | C,T,P | NC | NCEL |
| AISI 633 | 366 | 5 | <0.1 | 0 | I | -- | C | -- | INCO(10) |
| AISI 633 | 402 | 2370 | <0.1 | 0 | I | -- | C | -- | INCO(10) |
| AISI 633 | 403 | 6780 | <0.1 | 0 | I | -- | C | -- | INCO(10) |
| AISI 635 | 398 | 5 | 0.6 | 40 | 40 | 1200 | C,E,T,P | -- | NCEL |
| AISI 635 | 402 | 2370 | 0.3 | 0 | 275(PR) | 1200 | C,T | -- | NCEL |
| AISI 635 | 403 | 6780 | 0.2 | 0 | 20 | 0 | C | -- | NCEL |
| AISI 635 | 588 | 5 | 0.5 | 275(PR) | 275(PR) | 500 | C,P,T | -- | NCEL |
| 17-14-Cu-Mo | 366 | 5 | <0.1 | 0 | I | -- | C | -- | INCO(10) |
| 17-14-Cu-Mo | 402 | 2370 | <0.1 | 0 | I | -- | C | -- | INCO(10) |
| 17-14-Cu-Mo | 403 | 6780 | <0.1 | 0 | I | -- | C | -- | INCO(10) |

Footnotes

1. MPY - Mils penetration per year calculated from weight loss
2. Symbols for types of corrosion:
   - C - Crevice
   - E - Edge
   - HAZ - Heat affected zone along weld
   - I - Incipient
   - NC - No visible corrosion
   - P - Pitting
   - PR - Perforated
   - SCC - Stress corrosion cracking
   - T - Tunnel
   - WB - Weld bead
3. Applies only to weld bead and adjacent heat affected zones
4. Numbers refer to references at end of paper
5. Three inch diameter weld in center of specimens
6. Transverse butt weld across center of specimen.

Table 17. Corrosion of Miscellaneous Cast and Wrought Stainless Steels

| Alloy | Exposure | | Corrosion Rate, MPY[1] | Max. Pit Depth, Mils | Corrosion, Crevice, Depth, Mils | Corrosion Tunnel, Max. Lgth, Mils | Corrosion Type[2] | Source[3] |
|---|---|---|---|---|---|---|---|---|
| | Days | Depth, Ft | | | | | | |
| 20Cb | 398 | 5 | <0.1 | 14 | 0 | 0 | SLE,P | NCEL |
| 20Cb | 402 | 2370 | <0.1 | 0 | 0 | 0 | NC | NCEL |
| 20Cb | 403 | 6780 | 0.0 | 0 | 0 | 0 | NC | NCEL |
| 20Cb | 540 | 5 | <0.1 | 24 | 0 | 0 | P | NCEL |
| 20Cb | 588 | 5 | <0.0 | 0 | 21 | 0 | C | NCEL |
| 20Cb-3 | 366 | 5 | <0.1 | 0 | 0 | -- | NC | INCO[10] |
| 20Cb-3 | 402 | 2370 | <0.1 | I | 0 | -- | P | INCO[10] |
| 20Cb-3 | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO[10] |
| Ni-Cr-Cu-Mo#1 | 366 | 5 | <0.1 | 0 | I | -- | C | INCO[10] |
| Ni-Cr-Cu-Mo#1 | 402 | 2370 | <0.1 | 0 | 8 | -- | C | INCO[10] |
| Ni-Cr-Cu-Mo#1 | 403 | 6780 | <0.1 | 0 | 0 | -- | NC | INCO[10] |
| Ni-Cr-Cu-Mo#2 | 366 | 5 | 0.1 | 0 | 27 | -- | C | INCO[10] |
| Ni-Cr-Cu-Mo#2 | 402 | 2370 | 0.2 | 3 | 0 | -- | P | INCO[10] |
| Ni-Cr-Cu-Mo#2 | 403 | 6780 | <0.1 | 0 | 0 | -- | NC | INCO[10] |
| Ni-Cr-Mo | 366 | 5 | <0.1 | 0 | 0 | -- | NC | INCO[10] |
| Ni-Cr-Mo | 402 | 2370 | <0.1 | 0 | 1 | -- | C | INCO[10] |
| Ni-Cr-Mo | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO[10] |

Table 17. (cont'd)

| Alloy | Exposure Days | Exposure Depth, Ft | Corrosion Rate, MPY(1) | Max. Pit Depth, Mils | Corrosion, Crevice, Depth, Mils | Corrosion Tunnel, Max. Lgth, Mils | Corrosion Type(2) | Source(3) |
|---|---|---|---|---|---|---|---|---|
| Ni-Cr-Mo-Si | 366 | 5 | <0.1 | 0 | 0 | -- | NC | INCO(10) |
| Ni-Cr-Mo-Si | 402 | 2370 | <0.1 | 0 | 0 | -- | NC | INCO(10) |
| Ni-Cr-Mo-Si | 403 | 6780 | <0.1 | 0 | 0 | -- | NC | INCO(10) |
| 18Cr-14Mn-0.5N | 366 | 5 | 2.6 | 50(PR) | 50(PR) | -- | C,P | INCO(10) |
| 18Cr-14Mn-0.5N | 402 | 2370 | 1.1 | 0 | 62(PR) | -- | C | INCO(10) |
| 18Cr-14Mn-0.5N | 402 | 2370 | 0.8 | 115(PR) | 0 | 2000 | T,P | NCEL |
| 18Cr-14Mn-0.5N | 403 | 6780 | <0.1 | 0 | I | -- | C | INCO(10) |
| 18Cr-14Mn-0.5N | 403 | 6780 | 0.5 | 115(PR) | 0 | 2750 | T,P | NCEL |
| 18Cr-14Mn-0.5N | 588 | 5 | 1.6 | 0 | 34 | 2900(PR) | C,T | NCEL |
| 18Cr-14Mn-0.5N | 608 | 5 | 1.8 | 0 | 115(PR) | 600(PR) | C,T | NCEL |

1. MPY - Mils penetration per year calculated from weight loss
2. Symbols for types of corrosion:
   - C - Crevice
   - E - Edge
   - NC - No visible corrosion
   - P - Pitting
   - PR - Perforated
   - SL - Slight
   - T - Tunnel
3. Numbers refer to references at end of paper

Table 18. Chemical Composition of Titanium Alloys

| Material | C | Fe | N | H | O | Al | V | Cr | Other | Ti[1] | Source[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Titanium | 0.1 | -- | 0.02 | -- | -- | -- | -- | -- | -- | Rem. | INCO[10] |
| 75A | 0.027 | 0.20 | 0.026 | 0.004 | -- | -- | -- | -- | -- | Rem. | NCEL |
| 75A | 0.025 | 0.14 | 0.017 | 0.003 | 0.30 | -- | -- | -- | -- | Rem. | NCEL |
| Ti-0.15 Pd | 0.022 | 0.06 | 0.010 | 0.004 | 0.15 | -- | -- | -- | Pd-0.14 | Rem. | NCEL |
| 5 Al-2.5 Sn | 0.024 | 0.32 | 0.013 | 0.008 | 0.18 | 5.1 | -- | -- | Sn-2.4 | Rem. | NCEL |
| 7 Al-2 Cb-1 Ta | 0.023 | 0.06 | 0.006 | 0.002 | 0.07 | 7.0 | -- | -- | Cb-2.0<br>Ta-1.0 | Rem. | NCEL |
| 6 Al-4 V | 0.023 | 0.12 | 0.014 | 0.007 | 0.11 | 5.9 | 4.0 | -- | -- | Rem. | NCEL |
| 13 V-11 Cr-3 Al | 0.021 | 0.14 | 0.027 | 0.010 | 0.12 | 3.0 | 13.6 | 10.9 | -- | Rem. | NCEL |

1. Rem. = Remainder
2. Numbers indicate references at end of paper.

Table 19. Corrosion of Titanium Alloys in Sea Water

| Alloys | Exposure Days | Exposure Depth, Ft | Corrosion Rate, MPY(1) | Corrosion Type(2) | Source(3) |
|---|---|---|---|---|---|
| Titanium | 366 | 5 | <0.1 | NC | INCO(10) |
| Titanium | 402 | 2370 | <0.1 | NC | INCO(10) |
| Titanium | 403 | 6780 | <0.1 | NC | INCO(10) |
| 75A | 398 | 5 | 0.0 | NC | NCEL |
| 75A | 402 | 2370 | 0.0 | NC | NCEL |
| 75A | 403 | 6780 | 0.0 | NC | NCEL |
| 75A | 540 | 5 | 0.0 | NC | NCEL |
| 75A | 588 | 5 | 0.0 | NC | NCEL |
| 75A(4) | 398 | 5 | 0.0 | NC | NCEL |
| 75A(4) | 540 | 5 | 0.0 | NC | NCEL |
| 75A(4) | 588 | 5 | 0.0 | NC | NCEL |
| 75A(5) | 398 | 5 | 0.0 | NC | NCEL |
| 75A(5) | 540 | 5 | 0.0 | NC | NCEL |
| 75A(5) | 588 | 5 | 0.0 | NC | NCEL |
| Ti-0.15Pd(4) | 398 | 5 | 0.0 | NC | NCEL |
| Ti-0.15Pd(4) | 540 | 5 | 0.0 | NC | NCEL |
| Ti-0.15Pd(4) | 588 | 5 | 0.0 | NC | NCEL |
| Ti-0.15Pd(5) | 398 | 5 | 0.0 | NC | NCEL |
| Ti-0.15Pd(5) | 540 | 5 | 0.0 | NC | NCEL |
| Ti-0.15Pd(5) | 588 | 5 | 0.0 | NC | NCEL |
| 5Al-2.5Sn(4) | 398 | 5 | 0.0 | NC | NCEL |
| 5Al-2.5Sn(4) | 402 | 2370 | 0.0 | NC | NCEL |
| 5Al-2.5Sn(4) | 403 | 6780 | 0.0 | NC | NCEL |
| 5Al-2.5Sn(4) | 540 | 5 | 0.0 | NC | NCEL |
| 5Al-2.5Sn(4) | 588 | 5 | 0.0 | NC | NCEL |

Table 19. (cont'd)

| Alloy | Exposure | | Corrosion Rate, MPY(1) | Corrosion Type(2) | Source(3) |
|---|---|---|---|---|---|
| | Days | Depth, Ft | | | |
| 5Al-2.5Sn(5) | 398 | 5 | 0.0 | NC | NCEL |
| 5Al-2.5Sn(5) | 402 | 2370 | 0.0 | NC | NCEL |
| 5Al-2.5Sn(5) | 403 | 6780 | 0.0 | NC | NCEL |
| 5Al-2.5Sn(5) | 540 | 5 | 0.0 | NC | NCEL |
| 6Al-4V | 398 | 5 | 0.0 | NC | NCEL |
| 6Al-4V | 402 | 2370 | 0.0 | NC | NCEL |
| 6Al-4V | 403 | 6780 | 0.0 | NC | NCEL |
| 6Al-4V | 540 | 5 | 0.0 | NC | NCEL |
| 6Al-4V(4) | 398 | 5 | 0.0 | NC | NCEL |
| 6Al-4V(4) | 402 | 2350 | 0.0 | NC | NCEL |
| 6Al-4V(4) | 403 | 6780 | 0.0 | NC | NCEL |
| 6Al-4V(4) | 540 | 5 | 0.0 | NC | NCEL |
| 6Al-4V(4) | 588 | 5 | 0.0 | NC | NCEL |
| 6Al-4V(5) | 398 | 5 | 0.0 | NC | NCEL |
| 6Al-4V(5) | 402 | 2370 | 0.0 | NC | NCEL |
| 6Al-4V(5) | 403 | 6780 | 0.0 | NC | NCEL |
| 6Al-4V(5) | 540 | 5 | 0.0 | NC | NCEL |
| 6Al-4V(5) | 588 | 5 | 0.0 | NC | NCEL |
| 7Al-2Cb-1Ta(4) | 398 | 5 | 0.0 | NC | NCEL |
| 7Al-2Cb-1Ta(4) | 540 | 5 | 0.0 | NC | NCEL |
| 7Al-2Cb-1Ta(4) | 588 | 5 | 0.0 | NC | NCEL |
| 7Al-2Cb-1Ta(5) | 398 | 5 | 0.0 | NC | NCEL |
| 7Al-2Cb-1Ta(5) | 540 | 5 | 0.0 | NC | NCEL |
| 7Al-Cb-1Ta(5) | 588 | 5 | 0.0 | NC | NCEL |

Table 19. (cont'd)

| Alloy | Exposure | | Corrosion Rate, MPY(1) | Corrosion Type(2) | Source(3) |
|---|---|---|---|---|---|
| | Days | Depth, Ft | | | |
| 13V-11Cr-3Al(4) | 398 | 5 | 0.0 | SCC6 | NCEL |
| 13V-11Cr-3Al(4) | 402 | 2370 | 0.0 | NC | NCEL |
| 13V-11Cr-3Al(4) | 403 | 6780 | 0.0 | NC | NCEL |
| 13V-11Cr-3Al(4) | 540 | 5 | 0.0 | SCC12 | NCEL |
| 13V-11Cr-3Al(4) | 588 | 5 | 0.0 | SCC19 | NCEL |
| 13V-11Cr-3Al(5) | 398 | 5 | 0.0 | SCC2 | NCEL |
| 13V-11Cr-3Al(5) | 402 | 2370 | 0.0 | NC | NCEL |
| 13V-11Cr-3Al(5) | 403 | 6780 | 0.0 | NC | NCEL |
| 13V-11Cr-3Al(5) | 540 | 5 | 0.0 | SCC1 | NCEL |
| 13V-11Cr-3Al(5) | 588 | 5 | 0.0 | SCC1 | NCEL |

1. MPY - Mils penetration per year calculated from weight loss
2. Symbols for types of corrosion:
   NC - No visible corrosion
   SCC - Stress corrosion cracking, numbers indicate number of cracks
3. Numbers refer to references at end of paper
4. Three inch diameter weld
5. Transverse butt weld

Table 20. Chemical Composition of Miscellaneous Alloys, Percent by Weight

| Material | Chemical Composition | Source[1] |
|---|---|---|
| Chemical Lead | 99.9 Pb | INCO[10] |
| Antimonial Lead | 94.0 Pb, 6.0 Sb | INCO[10] |
| Tellurium Lead | 99 + Pb, 0.04 Te | INCO[10] |
| AX31B Magnesium | 96 Mg, 2.6 Al, 1.1 Zn, 0.4 Mn | INCO[10] |
| Tin | 99.9 Sn | INCO[10] |
| Zinc | 99.9 Zn, 0.09 Pb, 0.01 Fe | INCO[10] |
| Solder | 67 Pb, 33Sn | INCO[10] |
| Molybdenum | 99.9 Mo | NCEL |
| Tungsten | 99.95 W | NCEL |
| Columbium | 99.8 Cb | NCEL |
| Tantalum | 99.9 Ta, 0.010 C, 0.010 O, 0.005 N, 0.002 H | NCEL |
| Ta-60 | 88.8-91.3 Ta, 8.5-11 W | NCEL |

1. Numbers refer to references at end of paper.

Table 21. Corrosion of Miscellaneous Alloys in Sea Water

| Alloy | Exposure | | Corrosion Rate, MPY(1) | Pit Depth, Mils | | Corrosion, Depth, Mils | Corrosion, Type(2) | Source(3) |
|---|---|---|---|---|---|---|---|---|
| | Days | Depth, Feet | | Max. | Avg. | | | |
| Columbium | 364 | 5 | 0.00 | -- | -- | -- | NC | NCEL |
| Columbium | 402 | 2370 | 0.00 | -- | -- | -- | NC | NCEL |
| Columbium | 723 | 5 | 0.00 | -- | -- | -- | NC | NCEL |
| Columbium | 763 | 5 | 0.00 | -- | -- | -- | NC | NCEL |
| Lead Antimonial | 366 | 5 | 0.5 | -- | -- | -- | U | INCO |
| Lead Antimonial | 402 | 2370 | 0.3 | -- | -- | -- | U | INCO |
| Lead Antimonial | 403 | 6780 | 0.3 | -- | -- | -- | U | INCO |
| Lead Chemical | 366 | 5 | 0.5 | -- | -- | -- | U | INCO |
| Lead Chemical | 402 | 2370 | 0.2 | -- | -- | -- | U | INCO |
| Lead Chemical | 403 | 6780 | 0.2 | -- | -- | -- | U | INCO |
| Lead Tellurium | 366 | 5 | 0.5 | -- | -- | -- | U | INCO |
| Lead Tellurium | 402 | 2370 | 0.2 | -- | -- | -- | U | INCO |
| Lead Tellurium | 403 | 6780 | 0.3 | -- | -- | -- | U | INCO |
| Magnesium, FS-1 | 366 | 5 | >20.0 | PR | -- | -- | (4) | INCO |
| Magnesium, FS-1 | 402 | 2370 | >15.0 | PR | -- | -- | (4) | INCO |
| Magnesium, FS-1 | 403 | 6780 | >20.0 | PR | -- | -- | (4) | INCO |
| Molybdenum | 364 | 5 | 1.1 | 0 | 0 | 0 | UET | NCEL |
| Molybdenum | 402 | 2370 | 0.8 | -- | -- | 9 | U,C | NCEL |
| Molybdenum | 723 | 5 | 1.1 | -- | -- | -- | G | NCEL |
| Molybdenum | 763 | 5 | 1.0 | -- | -- | 6 | C,G | NCEL |
| Tantalum | 364 | 5 | 0.00 | -- | -- | -- | NC | NCEL |
| Tantalum | 402 | 2370 | 0.00 | -- | -- | -- | NC | NCEL |
| Tantalum | 723 | 5 | 0.00 | -- | -- | -- | NC | NCEL |
| Tantalum | 763 | 5 | 0.00 | -- | -- | -- | NC | NCEL |
| Ta60 | 364 | 5 | 0.00 | -- | -- | -- | NC | NCEL |
| Ta60 | 723 | 5 | 0.00 | -- | -- | -- | NC | NCEL |
| Ta60 | 763 | 5 | 0.00 | -- | -- | -- | NC | NCEL |

Table 21. (con't'd)

| Alloy | Exposure Days | Exposure Depth, Feet | Corrosion Rate, MPY(1) | Pit Depth, Mils Max. | Pit Depth, Mils Avg. | Crevice Corrosion, Depth, Mils | Corrosion, Type(2) | Source(3) |
|---|---|---|---|---|---|---|---|---|
| Tin | 366 | 5 | 2.8 | 30(PR) | -- | 30(PR) | P,C | INCO(10) |
| Tin | 402 | 2370 | 1.6 | 9.0 | -- | -- | P | INCO(10) |
| Tin | 403 | 6780 | 1.4 | 17.0 | -- | -- | P | INCO(10) |
| Tungsten | 364 | 5 | 3.2 | -- | 0 | 0 | U | NCEL |
| Tungsten | 402 | 2370 | 0.5 | -- | -- | 0 | U | NCEL |
| Tungsten | 723 | 5 | 3.7 | -- | -- | 0 | G | NCEL |
| Tungsten | 763 | 5 | 4.0 | -- | -- | 0 | G | NCEL |
| Zinc | 366 | 5 | 2.8 | 10.0 | -- | -- | P | INCO(10) |
| Zinc | 402 | 2370 | 2.8 | -- | -- | -- | G | INCO(10) |
| Ainc | 403 | 6780 | 5.9 | 30(PR) | -- | -- | CR | INCO(10) |
| 67Pb-33Sn, Solder | 366 | 5 | 1.5 | -- | -- | -- | G | INCO(10) |
| 67Pb-33Sn, Solder | 402 | 2370 | 0.6 | -- | -- | -- | U | INCO(10) |
| 67Pb-33Sn, Solder | 403 | 6780 | 1.1 | -- | -- | -- | U | INCO(10) |

1. MPY - Mils penetration per year calculated from weight loss.
2. Symbols for types of corrosion
   - C - Crevice
   - CR - Cratering
   - ET - Etched
   - G - General
   - NC - No visible corrosion
   - P - Pitting
   - U - Uniform
3. Numbers refer to references at end of paper.
4. Specimens completely disintegrated.

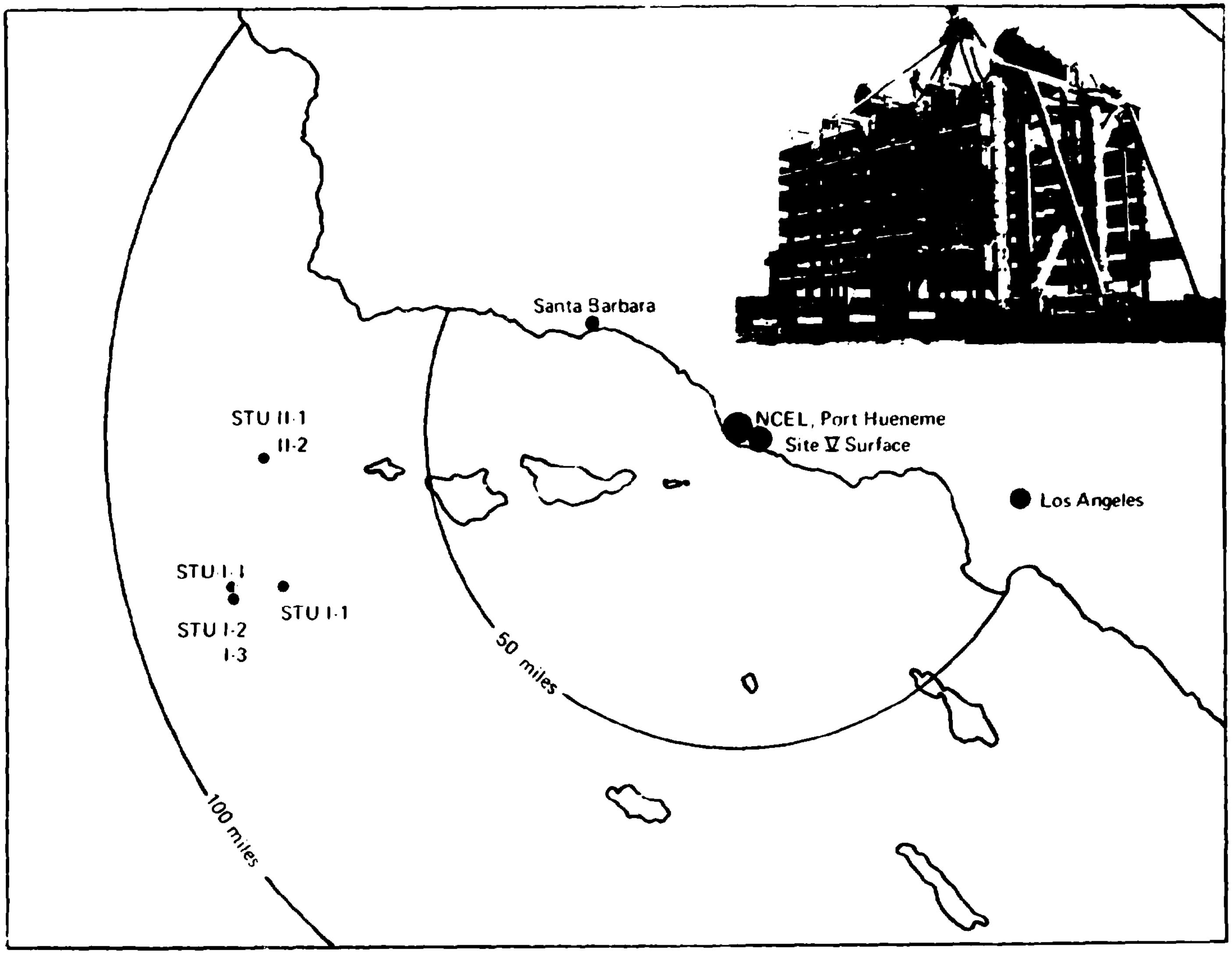


Figure 1. Area map of STU sites - STU in inset.

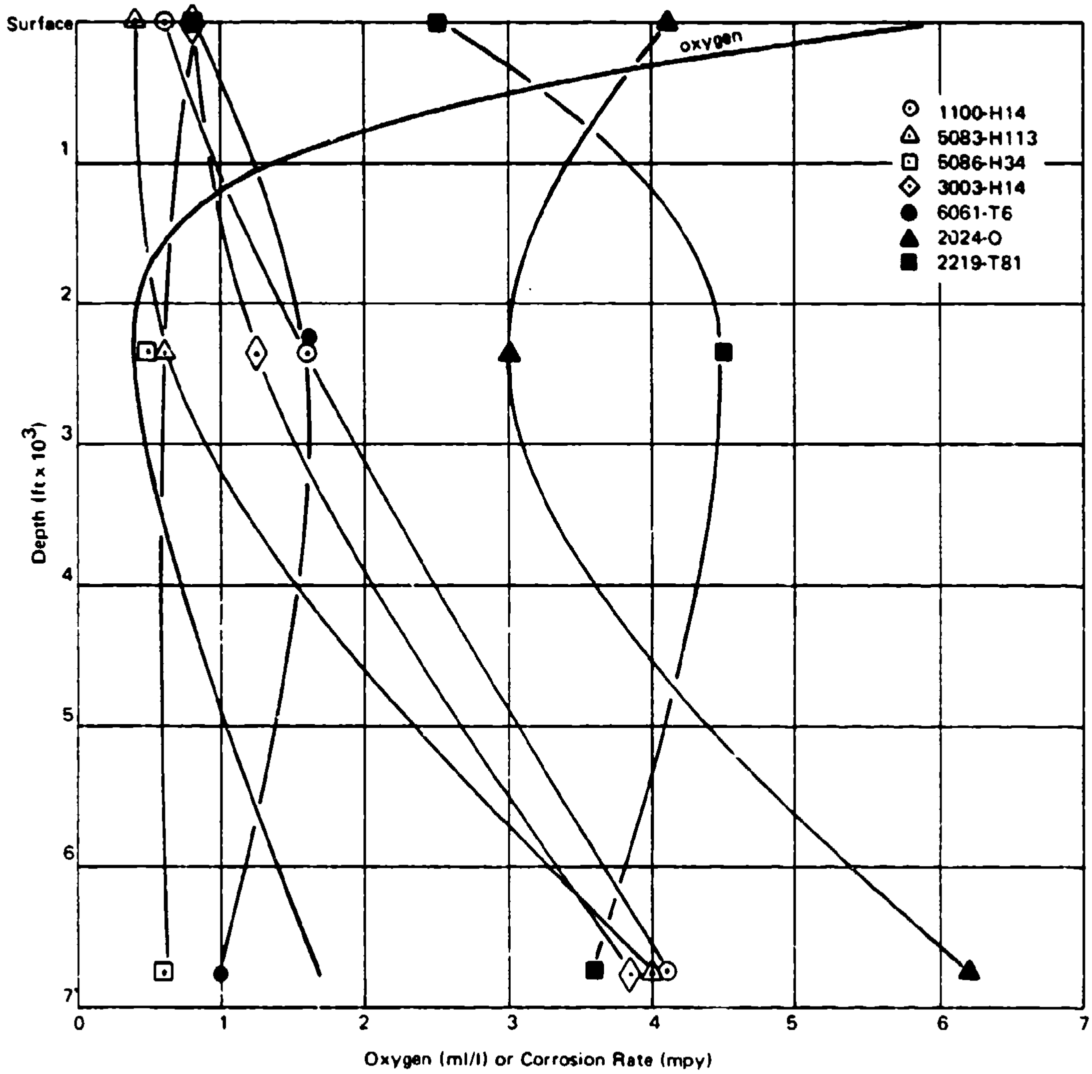


Figure 2. Corrosion rates of aluminum alloys vs depth after 1 year of exposure.

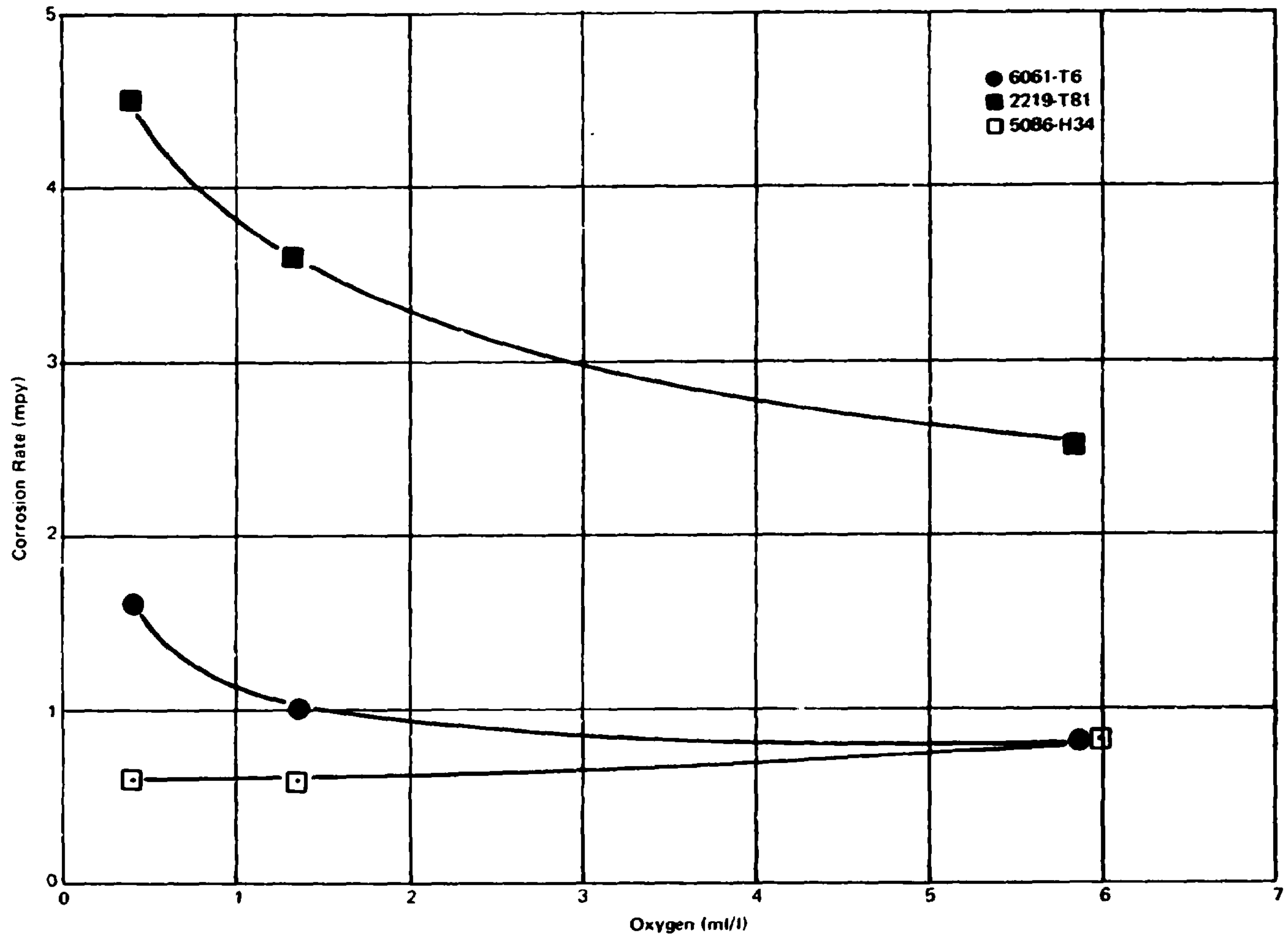


Figure 3. Corrosion rates of aluminum alloys vs oxygen content of seawater after 1 year of exposure.

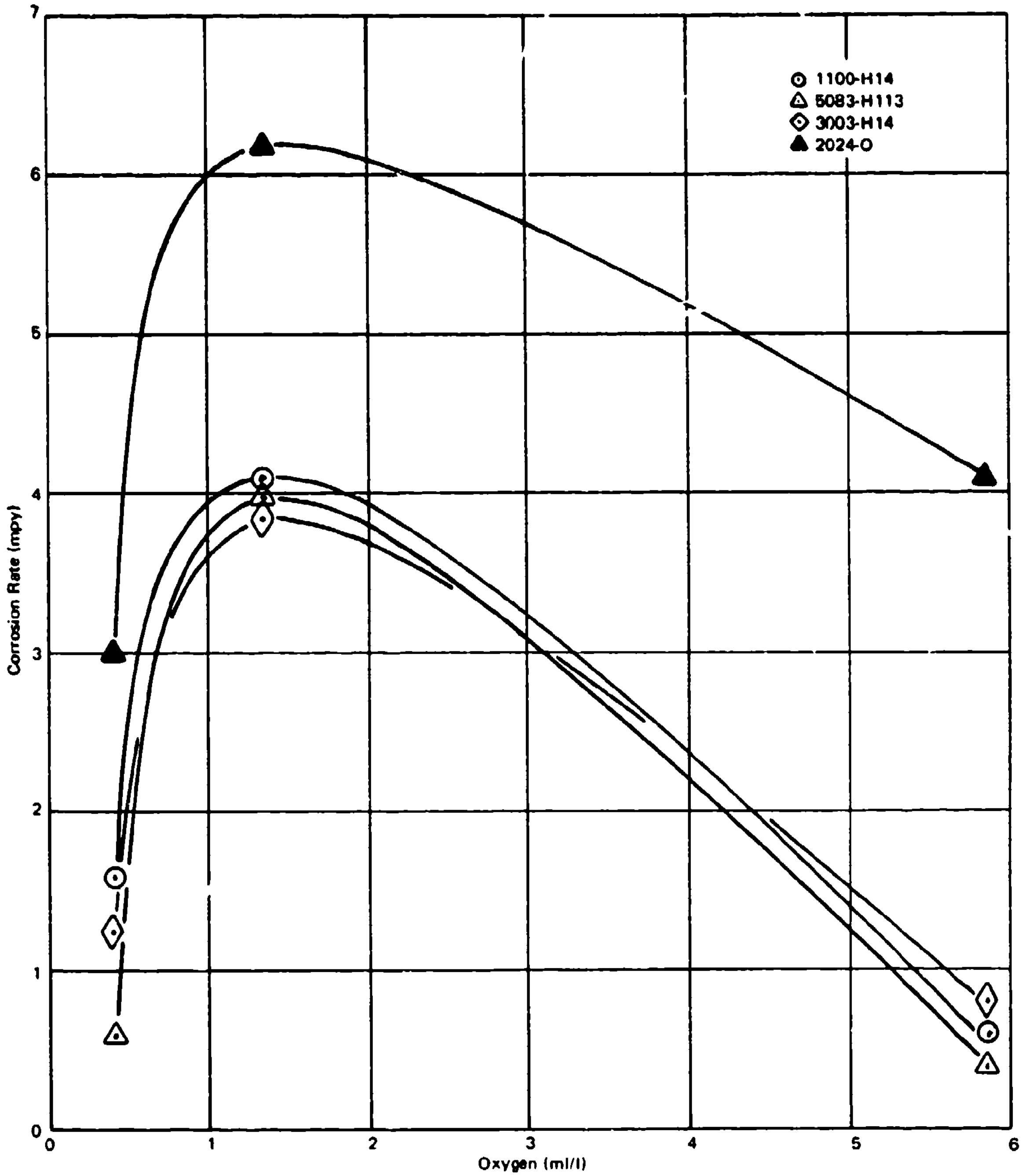


Figure 4. Corrosion rates of aluminum alloys vs oxygen content of seawater after 1 year of exposure.

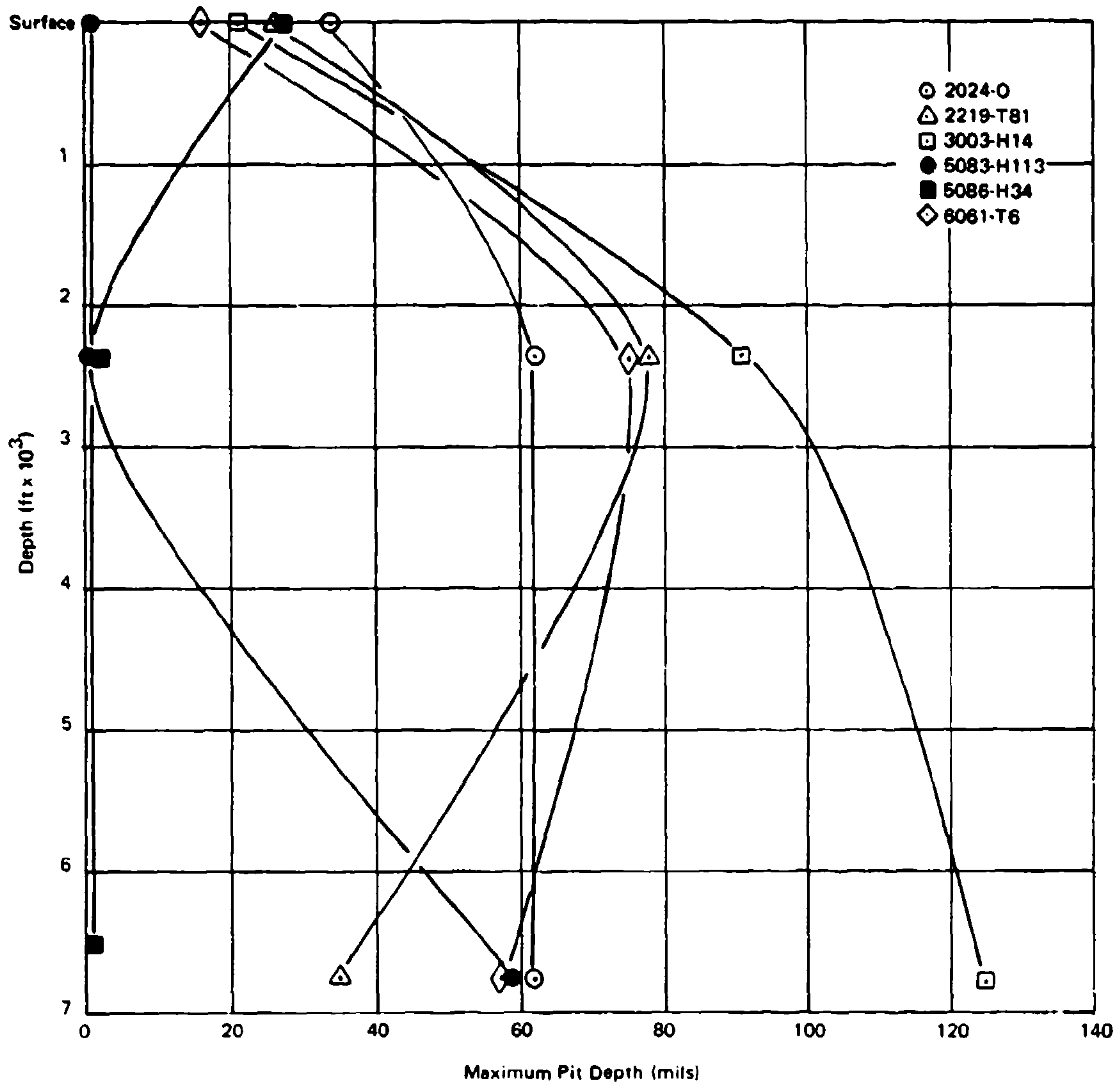


Figure 5. Maximum depths of pits of aluminum alloys vs depth after 1 year of exposure.

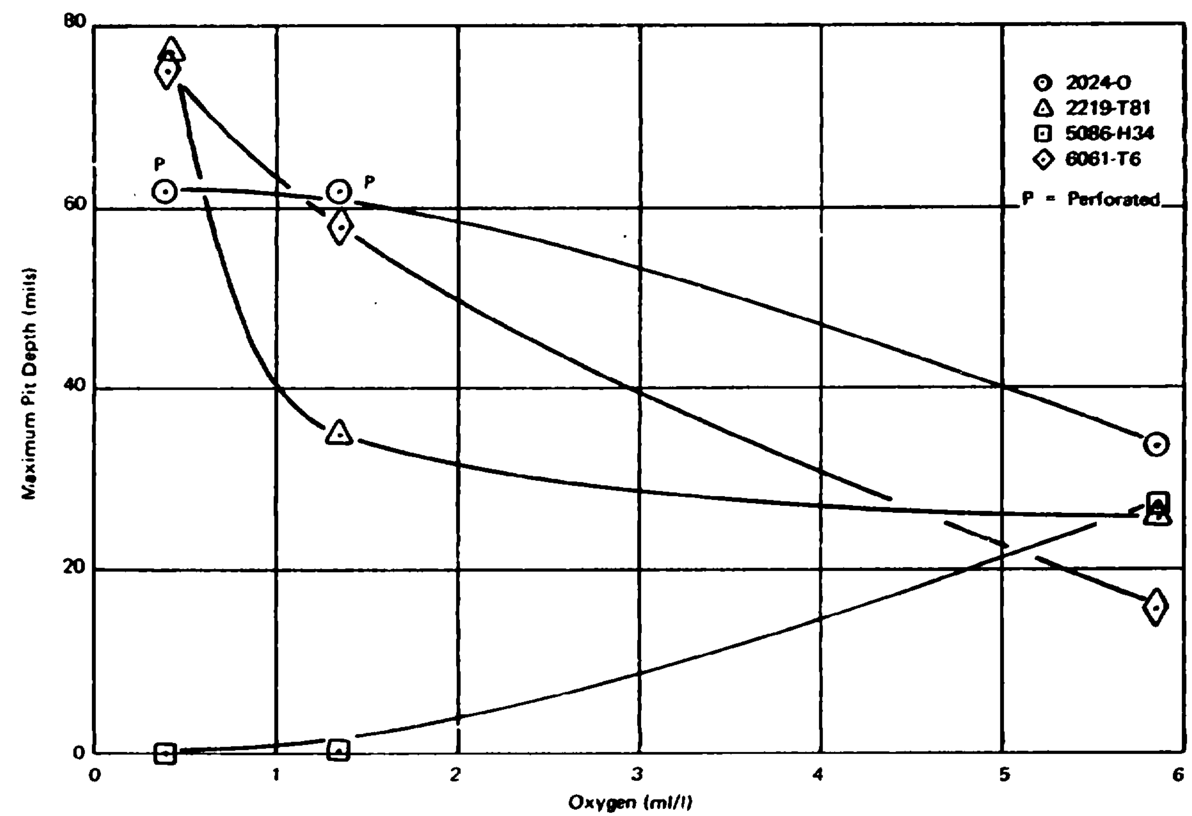


Figure 6. Maximum depths of pits of aluminum alloys vs oxygen content of seawater after 1 year of exposure.

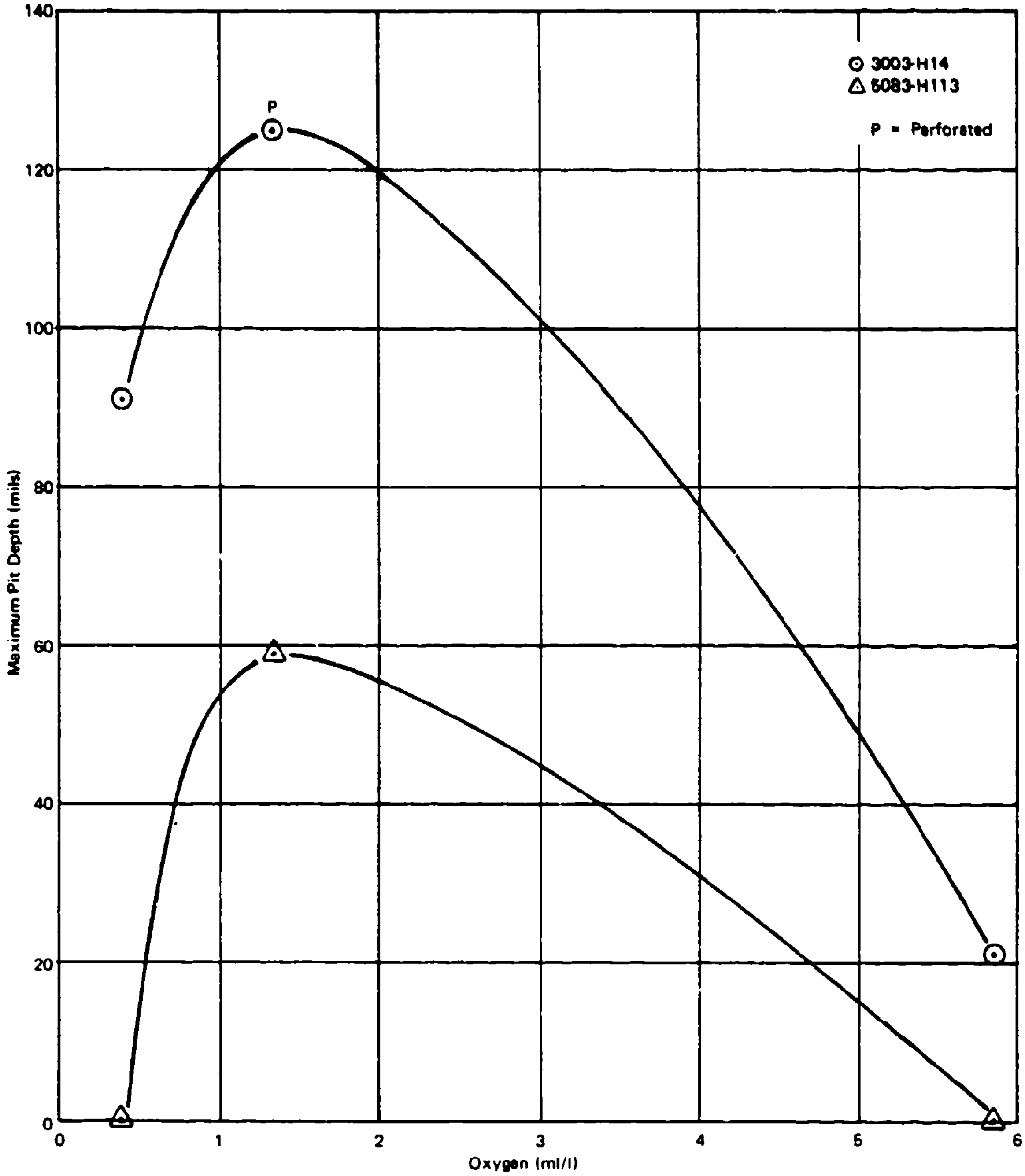


Figure 7. Maximum depths of pits of aluminum alloys vs oxygen content of seawater after 1 year of exposure.

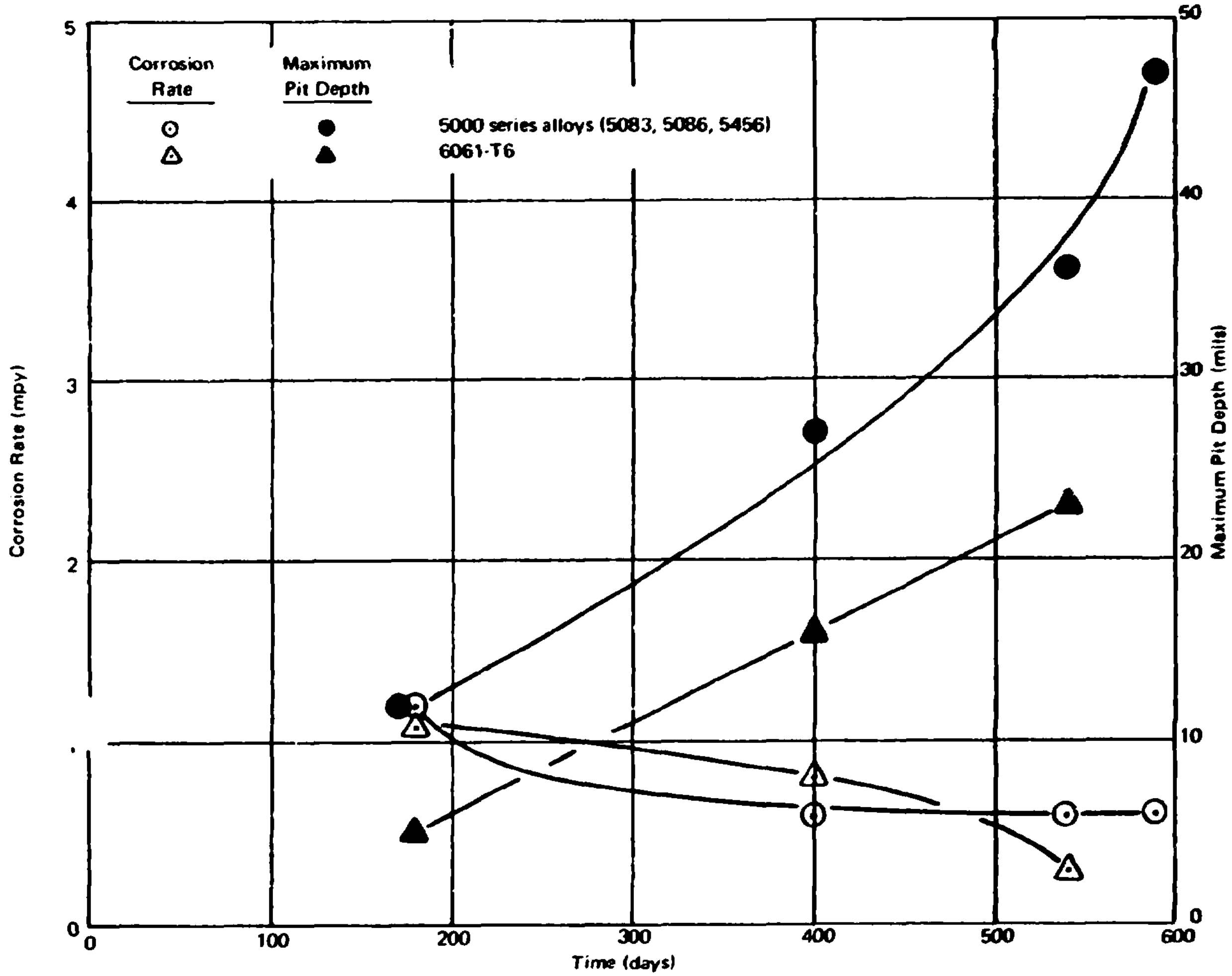


Figure 8. Corrosion rates and maximum depths of pits of aluminum alloys vs time of exposure in surface seawater.

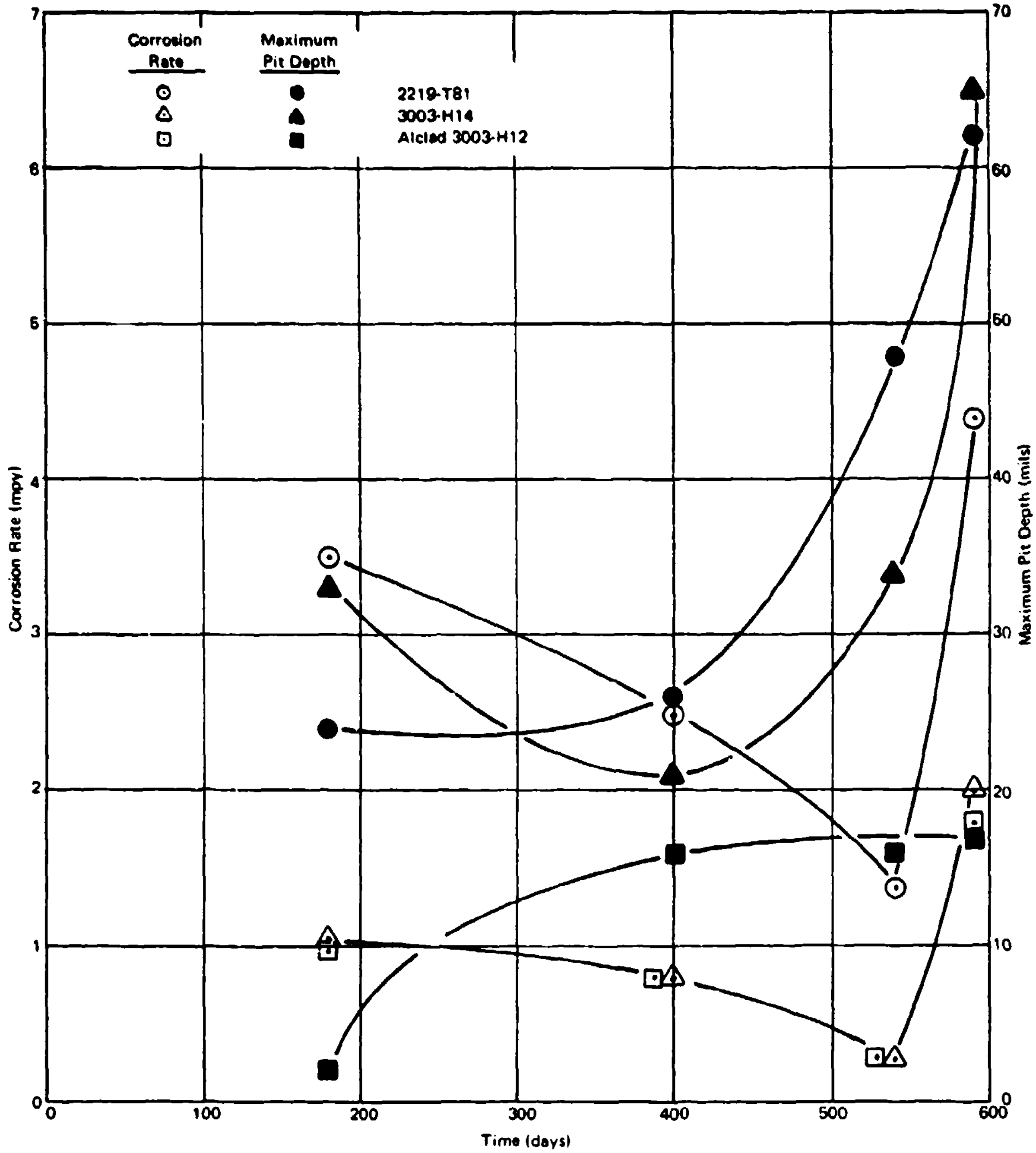


Figure 9. Corrosion rates and maximum depths of pits of aluminum alloys vs time of exposure in surface seawater.

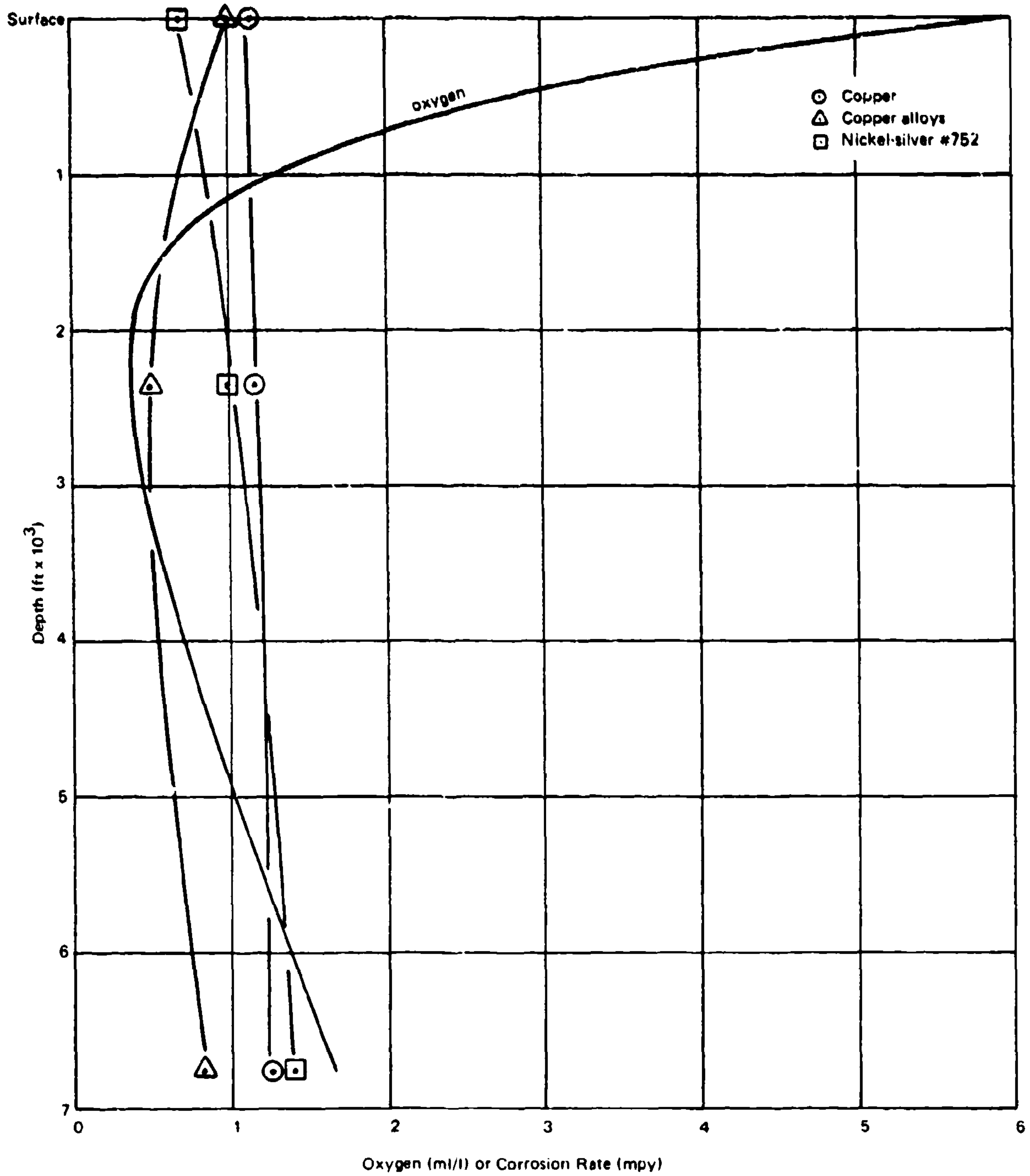


Figure 10. Corrosion of copper alloys vs depth after 1 year of exposure.

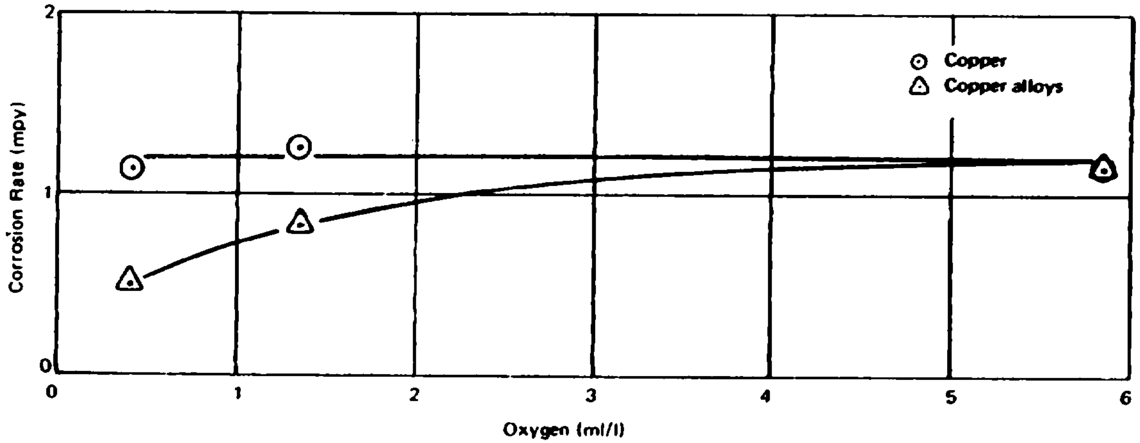


Figure 11. Corrosion of copper alloys vs oxygen content of seawater after 1 year of exposure.

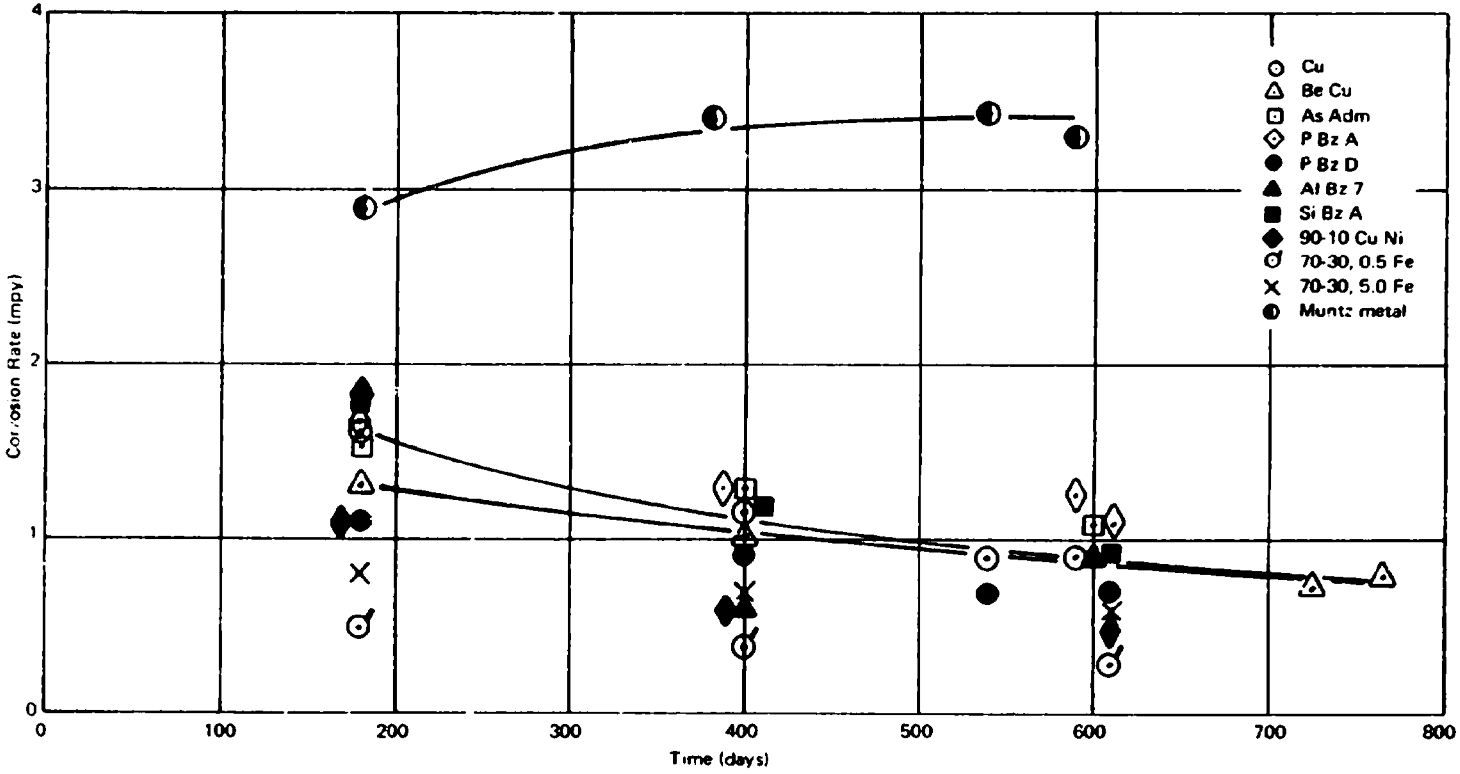


Figure 12. Corrosion of copper alloys vs time of exposure at the surface.

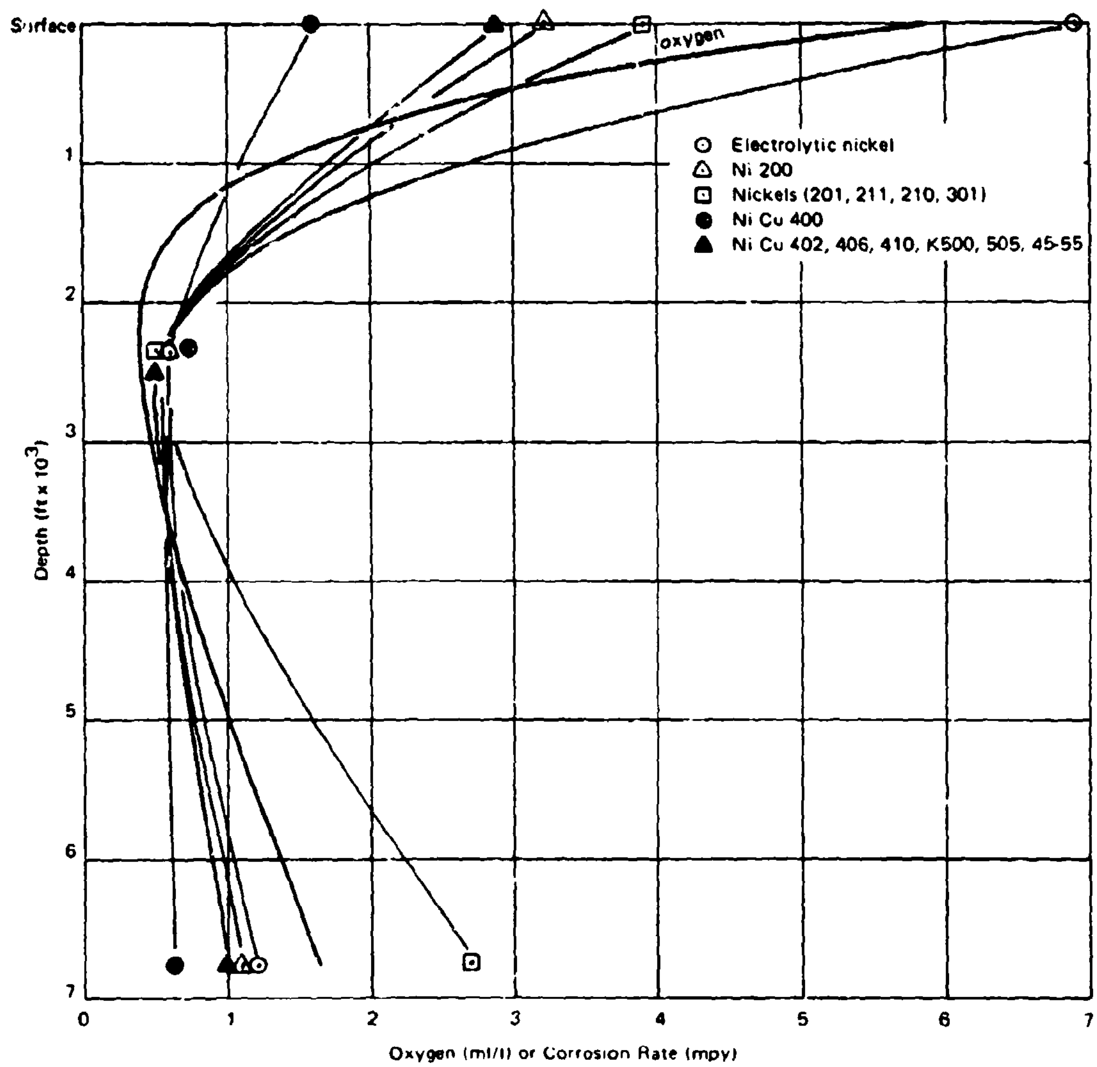


Figure 13. Corrosion of nickels and nickel-copper alloys vs depth after 1 year of exposure.

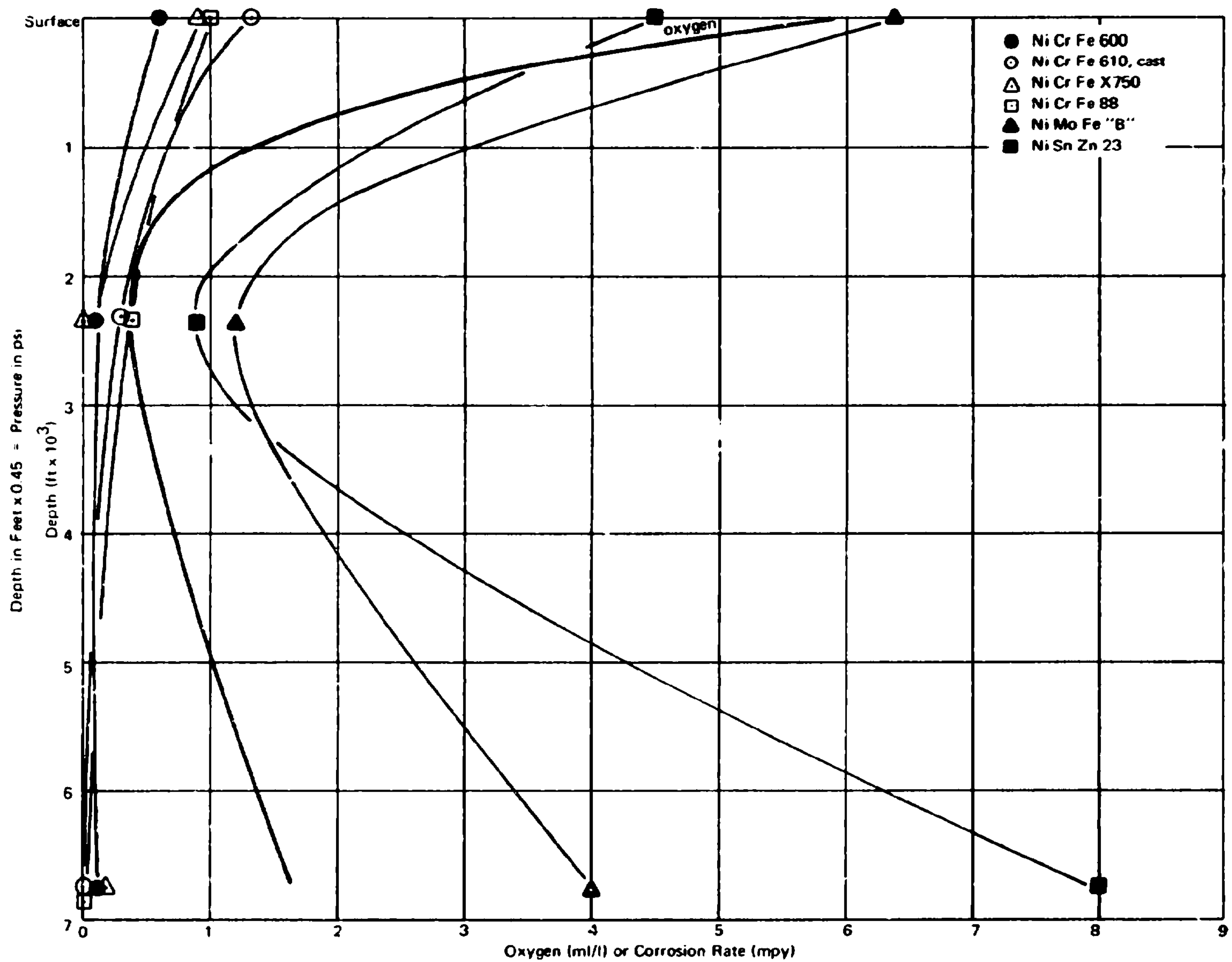


Figure 14. Corrosion of nickel alloys vs depth after 1 year of exposure.

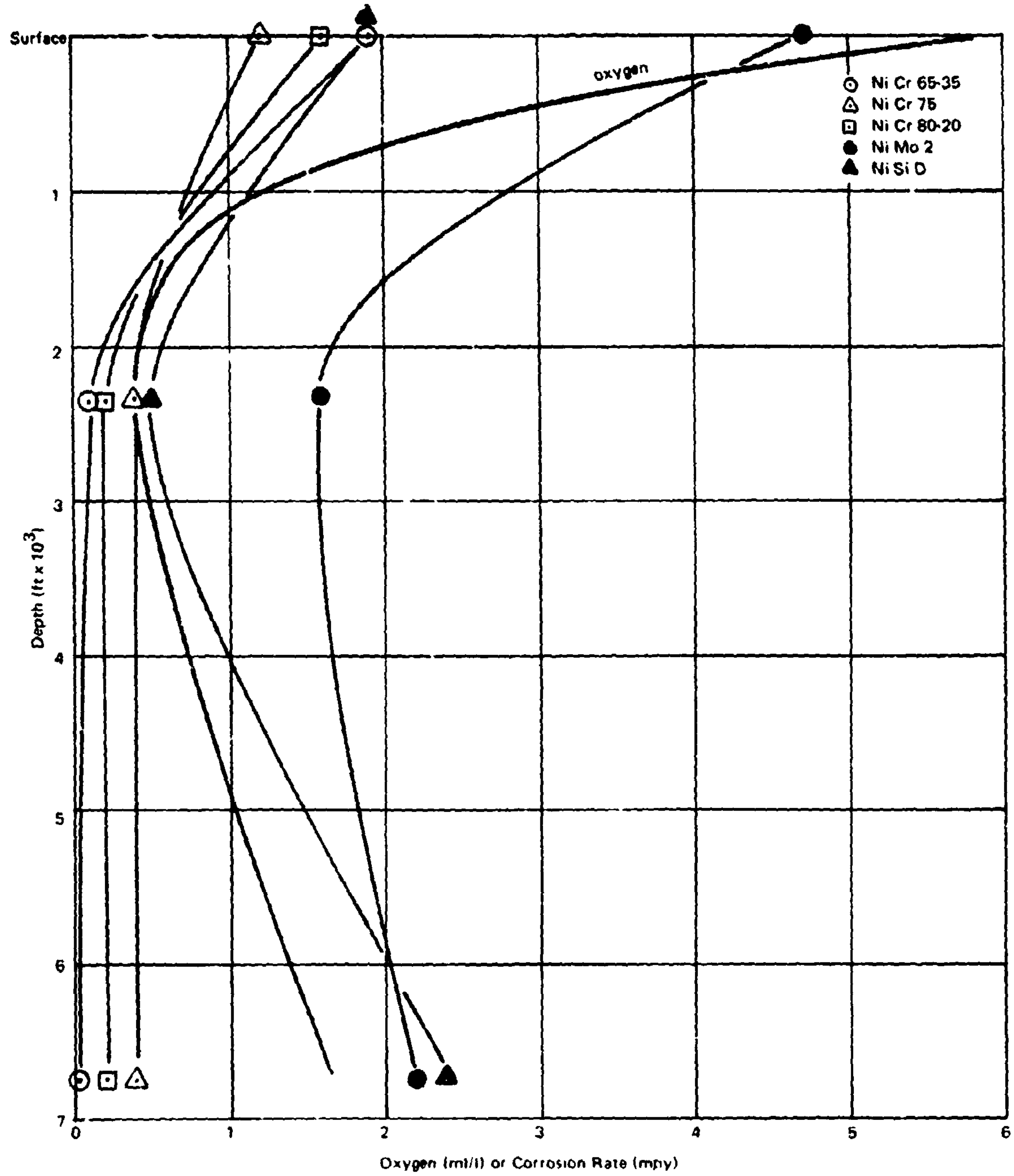


Figure 15. Corrosion of nickel alloys vs depth after 1 year of exposure.

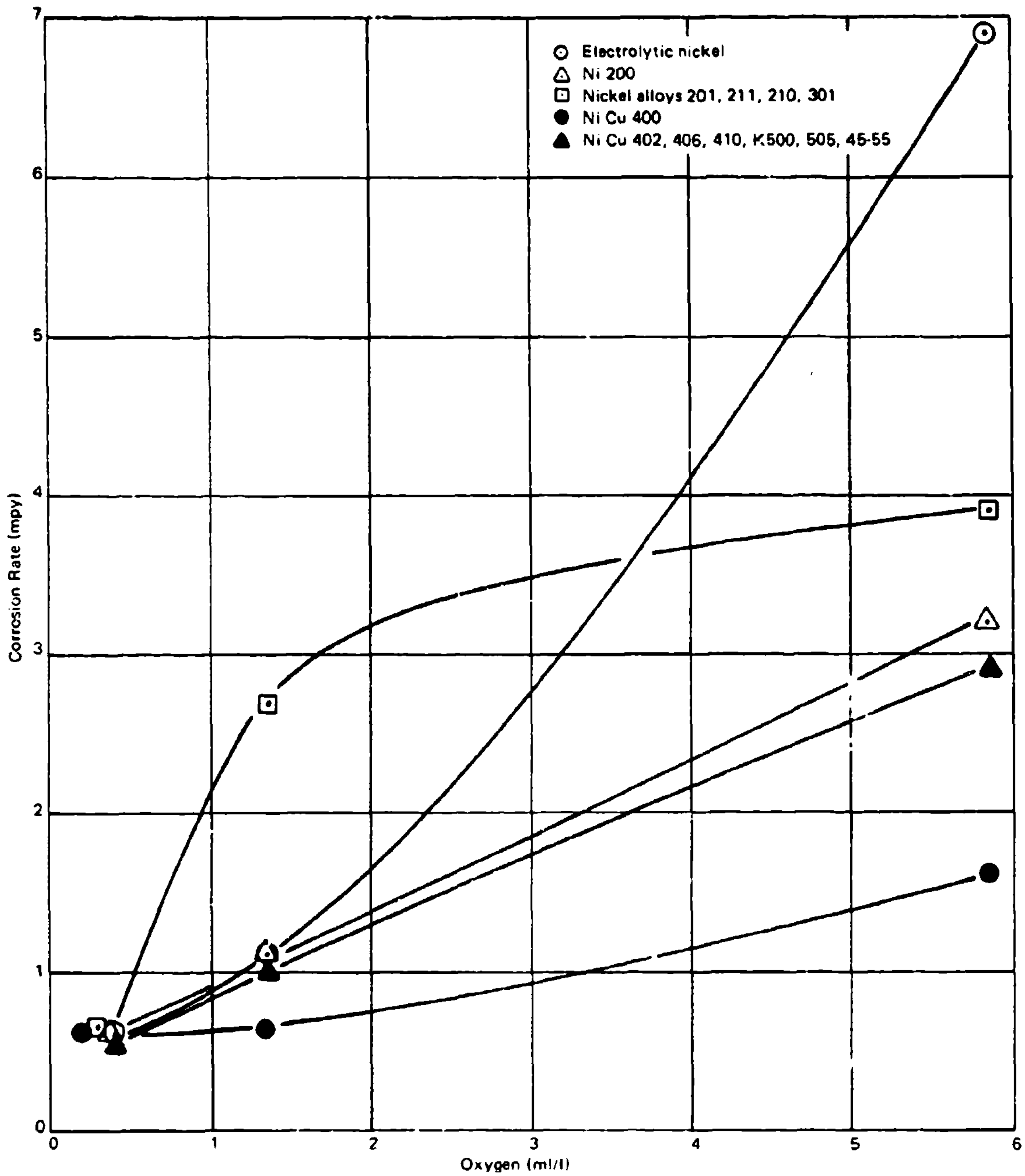


Figure 16. Corrosion of nickels and nickel-copper alloys vs oxygen content of seawater after 1 year of exposure.

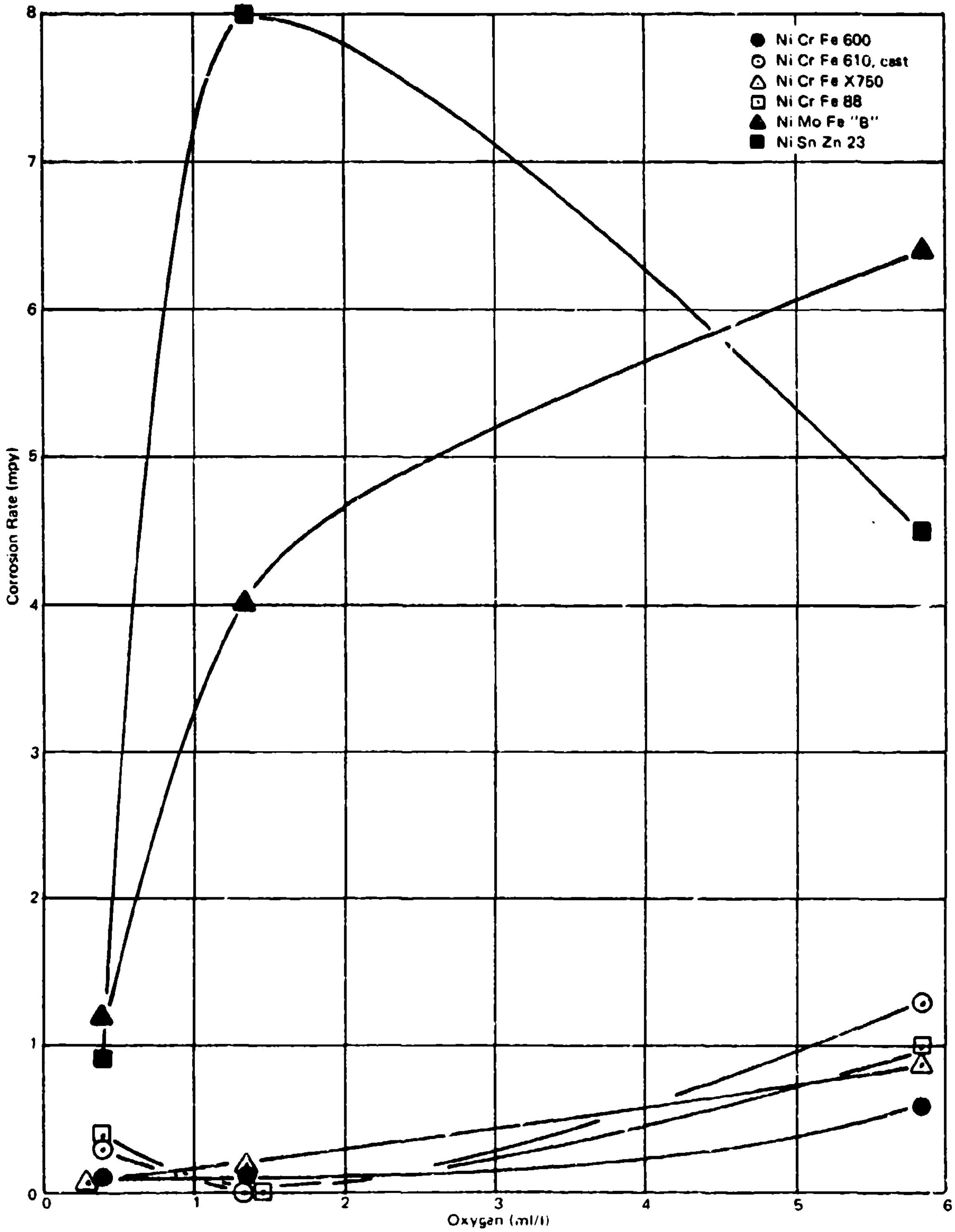


Figure 17. Corrosion of nickel alloys vs oxygen content of seawater after 1 year of exposure.

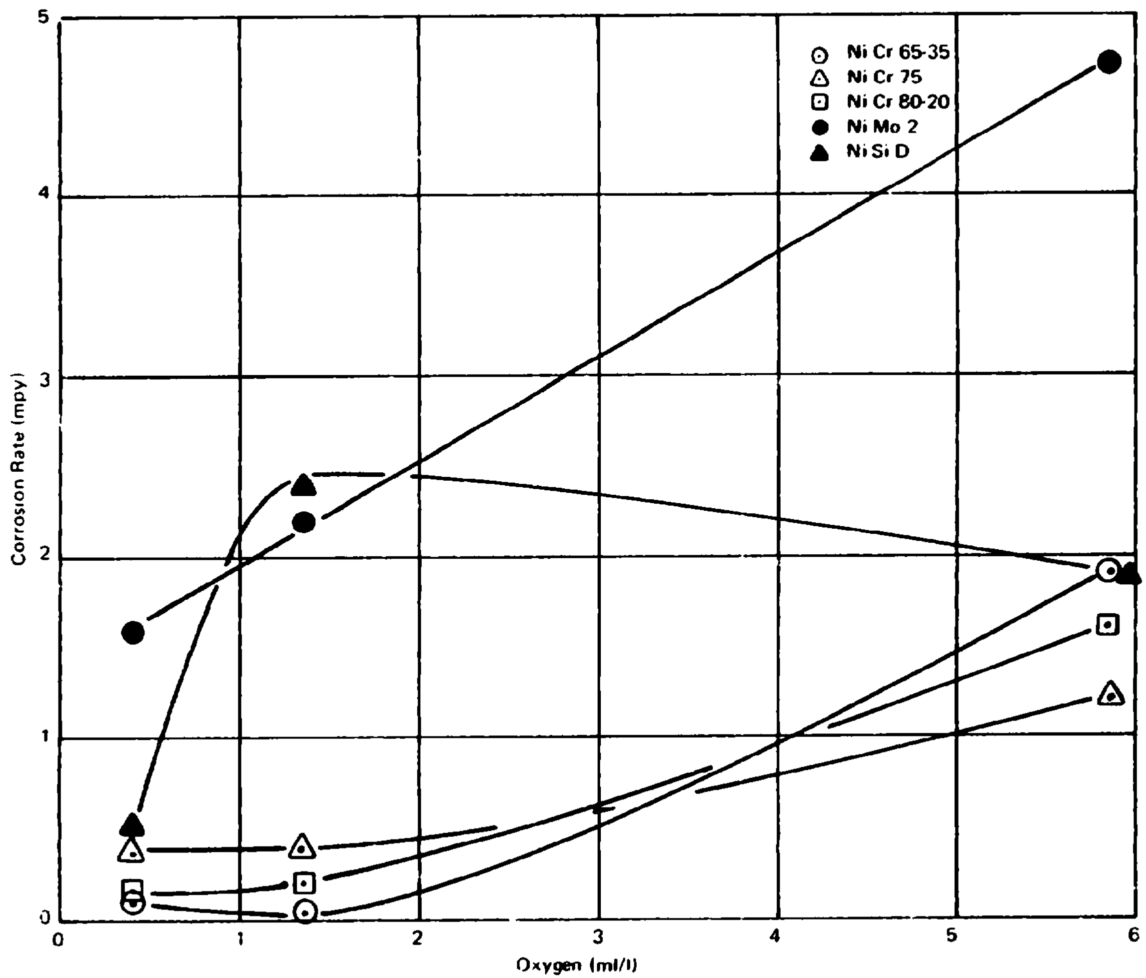


Figure 18. Corrosion of nickel alloys vs oxygen content of seawater after 1 year of exposure.

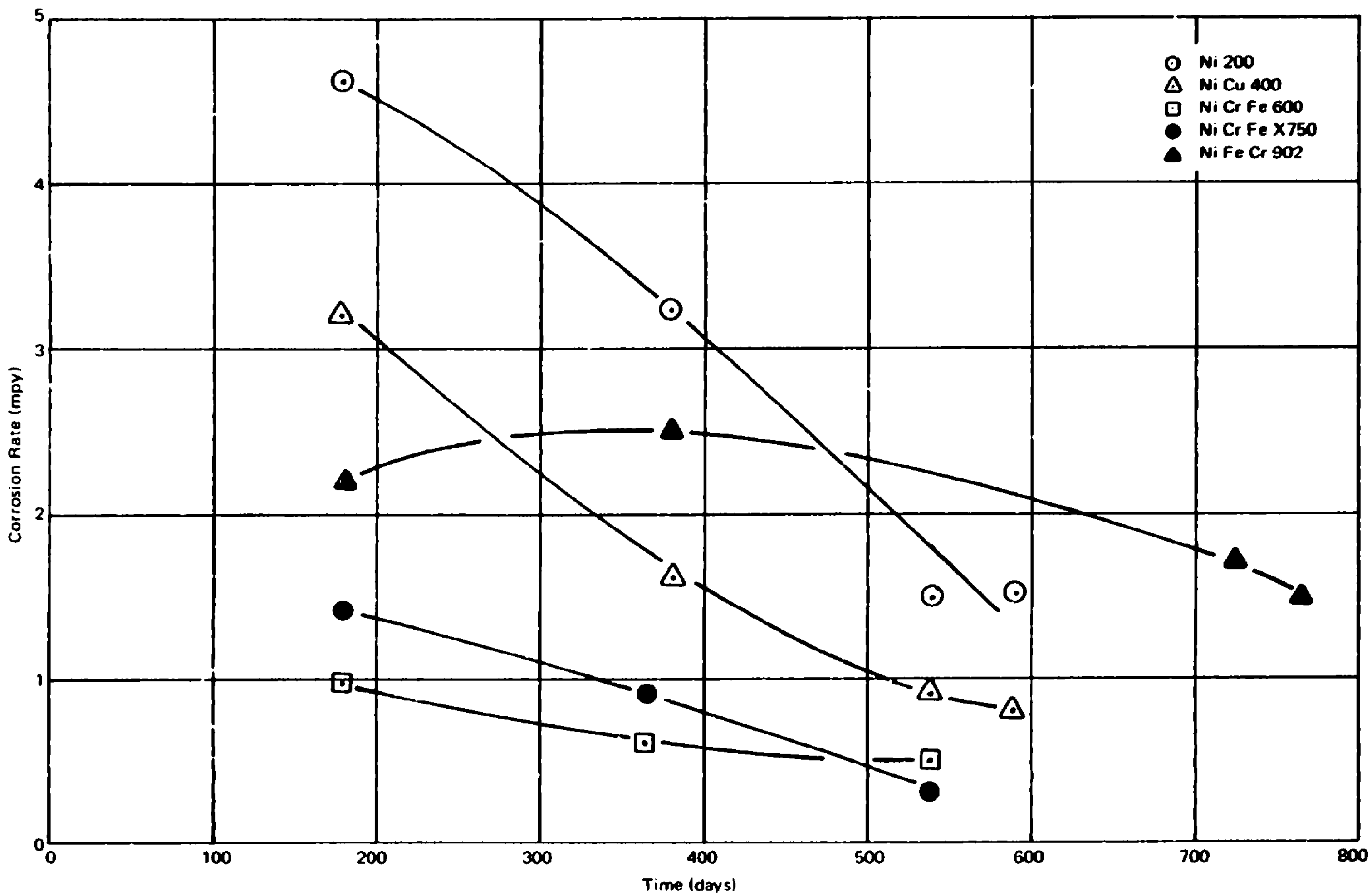


Figure 19. Corrosion of nickel alloys vs time of exposure at the surface.

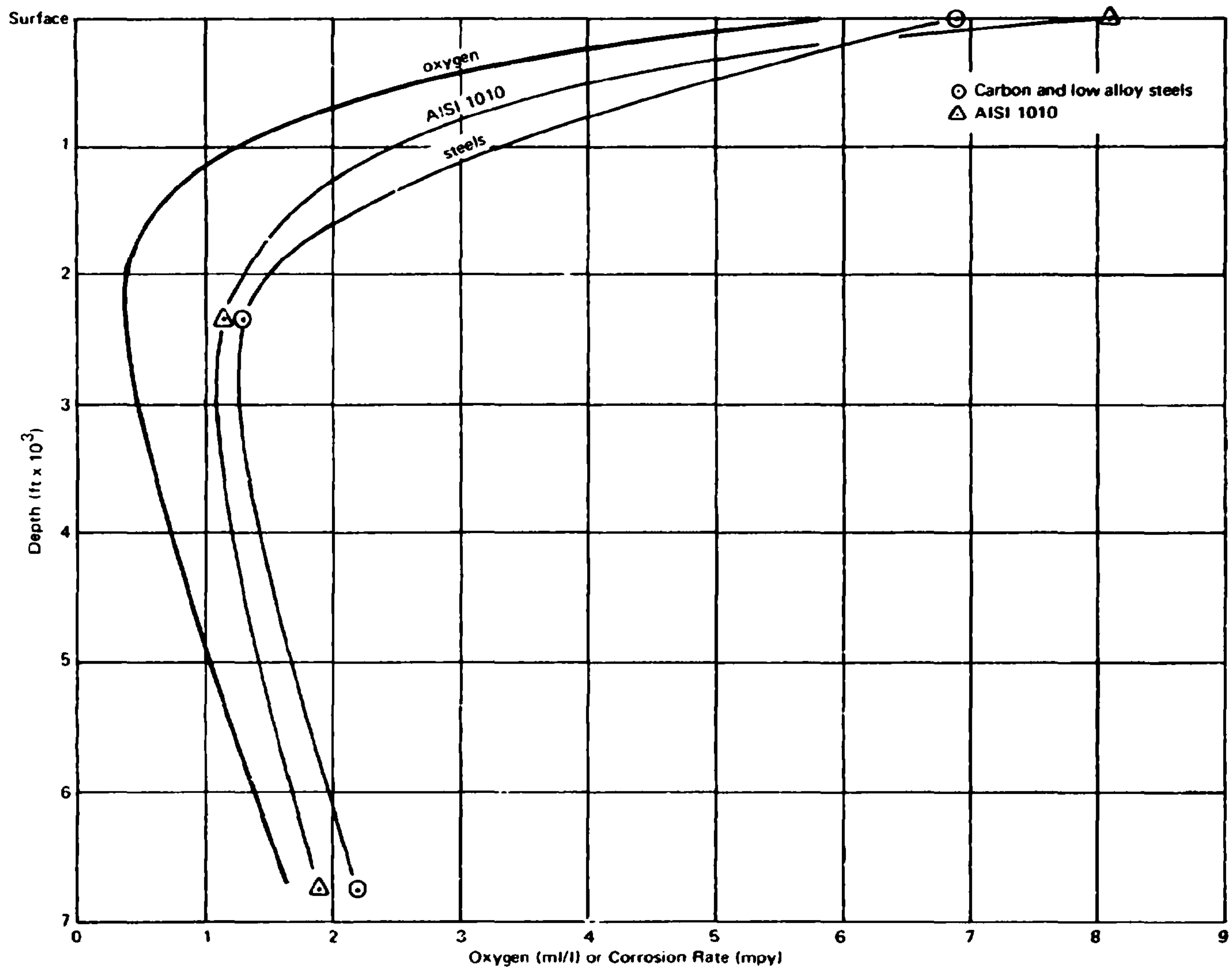


Figure 20. Corrosion of steels vs depth after 1 year of exposure.

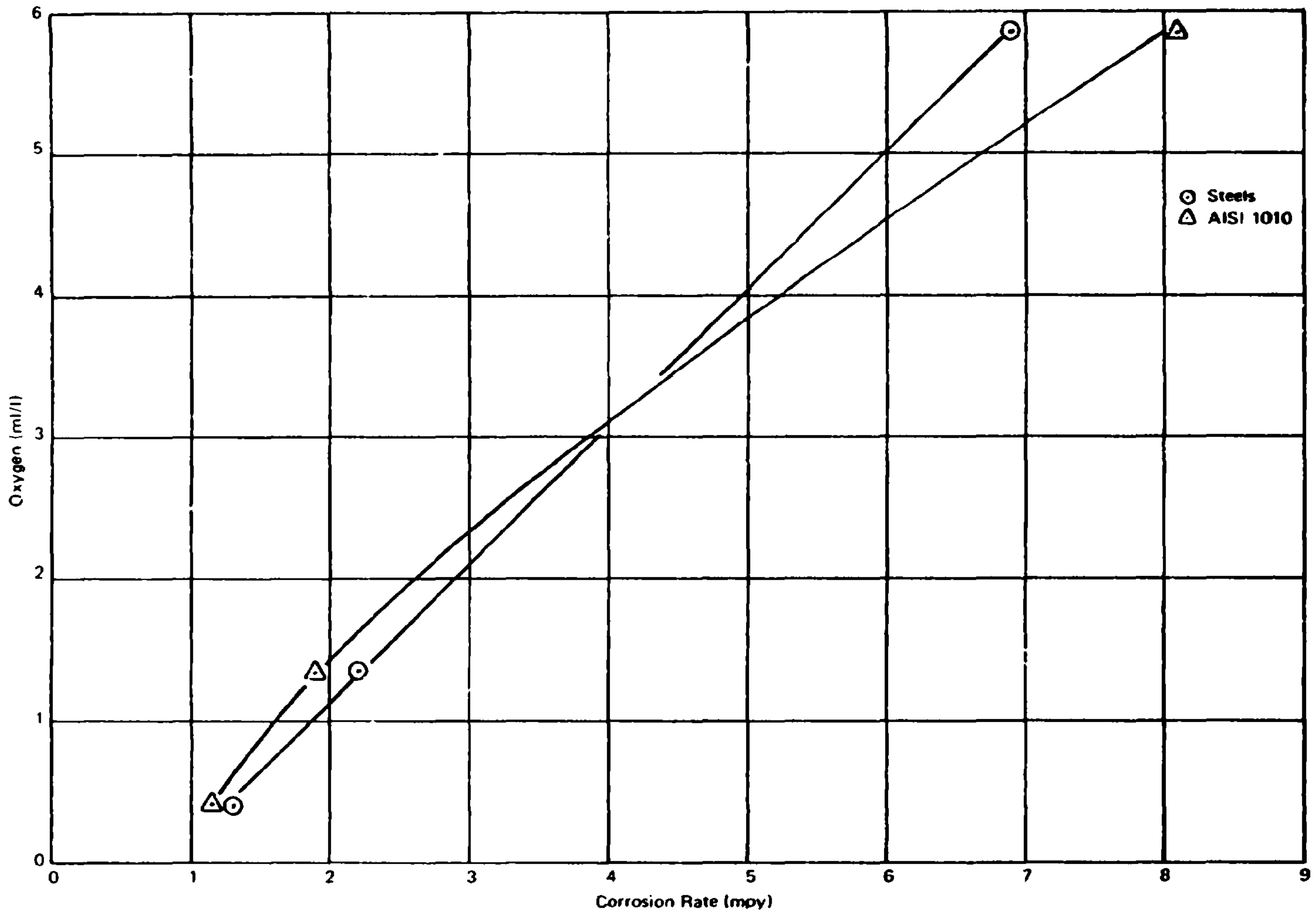


Figure 21. Corrosion of steels vs oxygen content of seawater after 1 year of exposure.

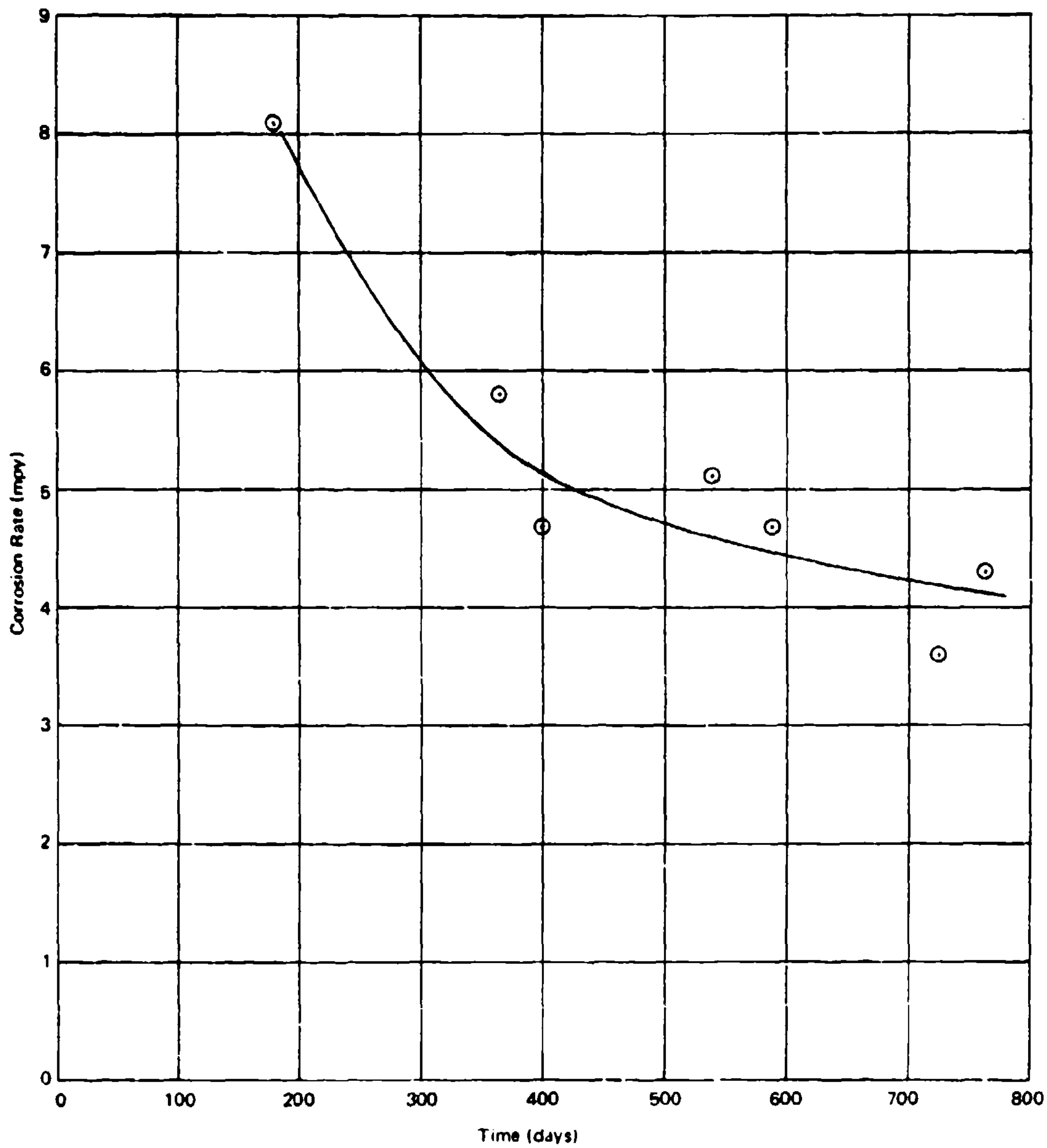


Figure 22. Corrosion of steels vs time of exposure at the surface.

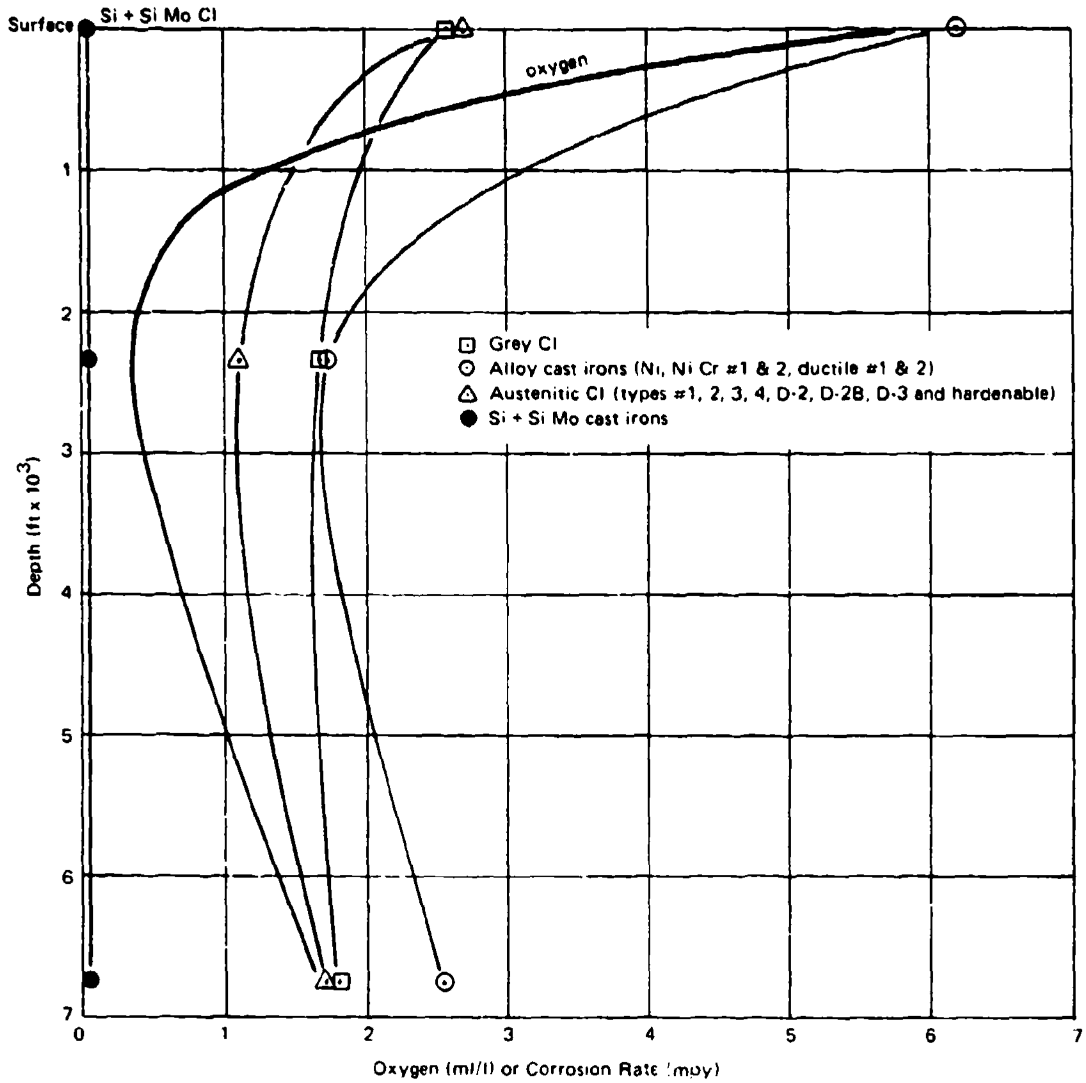


Figure 23. Corrosion of cast irons vs depth after 1 year of exposure.

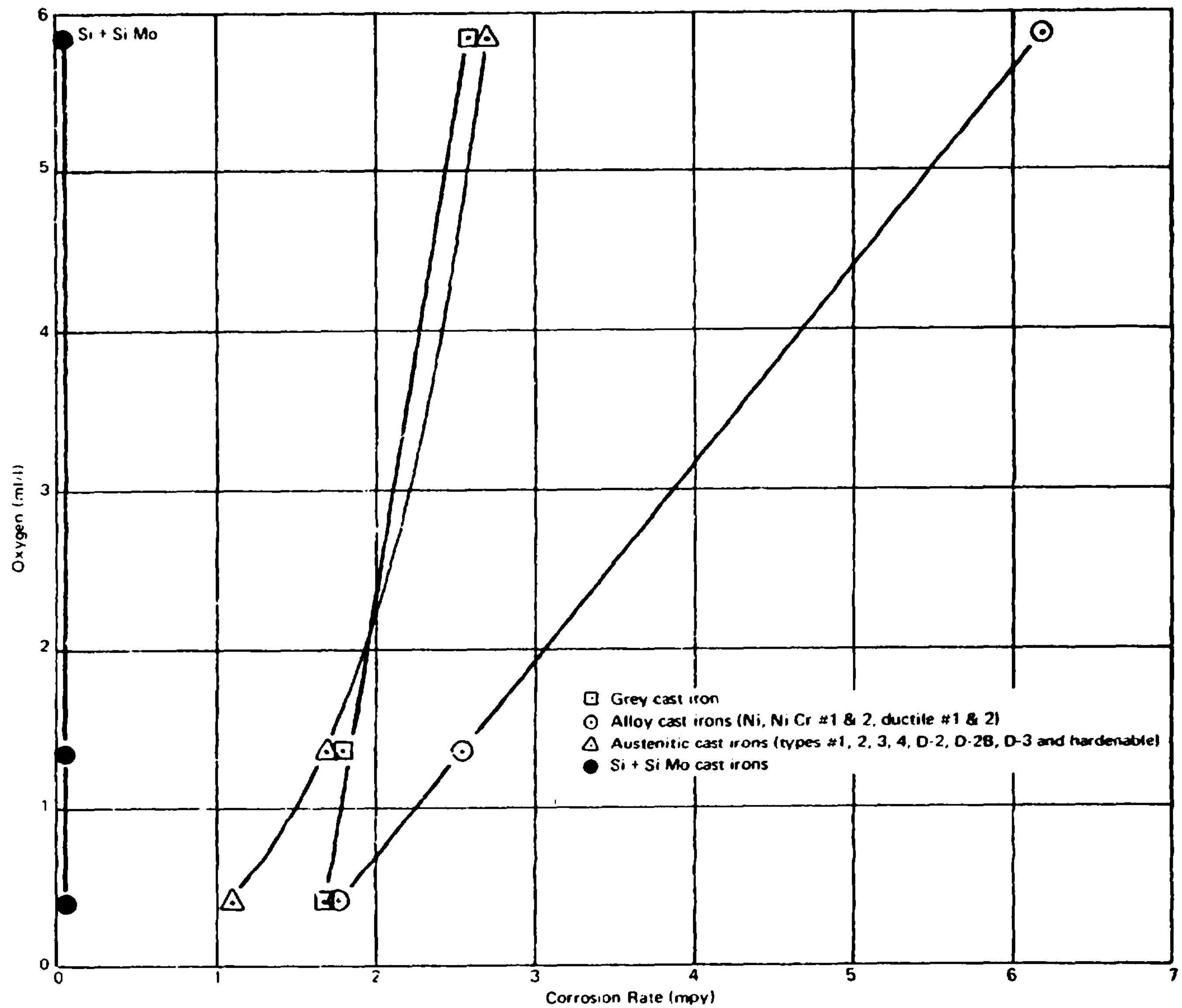


Figure 24. Corrosion of cast irons vs concentration of oxygen in seawater after 1 year of exposure.

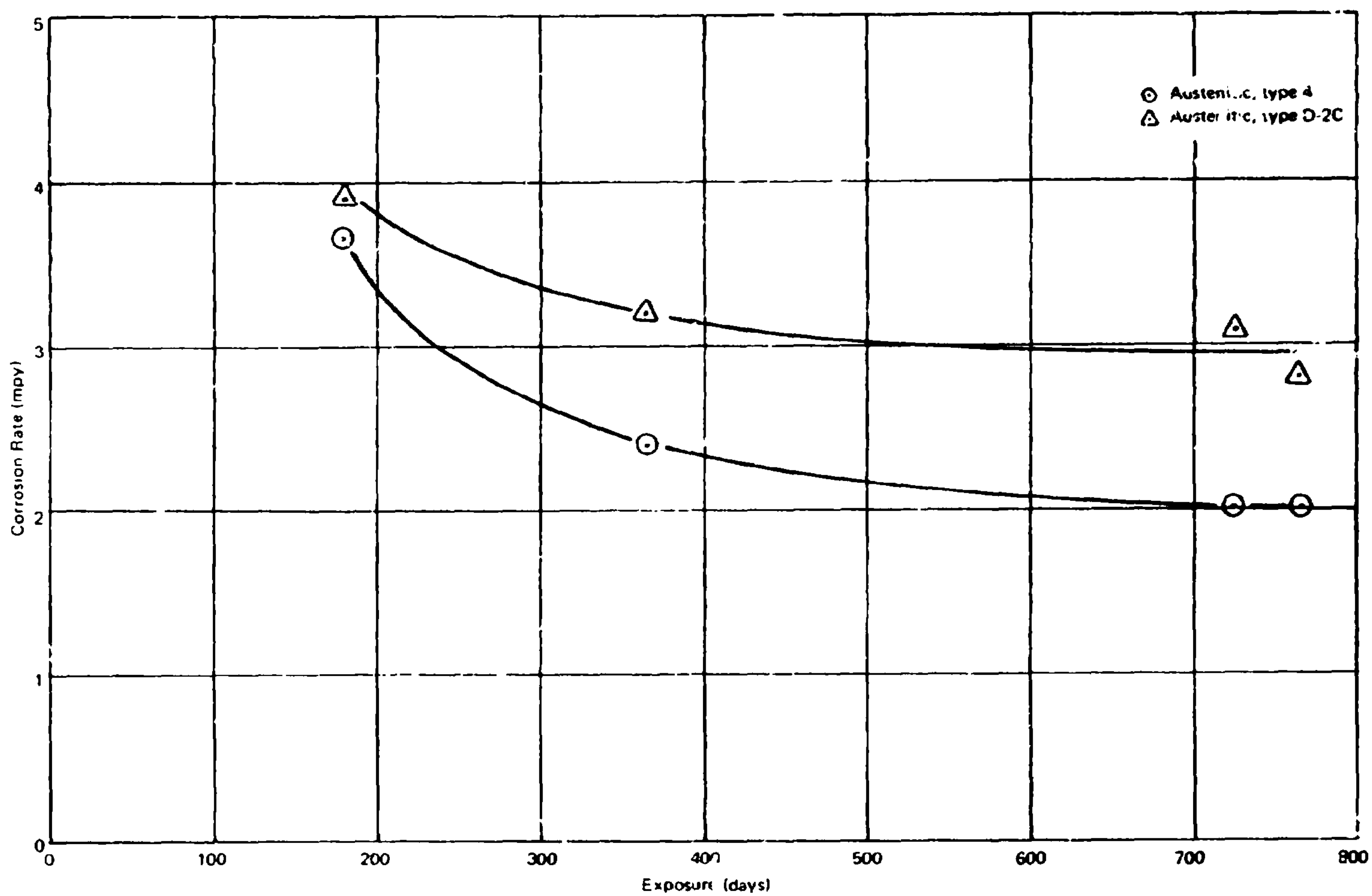


Figure 25. Corrosion of cast irons vs time of exposure in surface seawater.

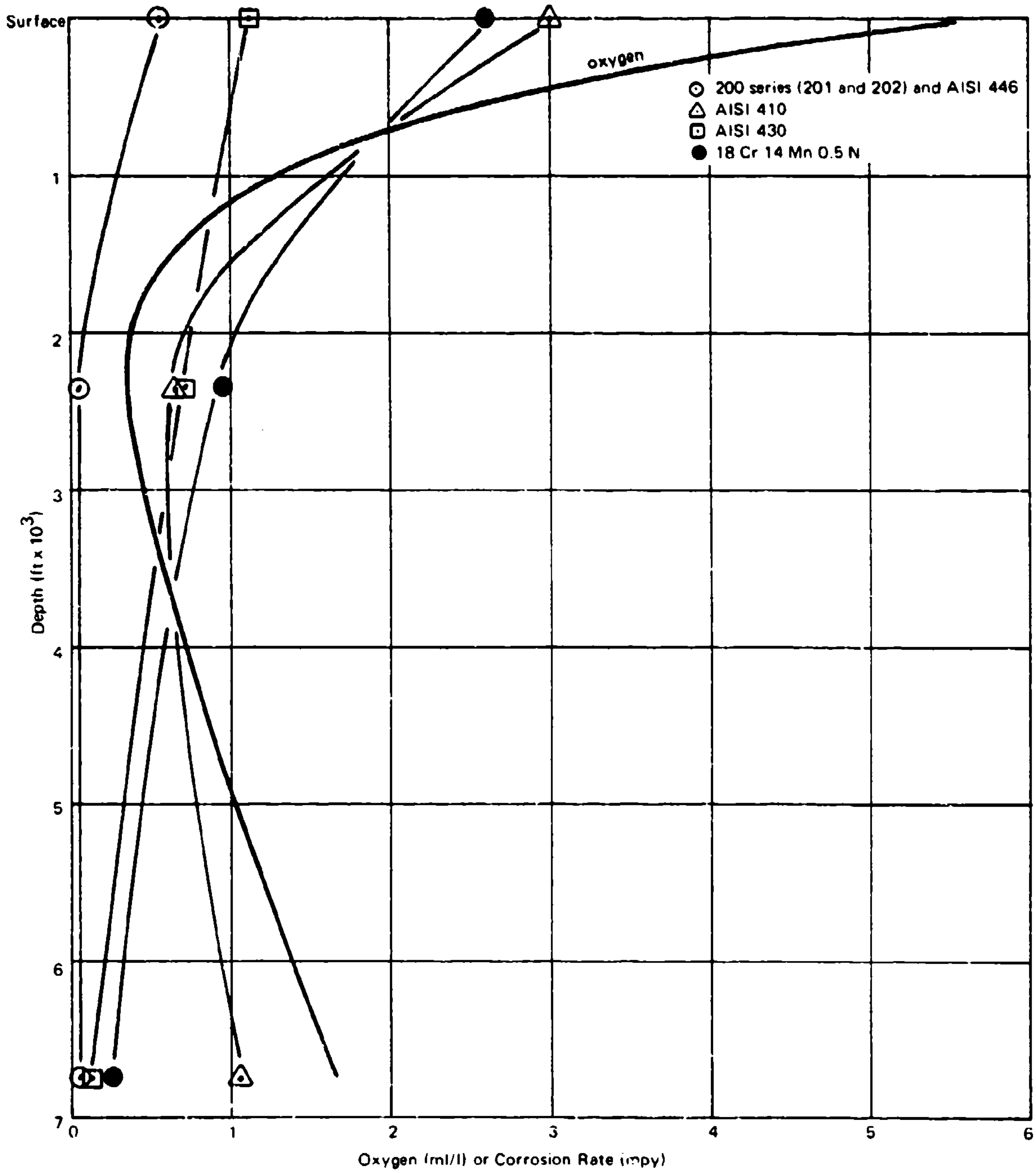


Figure 26. Corrosion of 200 and 400 Series stainless steels vs depth after 1 year of exposure.

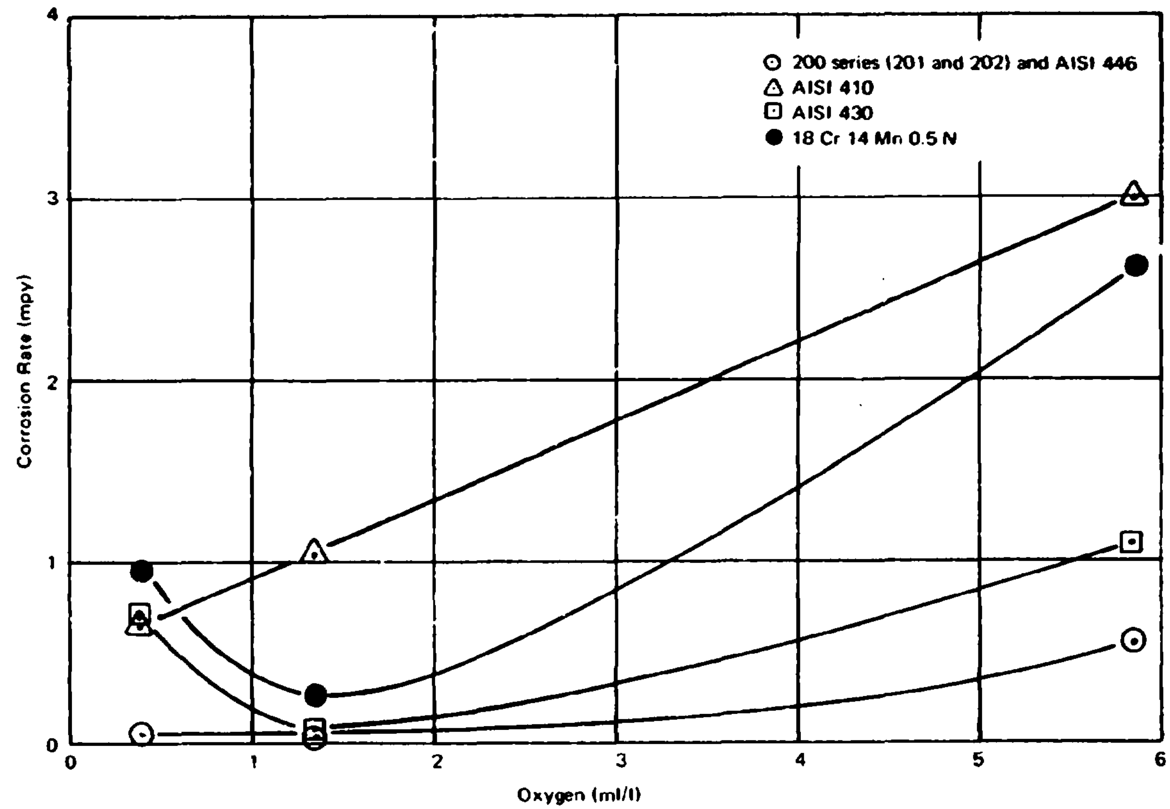


Figure 27. Corrosion of 200 and 400 Series stainless steels vs concentration of oxygen in seawater after 1 year of exposure.

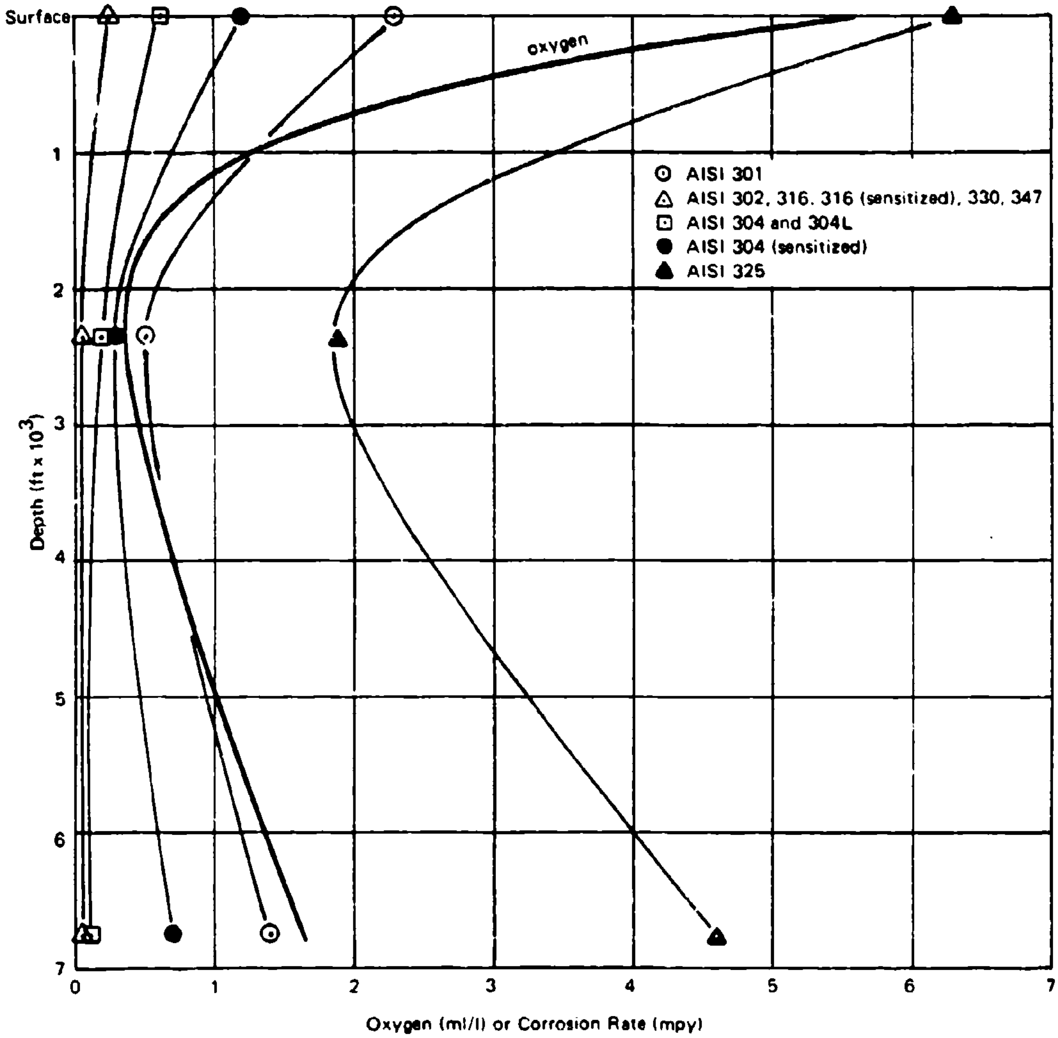


Figure 28. Corrosion of 300 Series stainless steels vs depth after 1 year of exposure.

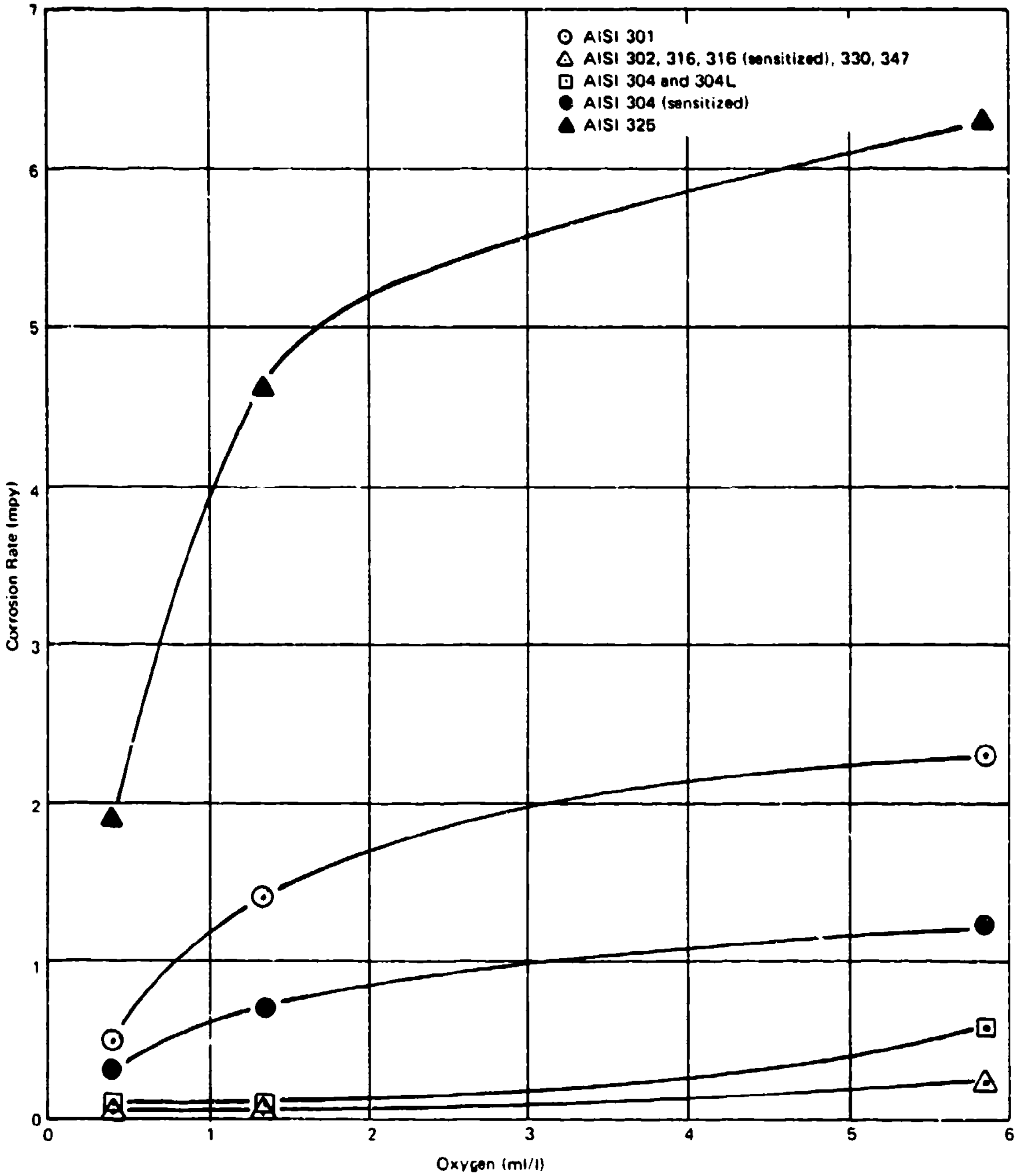


Figure 29. Corrosion of 300 Series stainless steels vs concentration of oxygen in seawater after 1 year of exposure.

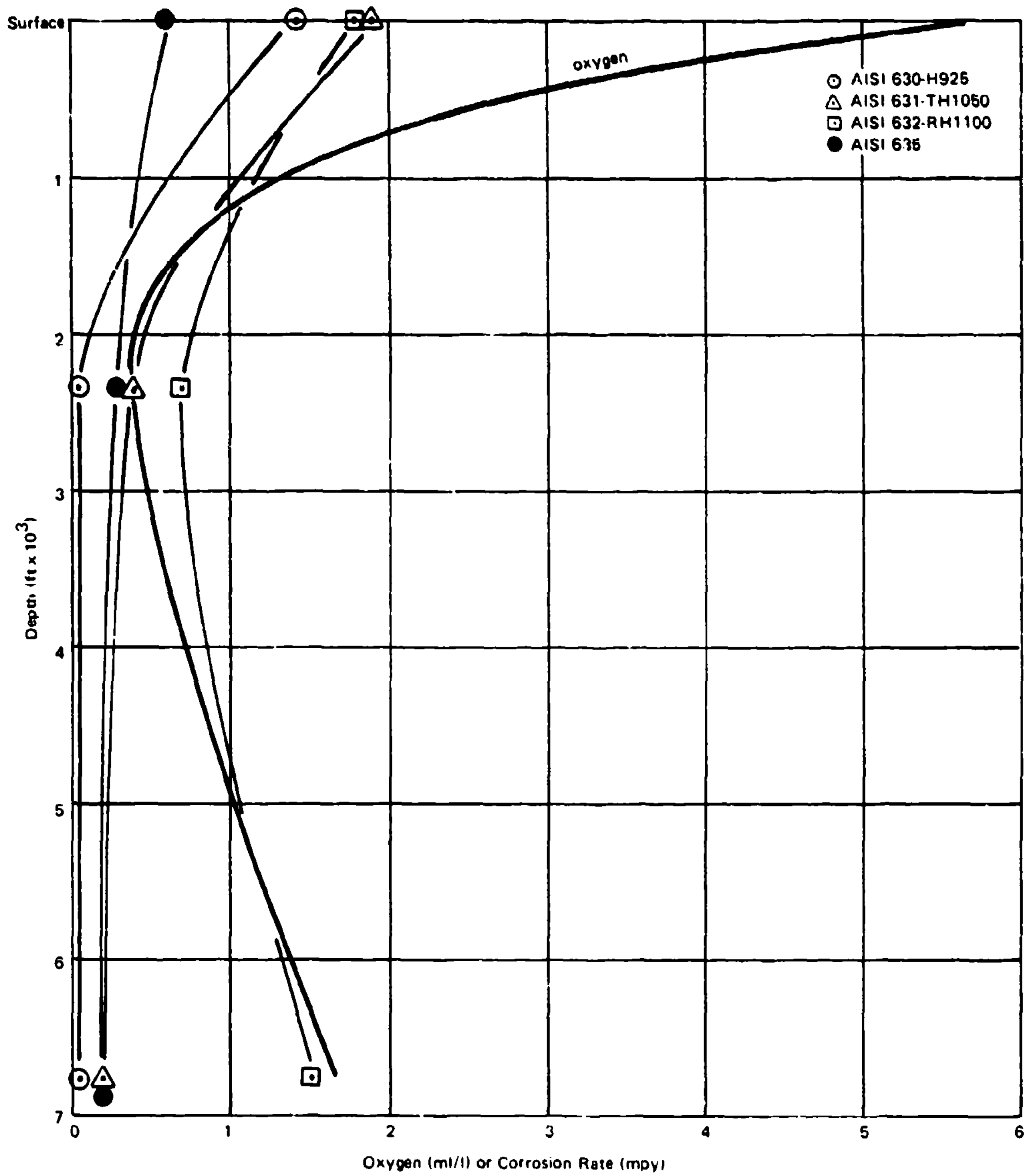


Figure 30. Corrosion of 600 Series stainless steels vs depth after 1 year of exposure.

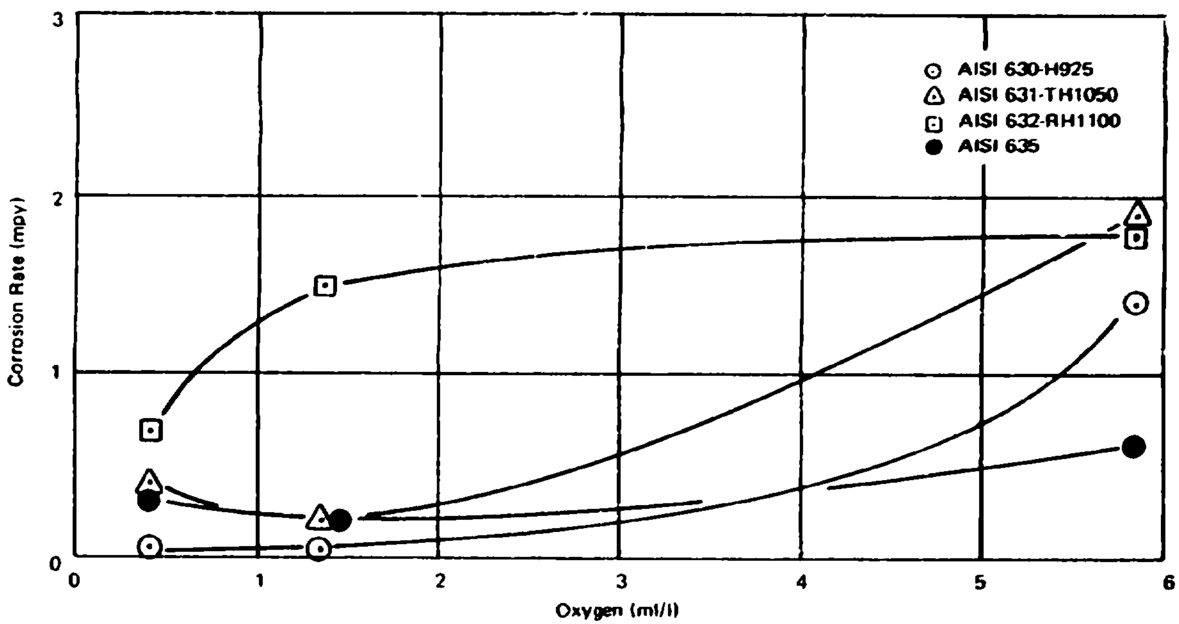


Figure 31. Corrosion of 600 Series stainless steels vs concentration of oxygen in seawater after 1 year of exposure.

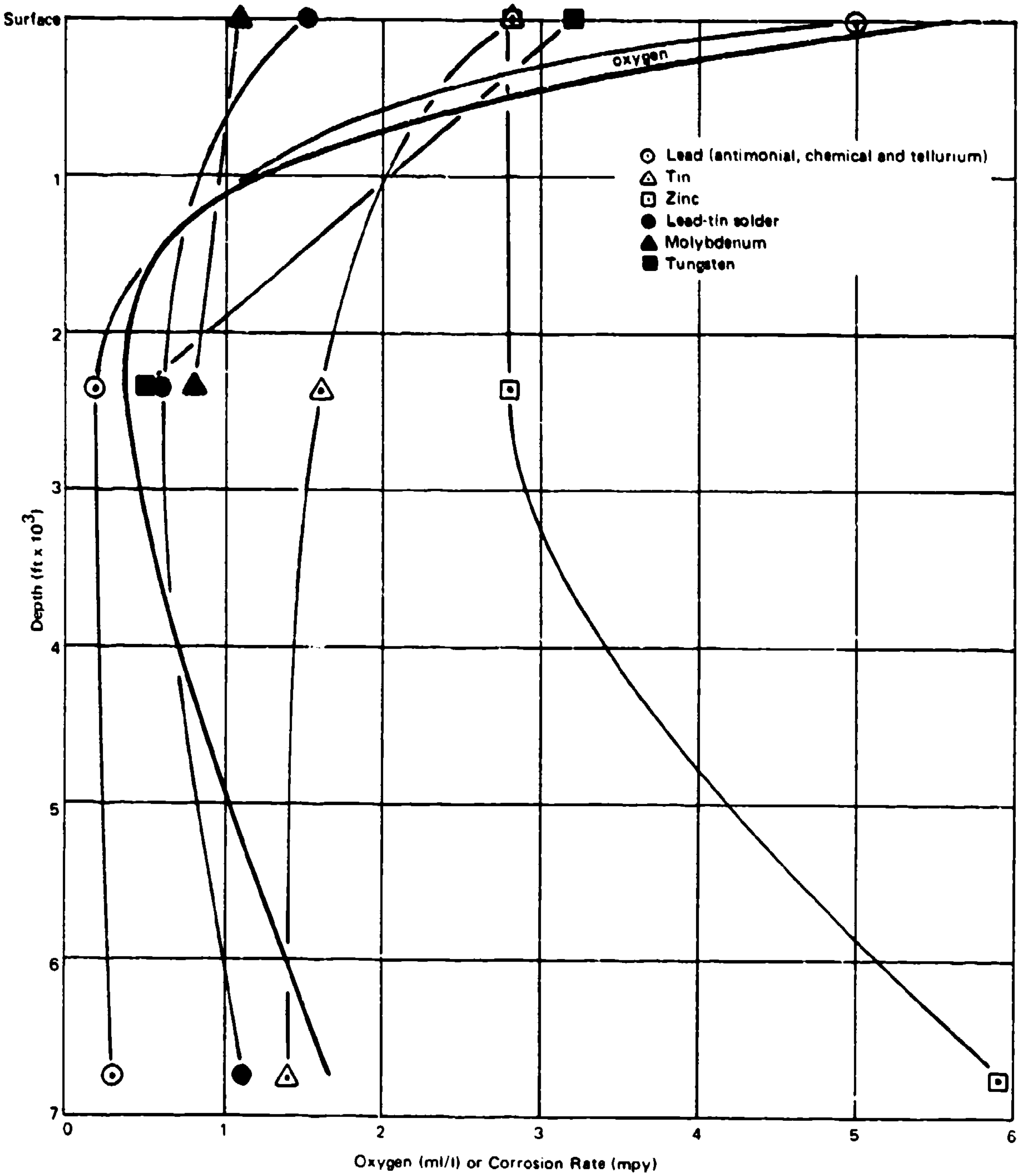


Figure 32. Corrosion of miscellaneous alloys vs depth after 1 year of exposure.

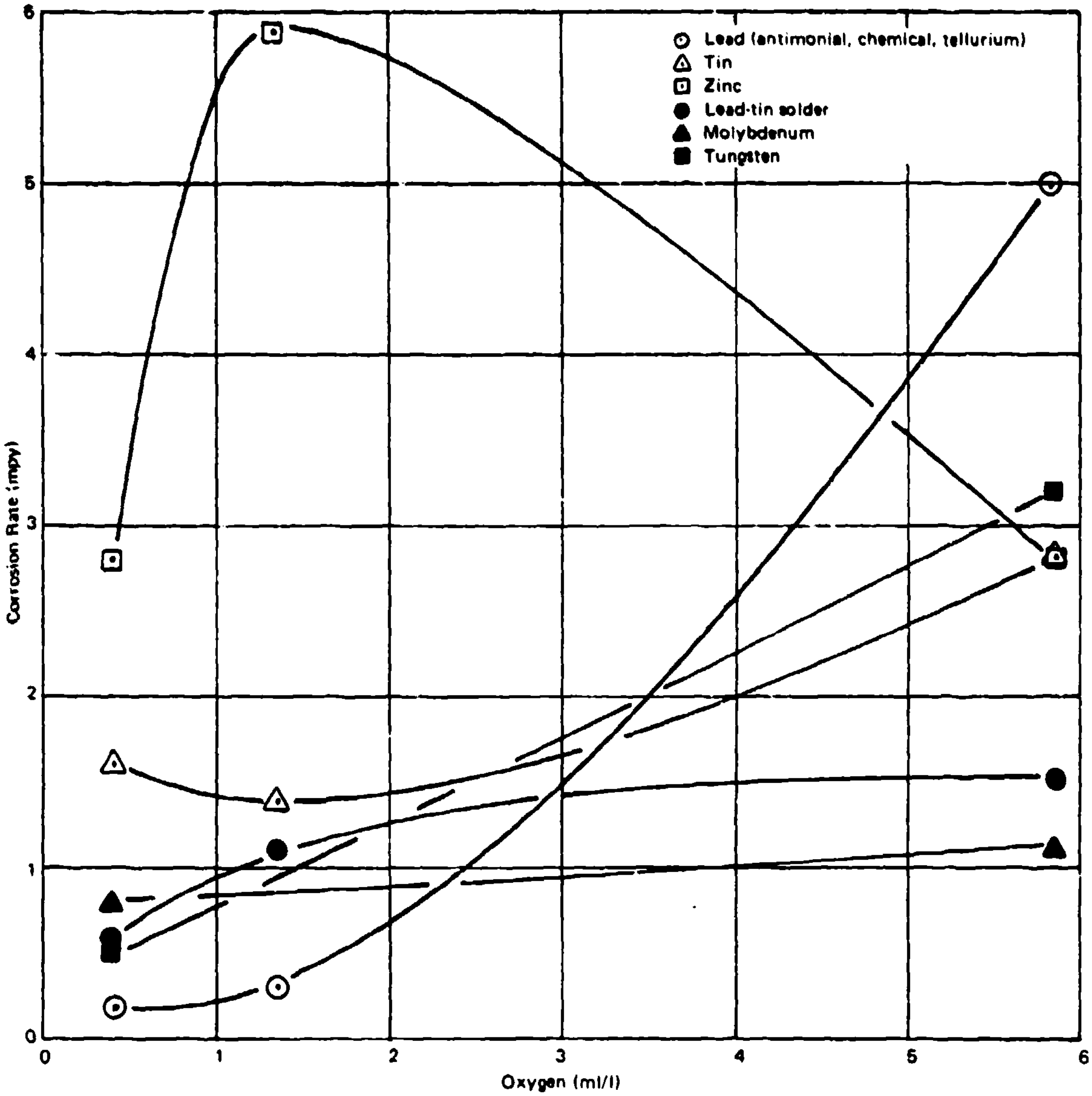


Figure 33. Corrosion of miscellaneous alloys vs concentration of oxygen in seawater after 1 year of exposure.

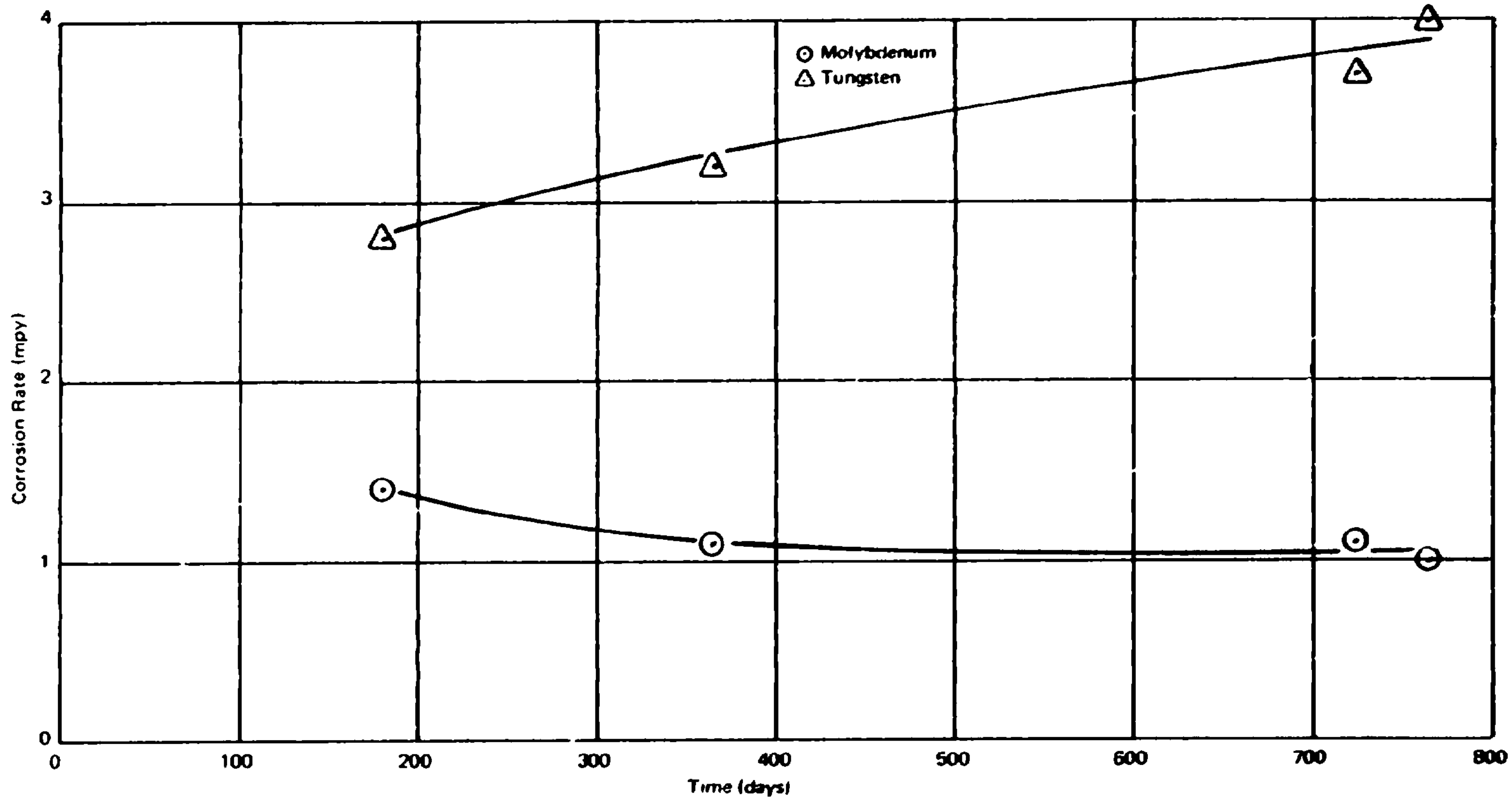


Figure 34. Corrosion of molybdenum and tunsten vs time of exposure at the surface.

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1. Naval Civil Engineering Laboratory. Technical Note N-781: Effect of deep ocean environment on the corrosion of selected alloys, by Fred M. Reinhart. Port Hueneme, Ca., Oct 1965.

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