Technical Note N-1023

CORROSION OF MATERIALS IN SURFACE SEA WATER AFTER 6 MONTHS OF EXPOSURE

By

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ABSTRACT

A total of 880 specimens of 215 different alloys were completely immersed in surface sea water for six months to obtain data for comparison with deep ocean corrosion data.

Corrosion rates, types of corrosion, pit depths, and changes in mechanical properties were determined.

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

The corrosion rates of the copper base alloys, nickel base alloys, steels, and cast irons decreased as the concentration of oxygen in sea water decreased.

The copper base alloys, steels, cast irons, molybdenum, tungsten, leads and lead-tin solder corroded uniformly.

All the aluminum alloys were attacked by pitting and crevice corrosion and sea water was more aggressive at depth than at the surface. The effect of the oxygen concentration of sea water on the corrosion of aluminum alloys was inconsistent.

The stainless steels were attacked by crevice, pitting, edge and tunnel corrosion except types 310, 317 and 329, 20Cb, 20Cb-3 and AM350 on which there was only incipient crevice corrosion. Crevice corrosion was more severe in surface waters than at depth.

PREFACE

The Naval Civil Engineering Laboratory is 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 sea water site in the Pacific Ocean. Six 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 sea water 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 a period of 6 months.

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 sea water 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 as 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 sea water 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 7.

This report presents a discussion of the results obtained of the corrosion of various alloys exposed at the surface, site V, for a period of 6 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 Co., Inc. Permission for their use has been granted by Dr. T. P. May, Reference 8.

The deep ocean data from 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, their corrosion rates and types of corrosion in Table 3, and changes in their mechanical properties after exposure in Table 4.

The corrosion rates of alloys 1100-H14, Alclad 3003, and 5052-0 were lower in the surface waters than at depths of 2,500 and 6,000 feet; those of 3003, and 5456-H321 were lower at the surface than at the 2,500 foot depth; those of 2024-0, were lower at the surface than at the 6,000 foot depth. The corrosion rates of the following alloys were higher at the surface than at depth: 2024-0 than at 2,500 feet; 2219-T6 than at both 2,500 and 6,000 feet; 3003 than at 6,000 feet; 5086-H34 than at both 2,500 and 6,000 feet; 5456-H321 than at 6,000 feet; 6061-T6 than at 6,000 feet. The corrosion rates of all the alloys, except 2024-0 and 2219-T81, immersed at the surface varied from 0.9 to 1.4 MPY with the average being 1.1 MPY. Those of 2024-0 and 2219-T81 were 3.8 and 3.5 MPY, respectively.

Pitting corrosion during the 6 months of immersion was insignificant except on alloys 2024-0, 2219-T81, 3003-H14 and 5456-H321. The maximum depths of the pits were deeper for surface waters than at depth for comparable periods of exposure for the following alloys: 2024-0 at both depths, 2,500 and 6,000 feet; 2219-T81 at 6,000 feet; 3003-H14 at 6,000 feet; 5086-H34 at 6,000 feet; and 5456-H321 at 6,000 feet. The maximum pit depths were deeper at depth than at the surface for the following alloys: 1100-H14 at 6,000 feet; 2219-T81 at 2,500 feet; 3003-H14 at 2,500 feet; Alclad 3003-H12 at both 2,500 and 6,000 feet; 5086-H34 at 2,500 feet; 5456-H321 at 2,500 feet; and 6061-T6 at 2,500 feet.

Except for the 2024-0 alloy, crevice corrosion was more severe at depth than at the surface.

Intergranular corrosion was present in alloys 2219-T81, 5083-H113, 5086-H32, 5086-H34 and 6061-T6.

There was an overall increase in the corrosion rates of alloys 1100-H14, 5052-0, 3003, Alclad 3003, 6061-T6 and 5456-H321 with a decrease in the concentration of the oxygen content of sea water as shown in Figure 2. There was an overall decrease in the corrosion rates of alloys 2024-0, 2219-T81 and 5086-H34 with a decrease in the concentration of the oxygen content of sea water as shown in Figure 3.

The changes in the mechanical properties due to exposure after surface immersion for 6 months in the Pacific Ocean are given in Table 4. Only the mechanical properties of alloy 2219-T81 were impaired.

Analyses of the corrosion data and mechanical property data supports the conclusion that, in general, sea water at depths of 2,500 and 6,000 feet in the Pacific Ocean is more aggressive than at the surface after 6 months of exposure.

COPPER ALLOYS

The chemical compositions of the copper alloys are given in Table 5, their corrosion rates in Table 6 and the effect of exposure on their mechanical properties in Table 7.

The corrosion rates of the majority of the alloys (28 of 33) were higher for surface waters than at both depths, 2,500 and 6,000 feet. The corrosion rates of nickel brass, 90-10 cupro-nickel (CDA706) and nickel silver (CDA752) were higher for surface waters than at the 2,500 foot depth but were lower than at the 6,000 foot depth. The corrosion rates of cast nickel-manganese bronze and 70-30 cupro-nickel containing 0.5 percent iron were lower at the surface than at both depths.

The corrosion rates of most of the copper alloys increased as the concentration of the dissolved oxygen of the sea water increased. The average, maximum and minimum corrosion rates of 26 of the alloys are plotted against the dissolved oxygen contents at the three depths (Table 1) in Figure 4. The corrosion rates of nickel brass, leaded tin bronze, 90-10 cupro-nickel, nickel silver and 55-45 cupro-nickel decreased as the concentration of oxygen in the sea water decreased. However, the corrosion rates of nickel brass, 90-10 cupro-nickel and nickel silver were higher at the intermediate concentration of oxygen, 1.3 ml/l (6,000 foot depth) than at the higher concentration of oxygen, 5.25 ml/l (surface) while those of leaded tin bronze and 55-45 cupro-nickel were lower at the intermediate concentration of oxygen than at the higher concentration of oxygen. The corrosion rates of 70-30 cupro-nickel containing 0.5 percent iron and cast nickel-manganese bronze increased with decreasing concentration of oxygen in sea water.

Slight dezincification was found on red brass at the surface whereas none was found at depth; dezincification of Muntz metal was more severe at the surface than at depth; and dezincification of manganese bronze A and cast nickel-manganese bronze were about the same in severity at the surface as at depth.

Aluminum bronze, 7%, CDA No. 614 was dealuminified at the surface, slightly dealuminified at the 6,000 foot depth but there was no such attack at the 2,500 foot depth. Aluminum bronze, 10% was moderately dealuminified at the surface and at the 2,500 foot depth but only slightly dealuminified at the 6,000 foot depth. Dealuminification decreased from severe to moderate to very slight as the depth increased in 13% aluminum bronze.

Crevice corrosion was found on only three alloys, copper, nickel-aluminum bronze No. 2 and 70-30 cupro-nickel with 5% iron at the surface while none was encountered at depth. Pitting also was found at the surface while none was found at depth on alloys, copper, P bronze A, Ni-Vee bronzes A and B, and 70-30 cupro-nickel containing 5% iron.

The percent change in the mechanical properties of the copper base alloys after exposure are shown in Table 7. The mechanical properties were adversely affected slightly by exposure at the surface while there were no significant effects at depth for comparable periods of exposure.

NICKEL ALLOYS

The chemical compositions of the nickel alloys are given in Table 8, their corrosion rates and types of corrosion in Table 9 and the effect of exposure on their mechanical properties in Table 10.

Corrosion

The corrosion rates, maximum and average pit depths, depth of crevice corrosion and types of corrosion are given in Table 9.

There was no visible corrosion on 14 of the alloys and their corrosion rates were less than 0.1 MPY (mils penetration per year). These alloys were: nickel-chromium-molybdenum alloys No. 3 and 625; nickel-cobalt-chromium alloy 700; nickel-chromium-iron alloy No. 718; nickel-iron-chromium alloys No. 800, 804, 825, 825 sensitized (heated 1 hour at 1200°F), 825 Cb and 901; nickel-chromium-iron-molybdenum alloys No. F, G and X; and nickel-molybdenum-chromium alloy No. C.

The corrosion rates of 23 of the other 24 alloys were higher at the surface than at both depths, 2,500 and 6,000 feet. The corrosion rate of the other alloy, cast nickel-copper 505, was higher at the surface than at the 2,500 foot depth but lower than at the 6,000 foot depth. The corrosion rates of 14 of the alloys decreased as the depth increased as shown in Figure 5. The averages of the corrosion rates of the 14 alloys at the three depths along with the maximum and minimum corrosion rates at each depth are plotted in Figure 5. However, for 10 of the alloys the corrosion rates were lower at the 2,500 foot depth than at the 6,000 foot depth and the latter were lower than the corrosion rates at the surface. The curves of the averages of the corrosion rates of the 10 alloys at each depth in addition to the curves of the maximum and minimum values are shown in Figure 6.

Five of the alloys which were corroded during the surface exposure were not attacked by crevice corrosion: nickel alloy 301; cast nickel-copper alloy 505; nickel-copper alloy 55-45; nickel-molybdenum-iron alloy B; and nickel-molybdenum alloy 2. There was crevice corrosion on 21 alloys which varied in intensity from a depth of 12 mils to perforation of 50 mil thick specimens. There was crevice corrosion on nickel-iron-chromium alloy 825, whose corrosion rate was less than 0.1 MPY to a depth of 33 mils at an intentional crevice and to a depth of 44 mils underneath barnacles.

The effect of the concentration of oxygen in sea water on the corrosion of nickel alloys is shown in Figures 7 and 8. The corrosion rates of 12 nickel alloys decreased as the concentration of oxygen in the sea water decreased. The averages, and maximum and minimum corrosion rates of these 12 alloys are shown in Figure 7. The decrease in corrosion rate is almost linear with the decrease in the concentration of oxygen. The decrease of the average corrosion rates, and the maximum and minimum rates of 10 other alloys with decreasing concentration of oxygen in the sea water are shown in Figure 8. In the case of these 10 alloys, the average corrosion rate at 1.3 ml/l of oxygen was slightly lower than at 0.4 ml/l oxygen but there was an overall decrease in corrosion rates as the concentration of oxygen decreased from 5.25 to 0.4 ml/l.

The effect of exposure on the mechanical properties of the nickel alloys is given in Table 10. The mechanical properties of four of the alloys were not affected by exposure at the surface for 181 days, at a depth of 2,500 feet for 197 days, and at a depth of 6,000 feet for 123 days. The elongation of nickel-iron-chromium alloy 902 was adversely affected during 181 days of exposure in surface water immersion.

STEELS

The chemical compositions of the steels are given in Table 11, their corrosion rates in Table 12, and changes in mechanical properties due to exposure in the ocean in Table 13.

The corrosion rates of all the steels were higher in surface waters than at both depths of 2,500 feet and 6,000 feet, Table 12. The corrosion rates at the 6,000 foot depth were greater than at the 2,500 foot depth. The effect of depth on the corrosion rates of the steels is shown in Figure 9. The corrosion rates of the steels at each depth were averaged to obtain an average corrosion rate for any one depth. It is these average values which are plotted in Figure 9. Also shown in Figure 9 are the maximum and minimum corrosion rates for each depth to indicate the spread in the values.

The average corrosion rates and, the maximum and minimum corrosion rates were also plotted against the concentration of oxygen in sea water from Table 1 to show the effect of oxygen on the corrosion rates of steels. This is shown in Figure 10 where it is clearly evident that the corrosion rates of the steels decrease with decreasing concentration of oxygen in sea water. The average corrosion rate at the surface is 5 times greater than at a depth of 2,500 feet and 2.7 times greater than at a depth of 6,000 feet.

The effect of exposure at the surface and at depths of 2,500 and 6,000 feet on the mechanical properties of some of the steels are given in Table 13. The mechanical properties were not affected.

CAST IRONS

The chemical compositions of the cast irons are given in Table 14; their corrosion rates in Table 15 and the effect of exposure on their mechanical properties in Table 16.

The silicon and silicon-molybdenum cast irons were uncorroded after 6 months of exposure at the surface except for slight etching of the silicon cast iron; their corrosion rates were less than 0.1 MPY. These two alloys also were uncorroded at depths of 2,500 and 6,000 feet after comparable periods of exposure.

The other cast irons and austenitic cast irons corroded at higher rates at the surface than at either depth. Also, their corrosion rates were lower at the 2,500 foot depth than at the 6,000 foot depth. The corrosion rates of the high nickel alloy austenitic cast irons were lower than those of the other cast irons except the silicon and silicon-molybdenum cast irons which were uncorroded.

The corrosion rates of the ordinary and low alloy cast irons were treated as a group while the high nickel austenitic cast irons were treated as another group. The corrosion rates of each group were averaged to obtain representative curves. These average curves and the maximum and minimum values are plotted in Figures 11 and 12 to show the effects of depth and concentration of oxygen in sea water on the corrosion rates.

It is shown in Figure 11 that the corrosion rates of the cast irons are higher at the surface than at both depths and that the corrosion rates at the 6,000 foot depth are higher than those at the 2,500 foot depth. Also the corrosion rates of the nickel, nickel-chromium and ductile cast irons are higher than those of the high nickel austenitic cast irons.

The corrosion rates of the cast irons also decreased with decreasing concentration of oxygen in sea water as shown in Figure 12. The corrosion rates of the nickel, nickel-chromium and ductile cast irons were higher than those of the austenitic cast irons and they decreased at a greater rate with decreasing concentration of oxygen than did those of the austenitic cast irons. At the lowest oxygen concentration, 0.4 ml/l, the corrosion rates of the two groups were comparable.

In Figure 13 are shown the average corrosion rate curves for the steels; nickel, nickel-chromium and ductile cast irons and; the austenitic cast irons. The corrosion rates for the steels and the group containing the nickel, nickel-chromium and ductile cast irons are comparable and for all practical purposes it can be concluded that their corrosion behavior is essentially the same. The corrosion rate curve for the austenitic cast irons is much lower than the other two and reflects the effect of the high nickel contents in reducing the corrosion rates of cast irons.

The effects of exposure in surface sea water on the mechanical properties of two of the austenitic cast irons are given in Table 16. The mechanical properties of Type 4 austenitic cast iron were not affected while those of Type D-2C were adversely affected. Metallographic examinations of polished cross sections of Type D-2C showed that it had been attacked by interdendritic corrosion which would explain the decrease in mechanical properties.

STAINLESS STEELS

The chemical compositions of the stainless steels are given in Table 17; their corrosion rates and types of corrosion in Table 18 and the effects of exposure on their mechanical properties in Table 19.

The alloys which were least corroded were AISI Types 310, 317 and 329; 20Cb; 20Cb-3 and; AM350. They were not entirely uncorroded in that there was incipient crevice corrosion evident on all of them even though their corrosion rates were less than 0.1 mils per year.

All the other alloys were attacked by pitting, crevice, edge or the tunnel types of corrosion or combinations of these types. The crevice and tunnel types of corrosion were the most prevalent and they are also the most insidious types.

Crevice corrosion occurs in the small space between two contacting surfaces and usually its severity is not evident from visual examination unless there is perforation of the alloy: generally the mating surfaces must be separated from each other to evaluate the degree of severity.

The tunnel type of corrosion usually appears as a tiny pin hole on the surface or on the edge of the material. However, once corrosion penetrates the surface it spreads out in a tunnel like configuration extending for a considerable distance underneath the surfaces of the material.

In general, the Type 300 stainless steels were less corroded than either the 200 or 400 Type alloys. The precipitation hardening stainless steels, except AM350, were severely attacked by the edge and the tunnel types of corrosion and were judged to be about as corrosion resistant as the 200 and 400 Type alloys. The precipitation hardening stainless steels are: PH14-8Mo, PH15-7Mo, 17-7PH, 17-4PH, 17Cr-14Ni-Cu-Mo, 18Cr-14Mn, AM350 and 17Cr-7Ni.

In general, crevice corrosion was more severe after 181 days of exposure at the surface than after comparable periods of exposure at depths of 2,500 and 6,000 feet.

The effects of exposure in sea water on the mechanical properties of some of the stainless steels are given in Table 19. The mechanical properties of the alloys were not adversely affected.

TITANIUM ALLOYS

The chemcial compositions of the titanium alloys are given in Table 20, their corrosion rates in Table 21 and the effect of exposure in sea water on their mechanical properties in Table 22.

The corrosion rates and types of corrosion of the titanium alloys are given in Table 21. There was neither any significant weight losses nor visible corrosion on any of the welded or unwelded alloys except stress corrosion cracking of the 13V-11Cr-3Al alloy containing a circular weld.

The welded titanium alloys were exposed in the "as welded" condition. That is, the stresses imposed in the specimens by the welding operation were not relieved by annealing prior to exposure. The process of placing a circular weld in a specimen imposes very high residual stresses in the specimen. Such circular welds simulate multiaxial stresses imposed in structures or parts fabricated by welding. Unrelieved circular welds will cause stress corrosion cracking if the residual stresses are high enough and if the environment is appropriate.

The specimen of titanium alloy 13V-11Cr-3Al with a circular weld cracked radially across the weld during 181 days of exposure at the surface of the sea water as shown in Figure 14, companion specimens exposed at depths of 2,500 and 6,000 feet for comparable periods of exposure did not fail by stress corrosion cracking. This indicates that sea water at depths is not as aggressive for promoting stress corrosion cracking of this alloy as is surface sea water.

The effects of exposure in sea water on the mechanical properties of titanium alloys are given in Table 22. The mechanical properties were unaffected by exposure both at the surface and at depth in sea water.

MISCELLANEOUS ALLOYS

The chemical compositions of the alloys are given in Table 23, their corrosion rates in Table 24, and the effect of exposure in surface sea water on the mechanical properties of some of the alloys in Table 25.

The corrosion rates and types of corrosion of the miscellaneous alloys are given in Table 24. The iron-nickel-chromium-molybdenum alloys, columbium, tantalum and Ta-60 alloy were uncorroded after 6 months of exposure. The iron-nickel-chromium alloys were attacked by crevice corrosion to depths of from 18 to 20 mils at the surface but were practically uncorroded at depths of 2,500 and 6,000 feet after equivalent periods of exposure.

Chemical lead, antimonial lead and tellurium lead corroded uniformly with their corrosion rates being lower at the 2,500 foot depth than at the surface and at the 6,000 foot depth. Chemical lead, in general, was more corrosion resistant than the other two alloys.

Magnesium alloy AZ31B was practically disintegrated within 6 months of exposure both in surface sea water and at depths of 2,500 and 6,000 feet.

Tin, zinc and lead-tin solder corroded at appreciable rates in sea water, those at the surface being higher than those at depth except zinc after 123 days at 6,000 feet. Tin and zinc were pitted while the lead-tin solder corroded uniformly.

Molybdenum and tungsten corroded at low rates and the type of attack was uniform.

The effects of exposure in surface sea water for 6 months on the mechanical properties for some of the alloys are given in Table 25.

The mechanical properties of columbium, molybdenum and tantalum were not impaired.

SUMMARY

The purpose of this investigation was to determine the effects of surface sea water on the corrosion of different types of alloys (aluminum alloys, copper alloys, nickel alloys, steels, cast irons, stainless steels, titanium alloys and miscellaneous alloys) for comparison with deep ocean corrosion behavior. To accomplish this 880 specimens of 215 different alloys were exposed 5 feet below the lowest tide level in the Pacific Ocean at Point Mugu, California (Site V) for a period of 6 months.

Aluminum Alloys

The corrosion rates of the various aluminum alloys were not consistently higher or lower at the surface than at depth in the Pacific Ocean: those of 2219-T6 and 5086-H34 were higher at the surface while those of 1100-H14, Alclad 3003 and 5052-0 were lower. The corrosion rates of 3003, 5456-H321, 2024-0 and 6061-T6 were inconsistent in that they were higher at one depth than at the surface and lower than at the surface than at the other depth.

Pitting corrosion was significant after six months of surface sea water immersion on alloys 2024-0, 2219-T81, 3003-H14 and 5456-H321. The maximum pit depths were deeper on more alloys at depth in the Pacific Ocean than at the surface.

Crevice corrosion was more severe at depth than at the surface for all alloys except 2024-0.

Alloys 2219-T81, 5083-H113, 5083-H32, 5086-H34 and 6061-T6 were attacked by intergranular corrosion.

There was an overall increase in the corrosion rates of alloys 1100-H14, 3003, Alclad 3003, 5052-0, 5456-H321 and 6061-T6 with decreasing concentration of oxygen in sea water while those of 2024-0, 2219-T81, and 5086-H34 decreased with decreasing concentration of oxygen after approximately 6 months of exposure.

The mechanical properties of alloy 2219-T81 were impaired after surface exposure in the sea water for 6 months.

Copper Alloys

The corrosion rates of the copper base alloys except cast nickel-manganese bronze and 70-30 copper-nickel containing 0.5 percent iron were higher at the surface than at depths of 2,500 and 6,000 feet in the Pacific Ocean.

The corrosion rates of the copper alloys except cast nickel-manganese bronze and 70-30 copper-nickel containing 0.5 percent iron decreased as the concentration of oxygen in sea water decreased.

Red brass, Muntz metal, and manganese bronze A were dezincified after 6 months of surface exposure in sea water. There was no dezincification of red brass at depth; that of Muntz metal was more severe than at depth and; it was the same at depth as at the surface on manganese bronze A and cast nickel-manganese bronze.

Dealuminification was present on 7, 10 and 13 percent aluminum bronzes, being more severe at the surface than at depth.

There was slight crevice corrosion and pitting of some of the alloys at the surface but none at depth.

The mechanical properties were slightly lowered by exposure at the surface but were unaffected at depth.

Nickel Alloys

Fourteen (14) of the nickel base alloys were uncorroded: nickel-chromium-molybdenum alloys No. 3 and 625; nickel-cobalt-chromium alloy 700; nickel-chromium-iron alloy 718; nickel-iron-chromium alloys No. 800, 804, 825, 825 (sensitized), 825 Cb and 901; nickel-chromium-iron-molybdenum alloys No. F, G and X; and nickel-molybdenum-chromium alloy C.

The corrosion rates of the other nickel base alloys were higher at the surface than at depth in the Pacific Ocean.

All except five of the corroded alloys were attacked by crevice corrosion.

The corrosion rates of the corroded alloys decreased as the concentration of oxygen in sea water decreased.

The elongation of nickel-iron-chromium alloy 902 was lowered considerably after six months of exposure at the surface.

Steels

The corrosion rates of the steels were higher at the surface than at depths of 2,500 and 6,000 feet in the Pacific Ocean.

The mechanical properties of the steels were not affected by exposure in sea water for a period of six months.

Cast Irons

The silicon and silicon-molybdenum cast irons were uncorroded at the surface and at depth in the Pacific Ocean.

The corrosion rates of the other cast irons were higher at the surface than at depth. The corrosion rates of the high nickel austenitic cast irons were lower than those of the other cast irons.

The corrosion rates of the cast irons decreased with decreasing concentration of oxygen in sea water.

Type D-2C austenitic cast iron was attacked by interdendritic corrosion.

The mechanical properties of Type D-2C austenitic cast iron were adversely affected by exposure for six months immersion in surface sea water.

Stainless Steels

All the stainless steels were attacked by crevice corrosion. Those with only incipient crevice corrosion were AISI Types 310, 317 and 329; 20Cb, 20Cb-3 and AM350.

Other types of corrosion on the alloys were pitting, edge or tunnel or combinations of these types.

The Type 300 stainless steels were less corroded than Type 200, Type 400 and the precipitation hardening stainless steels.

Crevice corrosion was more severe at the surface than at depths of 2,500 and 6,000 feet in the Pacific Ocean.

The mechanical properties of the alloys were not adversely affected.

Titanium Alloys

Titanium alloys unwelded, butt and circular welded titanium alloy 75A; unwelded, butt and circular welded titanium alloy 6Al-4V; butt and circular welded titanium alloy 0.15 Pd; butt and circular welded titanium alloy 5Al-2.5 Sn; butt and circular welded titanium alloy 7Al-2Cb-1Ta; and butt welded titanium alloy 13V-11Cr-3Al were uncorroded after six months of exposure at the surface and at depths of 2,500 and 6,000 feet.

Titanium alloy 13V-11Cr-3Al with an unrelieved circular weld failed by stress corrosion cracking after six months of exposure at the surface. There were no failures of companion specimens after comparable periods of exposure at depths of 2,500 and 6,000 feet.

The mechanical properties were unimpaired by six months of exposure either at the surface or at depth.

Miscellaneous Alloys

The iron-nickel-chromium-molybdenum alloys, columbium, tantalum and tantalum-tungsten alloy Ta-60 were uncorroded.

Molybdenum and tungsten corroded uniformly at low rates. Chemical lead, antimonial lead and tellurium lead also corroded uniformly but at higher rates than molybdenum and tungsten with chemical lead being the most resistant to sea water.

Tin, zinc and lead-tin solder corroded at appreciable rates in sea water with tin and zinc being pitted.

Magnesium alloy AZ31B was disintegrated by corrosion.

Iron-nickel-chromium alloys were attacked by crevice corrosion in surface sea water exposure but were uncorroded at depth in sea water.

CONCLUSIONS

Sea water at depths of 2,500 and 6,000 feet in the Pacific Ocean is more aggressive to aluminum alloys than is sea water at the surface.

Aluminum alloys, because of their susceptibility to pitting and crevice types of corrosion must be protected for sea water applications if reasonable service life is desired. In general, aluminum alloys would not be recommended for deep sea applications for periods longer than three years if protective maintenance cannot be performed.

Copper base alloys which are susceptible to dezincification and dealuminification are not recommended for sea water service. The other copper base alloys corroded uniformly and can be used in sea water service where their corrosion rates can be tolerated.

The nickel base alloys which were uncorroded can be used in sea water applications where their mechanical and physical properties fulfill the other requirements.

Because of the susceptibility of the other nickel base alloys to crevice corrosion, their use in sea water applications would not be recommended unless adequate precautions were taken to prevent this type of attack.

Steels, cast irons and austenitic cast irons because of their uniform corrosion can be used for sea water applications especially if adequate protective measures are employed.

The stainless steels because of their proneness to crevice corrosion and different manifestations of pitting are not recommended for sea water applications.

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

The iron-nickel-chromium-molybdenum alloys, columbium, tantalum and Ta-60 alloy are recommended for sea water service.

Molybdenum, tungsten, chemical lead, antimonial lead and tellurium lead, because of their low uniform corrosion, can be used in some sea water applications.

Tin, zinc and lead-tin solder are not recommended for sea water service. Zinc is used as a sacrificial anode when it is desired to use it to protect more noble alloys.

Magnesium alloy AZ31B is unsatisfactory for sea water applications.

Because of crevice corrosion, iron-nickel-chromium alloys are not recommended for sea water service.

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8. Dr. T. P. May, unpublished data, International Nickel Co., Inc. New York City, New York.

Table 1. Exposure Site Locations and Sea Water Characteristics

Site No.	Latitude N	Longitude W	Depth, Feet	Exposure, Days	Temp. °C	Oxygen ml/l[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	197	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	12-19	3.9-6.6	33.51	8.1	Variable

1. ml/l - 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 [8]
	-	-	4.3	0.6	1.5	-		-		Rem.	INCO [8]
2024	-	-	4.3	0.6	1.5	-	-	-	-	Rem.	INCO [8]
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 [8]
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 [8]
5052	-	-	-	-	2.5	0.25	-	-	-	Rem.	INCO [8]
5083	-	-	0.15	0.6	4.5	-	-	-	-	Rem.	INCO [8]
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 [8]
5086-H32	0.15	0.25	0.05	0.32	3.75	0.12	-	0.12	0.01	Rem.	NCEL
5086-H34&H112	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 [8]
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 [8]
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	Pit Depth,		Crevice Corrosion, Depth, Mils	Corrosion, Type[2]	Source[3]
	Days	Depth, Feet	MPY[1]	Max	Avg			
1100-H14	181	5	1.4	-	-	-	SC	INCO(8)
	197	2340	5.6	-	-	62(PR)[2]	SC	INCO(8)
	123	5640	1.9	39	-	-	P	INCO(8)
2024-0	181	5	3.8	32	-	32	P,C	INCO(8)
	197	2340	3.1	19	-	-	SE,P	INCO(8)
	123	5640	5.2	28	-	-	P	INCO(8)
2219-T81	181	5	3.5	24	22.3	-	P,IG[4]	NCEL
	197	2340	3.0	25	19.1	36	P,C	NCEL
	123	5640	1.8	13	11.6	15	E,P,C	NCEL
3003	181	5	1.0	-	-	-	IP	INCO(8)
3003-H14	181	5	1.1	33	17.6	-	P	NCEL
3003	197	2340	1.4	-	-	40(PR)	C	INCO(8)
3003-H14	197	2340	2.7	48	21.5	28	SE,P,C	NCEL
3003	123	5640	0.6	-	-	28	C	INCO(8)
3003-H14	123	5640	0.5	27	19.5	32	E,P,C	NCEL
Alclad 3003	181	5	1.0	2	-	-	P	INCO(8)
Alclad 3003-H12	181	5	1.0	-	-	-	IP	NCEL
Alclad 3003	197	2340	2.3	-	-	-	G	INCO(8)
Alclad 3003-H12	197	2340	2.2	15	14.3	13	P,C	NCEL
Alclad 3003	123	5640	2.7	-	-	-	G	INCO(8)
Alclad 3003-H12	123	5640	0.2	18	14.6	15	SLE,B,P,C	NCEL
5052-0	181	5	1.2	-	-	-	IP	INCO(8)
	197	2340	1.8	-	-	65(PR)	SC	INCO(8)
	123	5640	3.7	2	-	65(PR)	SC	INCO(8)

Table 3. Corrosion of Aluminum Alloys in Sea Water (Cont'd.)

Alloy	Exposure		Corrosion Rate	Pit Depth,		Crevice Corrosion, Depth, Mils	Corrosion, Type(2)	Source(3)
	Days	Depth, Feet	MPY(1)	Max	Avg			
5083	181	5	1.0	-	-	-	Et	INCO(8)
5083-H113	181	5	1.2	-	-	3	C,IP,IG(5)	NCEL
5083-H113,welded	181	5	0.9	-	-	-	Et	NCEL
5086	181	5	1.2	-	-	-	IP	INCO(8)
5086-H32	181	5	1.0	-	-	-	IP,IG(5)	NCEL
5068-H34	181	5	1.2	6	4	-	P,IG	NCEL
	197	2340	0.7	29	-	-	SLE,P	NCEL
	123	5640	<0.1	-	-	-	SLE,SLC	NCEL
5086-H112,angle	181	5	1.1	-	-	-	IP	NCEL
5454	181	5	1.0	-	-	-	IP	INCO(8)
5456-H321	181	5	1.2	12	7	-	P	NCEL
	197	2340	2.7	17	11.7	-	P	NCEL
	123	5640	<0.1	-	-	-	SLE,SLC	NCEL
6061	181	5	1.2	5	-	-	P	INCO(8)
6061-T6	181	5	1.0	-	-	8	IP,C,IG	NCEL
	197	2340	1.1	47	44.1	42	C,P	NCEL
	123	5640	<0.1	-	-	-	IP	NCEL
7039-T64	181	5	1.1	-	-	-	Et	NCEL
7039-T64,welded	181	5	1.2	-	-	-	IPHAZ	NCEL

1. MPY - Mils penetration per year calculated from weight loss.
2. Symbols for types of corrosion:
   - B - Blistering
   - C - Crevice
   - E - Edge
   - Et - Etched
   - G - General
   - HAZ - Heat affected zone
   - I - Incipient
   - IG - Intergranular
   - P - Pitting
   - PR - Perforated
   - S - Severe
   - SL - Slight
3. Numbers refer to references at end of paper.
4. Intergranular corrosion extended from sides of corrosion pits.
5. Intergranular corrosion on edges of specimens.

Table 4. Effect of Exposure in Sea Water on the Mechanical Properties of Aluminum Alloys

Alloy	Original Properties(1)			Percent Change(2)								
				Surface, 181 Days			2,340', 197 Days			5,640', 123 Days		
	TS	YS	El	TS	YS	El	TS	YS	El	TS	YS	El
2219-T81	64.7	50.0	11.8	-16.5	-12.6	-61.9	-5.0	- 6.0	-30.2	- 2.9	-1.2	-42.4
3003-H14	22.5	21.4	17.5	+ 4.0	- 0.9	- 1.1	-6.2	-10.3	+15.2	- 4.4	-7.5	-42.9
Alclad 3003-H12	18.7	17.5	13.7	+ 4.3	+ 1.1	+ 2.1	+1.0	+ 2.3	+ 7.3	- 2.1	-0.6	-41.6
5083-H113	48.2	34.7	18.8	- 1.6	-11.0	+16.0	-1.3	- 0.5	+ 2.9	-	-	-
5083-H113,welded	40.8	21.8	12.5	+ 9.3	+11.1	+ 8.0	+5.5	- 0.3	+21.1	+ 3.8	-0.5	+25.6
5086-H32	46.4	31.8	16.7	- 4.1	+ 0.4	+40.7	-	-	-	-	-	-
5086-H34	48.3	37.2	11.8	- 0.4	+ 1.5	- 8.6	-4.6	- 5.7	+ 4.2	- 0.8	+1.6	- 0.8
5086-H112,angle	46.7	28.5	15.8	- 0.4	- 2.5	- 1.9	-	-	-	-	-	-
5456-H321	55.5	38.8	13.5	- 0.9	- 5.7	+ 8.9	-3.7	-10.2	0.0	-10.0	-5.4	-24.4
6061-T6	47.4	41.3	16.2	- 0.4	+ 1.5	- 8.6	-5.2	0.0	-41.6	- 7.3	-1.8	-57.9
7039-T64	62.5	53.3	15.5	+ 2.2	+ 5.8	+12.9	-	-	-	-	-	-
7039-T64,welded	49.2	35.0	6.0	+17.4	+ 4.1	+66.7	-	-	-	-	-	-

1. TS - Tensile strength, KSI
   YS - Yield strength, KSI
   El - Elongation, percent in 2 inches

2. TS - Tensile strength
   YS - Yield strength
   El - Elongation

Table 5. 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(8)
172	Be-Cu	97.80	--	--	0.05	--	--	--	--	Be 1.90 Co 0.25	NCEL
172	Be-Cu, chain, cast	97.5	--	--	--	--	--	--	--	Be 2.0 Co 0.5	NCEL
220	Commercial Bronze	90	10	--	--	--	--	--	--	--	INCO(8)
230	Red Brass	85	15	--	--	--	--	--	--	--	INCO(8)
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(8)
270	Yellow Brass	65.0	35.0	--	--	--	--	--	--	--	INCO(8)
280	Muntz Metal	60.69	39.29	--	--	--	<0.02	--	--	--	NCEL
280	Muntz Metal	60.0	40.0	--	--	--	--	--	--	--	INCO(8)
675	Mn Bronze A	56.0	42.0	--	--	1.0	1.0	--	--	Mn-0.01	INCO(8)
--	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(8)
--	Ni Brass	50.0	40.0	--	8.0	--	2.0	--	--	--	INCO(8)
--	G Bronze, cast	88.0	10.0	2.0	--	--	--	--	--	--	INCO(8)
--	G Bronze, Modified, cast	88.0	4.0	8.0	--	--	--	--	--	--	INCO(8)
--	M Bronze, cast	88.2	4.0	6.0	--	--	--	--	2.0	--	INCO(8)
--	Leaded Tin Bronze, cast	85.0	5.0	5.0	--	--	--	--	5.0	--	INCO(8)
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(8)
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(8)
614	Al Bronze D	90.11	--	0.15	--	6.59	3.15	--	<0.02	--	NCEL
614	Al Bronze 7%	90.0	--	--	--	7.0	3.0	--	--	--	INCO(8)
--	Al Bronze 10% cast	89.0	--	--	--	10.0	1.0	--	--	--	INCO(8)
--	Al Bronze 11%, cast	86.0	--	--	--	10.0	4.0	--	--	--	INCO(8)
--	Al Bronze 13%, cast	83.0	--	--	--	13.0	4.0	--	--	--	INCO(8)
--	Ni-Al Bronze #1	80.0	--	--	4.0	11.0	4.0	--	--	Mn-1.0	INCO(8)
--	Ni-Al Bronze #2	80.0	--	--	5.0	10.0	4.0	--	--	Mn-0.5	INCO(8)

Table 5. (cont'd)

CDA No.[1]	Material	Cu	Zn	Sn	Ni	Al	Fe	Si	Pb	Other	Source[2]
--	Ni-Al Bronze #3	80.0	--	--	5.0	9.0	3.5	--	--	Mn-3.0	INCO[8]
653	Si Bronze 3%	97.0	--	--	--	--	--	3.0	--	--	INCO[8]
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[8]
--	Ni-Vee Bronze A, cast	88.0	5.0	2.0	5.0	--	--	--	--	--	INCO[8]
--	Ni-Vee Bronze B, cast	87.0	5.0	2.0	5.0	--	--	1.0	--	--	INCO[8]
--	Ni-Vee Bronze C, cast	80.0	5.0	5.0	5.0	--	--	5.0	--	--	INCO[8]
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[8]
--	Cu-Ni 90-10, cast	86.0	--	--	11.0	--	1.4	--	--	Mn-1.3	INCO[8]
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[8]
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[8]
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[8]
--	Cu-Ni-Zn-Pb	62.0	8.0	--	25.0	--	--	--	5.0	--	INCO[8]
752	Nickel-Silver	65.0	17.0	--	18.0	--	--	--	--	--	INCO[8]

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

Table 6. Corrosion of Copper Alloys in Sea Water

Alloy	CDA No.[1]	Exposure Days	Exposure Depth, Feet	Corrosion Rate MPY[2]	Corrosion Type[3]	Source[4]
Copper, O Free	102	181	5	1.4	C,P[5]	NCEL
		181	5	1.8	G	INCO[8]
		197	2340	0.8	U	NCEL
		197	2340	1.4	U	INCO[8]
		123	5640	1.6	U	NCEL
		123	5640	1.5	U	INCO[8]
Be-Cu	172	181	5	0.1	U	NCEL
Be-Cu,MIG Weld		181	5	0.1	U	NCEL
Be-Cu, TIG Weld		181	5	0.1	ET	NCEL
Be-Cu, Chain		181	5	0.1	U	NCEL
Commercial Bronze	220	181	5	1.1	U	INCO[8]
		197	2340	0.3	U	INCO[8]
		123	5640	0.6	U	INCO[8]
Red Brass	230	181	5	1.8	SL DZ	INCO[8]
		197	2340	1.0	U	INCO[8]
		123	5640	1.3	U	INCO[8]
As Admiralty	443	181	5	1.3	U	NCEL
		181	5	1.8	G	INCO[8]
		197	2340	0.6	U	NCEL
		197	2340	1.0	U	INCO[8]
		123	5640	1.0	U	NCEL
		123	5640	1.1	U	INCO[8]
Yellow Brass	270	181	5	2.1	U	INCO[8]
		197	2340	0.9	U	INCO[8]
		123	5640	1.4	U	INCO[8]
Muntz Metal	280	181	5	2.4	DZ	NCEL
		181	5	3.4	SL DZ	INCO[8]
		197	2340	0.7	SL DZ,P[6]	NCEL
		197	2340	0.7	U	INCO[8]
		123	5640	1.6	SL DZ	NCEL
		123	5640	2.1	U	INCO[8]
Mn Bronze A	675	181	5	4.8	S DZ	INCO[8]
		197	2340	1.2	S DZ	INCO[8]
		123	5640	2.9	S DZ	INCO[8]
Ni-Mn Bronze, Cast		181	5	<0.1	SL DZ	NCEL
		197	2340	0.4	SL DZ	NCEL
		123	5640	0.5	SL DZ	NCEL
Al Brass		181	5	0.8	G	INCO[8]
		197	2340	0.5	U	INCO[8]
		123	5640	0.7	U	INCO[8]
Ni Brass		181	5	1.1	U	INCO[8]
		197	2340	0.8	U	INCO[8]
		123	5640	1.3	U	INCO[8]
G Bronze		181	5	1.3	U	INCO[8]
		197	2340	0.2	U	INCO[8]
		123	5640	0.5	U	INCO[8]
Modified G Bronze		181	5	1.3	G	INCO[8]
		197	2340	0.3	U	INCO[8]
		123	5640	0.5	U	INCO[8]

Table 6. Corrosion of Copper Alloys in Sea Water (Cont'd)

Alloy	CDA No.[1]	Exposure Days	Exposure Depth, Feet	Corrosion Rate MPY[2]	Corrosion Type[3]	Source[4]
M Bronze	-	181	5	1.6	G	INCO[8]
		197	2340	0.4	U	INCO[8]
		123	5640	0.5	U	INCO[8]
Leaded Sn Bronze	-	181	5	1.4	G	INCO[8]
		197	2340	0.5	U	INCO[8]
		123	5640	0.4	U	INCO[8]
P Bronze A	510	181	5	1.1	U	NCEL
		181	5	1.6	P[7]	INCO[8]
		197	2340	0.3	U	NCEL
		197	2340	0.4	U	INCO[8]
		123	5640	0.6	U	NCEL
		123	5640	0.5	U	INCO[8]
P Bronze D	524	181	5	1.1	NU	INCO[8]
		197	2340	0.4	U	INCO[8]
		123	5640	0.5	U	INCO[8]
Al Bronze, 5%	606	181	5	1.1	G	INCO[8]
		197	2340	0.4	U	INCO[8]
		123	5640	0.6	U	INCO[8]
Al Bronze, 7%	614	181	5	2.9	NU,DA	NCEL
		181	5	0.8	G	INCO[8]
		197	2340	0.3	U	NCEL
		197	2340	0.3	U	INCO[8]
		123	5640	0.5	SL DA	NCEL
		123	5640	0.6	U	INCO[8]
Al Bronze, 10%	-	181	5	2.1	MO DA	INCO[8]
		197	2340	0.3	MO DA	INCO[8]
		123	5640	0.7	SL DA	INCO[8]
Al Bronze, 13%	-	181	5	2.1	S DA	INCO[8]
		197	2340	0.4	MO DA	INCO[8]
		123	5640	0.5	VSL DA	INCO[8]
Ni-Al Bronze #2	-	181	5	1.0	C[8]	INCO[8]
		197	2340	0.3	U	INCO[8]
		123	5640	0.5	U	INCO[8]
Si Bronze, 3%	653	181	5	1.7	U	INCO[8]
		197	2340	1.1	U	INCO[8]
		123	5640	1.3	U	INCO[8]
Si Bronze, A	655	181	5	1.8	U	NCEL
		181	5	1.6	G	INCO[8]
		197	2340	0.9	U	NCEL
		197	2340	1.1	U	INCO[8]
		123	5640	1.6	U	NCEL
		123	5640	1.4	U	INCO[8]
Ni-Vee Bronze A	-	181	5	2.0	P[9]	INCO[8]
		197	2340	0.6	U	INCO[8]
		123	5640	0.7	U	INCO[8]
Ni-Vee Bronze B	-	181	5	1.8	P[7]	INCO[8]
		197	2340	0.6	U	INCO[8]
		123	5640	0.6	U	INCO[8]

Table 6. Corrosion of Copper Alloys in Sea Water (Cont'd)

Alloy	CDA No[1]	Exposure		Corrosion Rate MPY[2]	Corrosion Type[3]	Source[4]
		Days	Depth, Feet			
Ni-Vee Bronze C	-	181	5	1.8	U	INCO[8]
		197	2340	0.8	U	INCO[8]
		123	5640	0.8	U	INCO[8]
Cu-Ni, 90-10	706	181	5	1.1	NU	NCEL
		181	5	0.9	U	INCO[8]
		197	2340	0.8	U	NCEL
		197	2340	0.8	U	INCO[8]
		123	5640	1.6	U	NCEL
		123	5640	0.8	U	INCO[8]
Cu-Ni,90-10,Cast	-	181	5	1.1	U	INCO[8]
Cu-Ni, 80-20	710	181	5	2.8	G	INCO[8]
		197	2340	0.7	U	NCEL
		197	2340	1.1	U	INCO[8]
		123	5640	1.2	U	INCO[8]
		123	5640	1.9	U	INCO[8]
Cu-Ni,70-30,0.5 Fe	715	181	5	0.5	U	NCEL
		181	5	0.5	G	INCO[8]
		197	2340	0.7	U	NCEL
		197	2340	0.9	U	INCO[8]
		123	5640	1.2	U	NCEL
		123	5640	1.3	U	INCO[8]
Cu-Ni,70-30,5.0 Fe	716	181	5	0.8	IP,C[10]	NCEL
		197	2340	0.1	U	NCEL
		123	5640	0.2	U	NCEL
Cu-Ni, 55-45	-	181	5	1.8	U	INCO[8]
		197	2340	0.8	U	INCO[8]
		123	5640	0.7	U	INCO[8]
Nickel-Silver	752	181	5	1.1	U	INCO[8]
		197	2340	1.0	U	INCO[8]
		123	5640	2.0	U	INCO[8]
Cu-Ni-Zn-Pb	-	181	5	1.0	U	INCO[8]
		197	2340	0.5	U	INCO[8]
		123	5640	0.9	U	INCO[8]

1. Copper Development Association Number.
2. MPY - mils penetration per year, calculated from weight loss.
3. Type of corrosion:
   - C - crevice
   - DA - dealuminification
   - DZ - dezincification
   - ET - etched
   - G - general
   - I - Incipient
   - MO - moderate
   - NU - non-uniform
   - P - pitting
   - S - severe
   - SL - slight
   - U - uniform
   - V - very
4. Numbers refer to references at end of paper.
5. Crevice corrosion to 5 mils maximum pit depth 22 mils.
6. Maximum pit depth 10 mils average 2.3 mils.
7. Maximum pit depth 4 mils.
8. Crevice corrosion to 8 mils.
9. Maximum pit depth 7 mils.
10. Crevice corrosion to 5 mils.

Table 7. Changes in Mechanical Properties of Copper Alloys After Exposure.

Alloy	CDA No.[1]	Original Properties[2]			Percent Change After Exposure[3]								
					181 Days Surface			197 Days, 2,500 Feet			123 Days, 6,000 Feet		
		TS	YS	El	TS	YS	El	TS	YS	El	TS	YS	El
Copper, O Free	102	33.4	14.2	52.0	+4.2	+19.7	-14.4	-7.8	-18.3	- 3.7	+1.5	- 5.6	- 1.9
Be-Cu	172	176.2	162.1	3.5	-6.6	- 6.0	-28.6	--	--	--	--	--	--
Be-Cu, MIG welded	172	158.2	156.5	3.5	+0.3	- 1.0	-28.6	--	--	--	--	--	--
Be-Cu, TIG welded	172	166.4	162.2	3.0	+3.2	- 3.9	-16.7	--	--	--	--	--	--
As Admiralty	443	50.9	19.0	66.0	-2.2	- 9.5	-11.7	-6.1	-20.5	- 3.0	-0.4	+ 3.2	- 2.0
Muntz Metal	280	55.5	24.4	52.8	-6.8	-16.4	-12.9	-6.2	-16.7	- 5.8	-3.8	- 3.3	- 5.9
Ni-Mn Bronze, cast	--	70.6	31.0	20.0	-9.5	+14.2	-35.0	-3.4	-16.6	+15.8	-1.8	-10.0	+25.0
P Bronze A	510	51.3	25.0	64.2	-0.2	- 6.8	- 2.3	-3.2	-12.8	- 0.9	0.0	- 2.8	+ 3.3
P Bronze D	524	63.9	27.9	69.8	-0.5	+ 0.7	+ 3.6	0.0	- 3.3	+ 2.6	+0.6	0.0	0.0
Al Bronze, 7%	614	84.6	51.2	45.0	-2.5	- 2.9	-20.4	+0.3	- 1.8	- 7.4	+2.0	- 8.5	+ 0.3
Si Bronze A	655	64.4	27.5	61.3	-1.4	- 7.3	+ 3.3	-1.6	-14.0	- 3.1	+4.0	- 2.4	- 1.6
Cu-Ni, 90-10	706	42.7	15.9	42.0	+3.7	+ 9.4	-17.9	-0.7	+ 0.4	- 2.4	+3.3	+11.3	0.0
Cu-Ni, 70-30, 0.5 Fe	715	58.3	26.4	41.2	+2.9	- 9.1	-13.1	-2.6	-14.3	+ 0.8	+1.0	- 2.3	+ 2.7
Cu-Ni, 70-30, 5 Fe	716	78.3	41.2	35.2	+3.4	+ 5.8	-18.2	+1.1	- 4.0	0.0	+2.2	+ 4.9	+ 0.9

1. Copper Development Association Number.
2. TS - Tensile strength, KSI
   YS - Yield strength, KSI
   El - Elongation, percent in 2 inches
3. TS - Tensile strength
   YS - Yield strength
   El - Elongation

Table 8. 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[8]
Ni-200	99.50	0.05	0.29	0.04	0.006	0.07	0.02	--	--	--	--	NCEL
Ni-200	99.5	0.06	--	--	--	--	--	--	--	--	--	INCO[8]
Ni-201	99.5	0.01	--	--	--	--	--	--	--	--	--	INCO[8]
Ni-211	95.0	--	5.0	--	--	--	--	--	--	--	--	INCO[8]
Ni-270	99.97	--	--	--	--	--	--	--	--	--	--	INCO[8]
Ni-210, cast	95.6	--	1.0	--	--	2.0	--	--	--	--	--	INCO[8]
Ni-301	94.0	--	--	--	--	--	--	--	--	--	Al-4.5	INCO[8]
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[8]
Ni-Cu 402	58.00	--	0.90	1.20	--	0.10	40.00	--	--	--	--	INCO[8]
Ni-Cu 406	84.00	--	0.90	1.40	--	0.20	13.00	--	--	--	--	INCO[8]
Ni-Cu 410, cast	66.00	--	0.80	1.00	--	1.60	31.00	--	--	--	--	INCO[8]
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[8]
Ni-Cu 505, cast	64.00	--	0.80	2.00	--	4.00	29.00	--	--	--	--	INCO[8]
Ni-Cu	45.00	--	1.00	0.10	--	--	54.00	--	--	--	--	INCO[8]
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[8]
Ni-Cr-Fe 610, cast	71.0	--	--	9.0	--	2.0	--	16.0	--	--	--	INCO[8]
Ni-Cr-Fe X750	73.0	--	--	7.0	--	--	--	15.0	2.5	--	--	INCO[8]
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 Al-0.60	NCEL
Ni-Cr-Fe 88	71.0	--	--	7.0	--	--	--	10.0	--	--	Sn-5.0 Bi-3.0	INCO[8]
Ni-Cr-Mo 3	58.0	--	--	3.0	--	--	--	19.0	--	19.0	--	INCO[8]
Ni-Cr-Mo 625	63.0	--	--	--	--	--	--	22.0	--	9.0	--	INCO[8]
Ni-Co-Cr-Mo 700	46.0	--	--	1.0	--	--	--	15.0	--	3.75	Co-28.5 Al-3.0	INCO[8]
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[8]
Ni-Fe-Cr 804	43.0	--	--	25.0	--	--	--	29.0	--	--	--	INCO[8]

Table 8. (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(8)
Ni-Fe-Cr 825Cb	42.0	--	--	30.0	--	--	2.0	22.0	--	3.0	--	INCO(8)
Ni-Fe-Cr 901	43.0	--	--	34.0	--	--	--	14.0	--	--	--	INCO(8)
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(8)
Ni-Cr-Fe-Mo "G"	45.0	--	--	20.0	--	--	2.0	21.0	--	7.0	--	INCO(8)
Ni-Cr-Fe-Mo "X"	60.0	--	--	19.0	--	--	--	22.0	--	9.0	--	INCO(8)
Ni-Mo-Fe "B"	60.0	--	--	5.0	--	--	--	--	--	26.0	--	INCO(8)
Ni-Mo-Cr "C"	55.68	0.05	0.52	6.32	0.009	0.62	--	15.33	--	16.71	W-3.53 Co-0.96 V-0.26 P-0.010	NCEL
Ni-Mo-Cr "C"	60.0	--	--	5.0	--	--	--	15.0	--	16.0	W-4.0	INCO(8)
Ni-Sn-Zn 23	79.0	--	2.0	--	--	--	--	--	--	--	Sn-8.0 Zn-7.0 Pb-4.0	INCO(8)
Ni-Cr 65-35	65.0	--	--	--	--	--	--	35.0	--	--	--	INCO(8)
Ni-Cr 75	78.0	--	--	--	--	--	--	20.0	--	--	--	INCO(8)
Ni-Cr 80-20	80.0	--	--	--	--	--	--	20.0	--	--	--	INCO(8)
Ni-Mo 2	66.0	--	--	2.0	--	--	--	--	--	30.0	--	INCO(8)
Ni-Si D	86.0	--	--	--	--	10.0	3.0	--	--	--	--	INCO(8)

1. Numbers refer to references at end of paper.

Table 9. Corrosion of Nickel Alloys in Sea Water.

Alloy	Exposure		Corrosion[1] Rate, MPY	Pit Depth, mils,		Crevice[2] Corrosion, Depth, Mils	Corrosion[2] Type	Source[3]
	Days	Depth, Feet		Max.	Avg.			
Electrolytic Ni	181	5	4.5	30(PR)	--	30(PR)	C,P	INCO[8]
	197	2340	0.4	50(PR)	--	50(PR)	C,P	INCO[8]
	123	5640	<0.1	--	--	3	C	INCO[8]
Ni-200	181	5	1.9	45	--	50	C,P	NCEL
	181	5	7.2	50(PR)	--	50(PR)	C,P	INCO[8]
	197	2340	0.5	--	--	43	C,EXE	NCEL
	197	2340	0.5	--	--	10	C,P	INCO[8]
	123	5640	0.7	--	--	SL	SLC,EXE	NCEL
	123	5640	<0.1	--	--	2	C	INCO[8]
Ni-201	181	5	6.7	50(PR)	--	50(PR)	C,P	INCO[8]
	197	2340	0.5	50(PR)	--	50(PR)	C,P	INCO[8]
	123	5640	0.5	50(PR)	--	--	P	INCO[8]
Ni-211	181	5	5.0	50(PR)	--	50(PR)	C,P	INCO[8]
	197	2340	0.5	32(PR)	--	32(PR)	C,P	INCO[8]
	123	5640	0.3	--	--	22	C	INCO[8]
Ni-270	181	5	6.5	10	--	21	C,P	INCO[8]
Ni-210, cast	181	5	5.0	30	--	12	C,P	INCO[8]
	197	2340	0.6	--	--	--	IC,IP	INCO[8]
	123	5640	2.0	8	--	--	P	INCO[8]
Ni-301	181	5	3.8	18	--	--	P	INCO[8]
	197	2340	1.1	--	--	50(PR)	C	INCO[8]
	123	5640	2.8	--	--	50(PR)	C	INCO[8]
Ni-Cu 400	181	5	0.6	28	18.7	15	C,P	NCEL
	181	5	5.8	12	--	40(PR)	C,P	INCO[8]
	197	2340	0.4	10	9.5	11	C,P	NCEL
	197	2340	0.4	--	--	7	C	INCO[8]
	123	5640	0.8	--	--	--	U	NCEL
	123	5640	0.4	--	--	--	U	INCO[8]

Table 9. (cont'd)

Alloy	Exposure		Corrosion[1] Rate MPY	Pit Depth, mils,		Crevice[2] Corrosion, Depth, Mils	Corrosion[2] Type	Source[3]
	Days	Depth, Feet		Max.	Avg.			
Ni-Cu 400, welded, 180 electrode	181	5	0.7	11	7.6	--	P	NCEL
Ni-Cu 400, welded, 60 electrode	181	5	0.5	12	8	--	P	NCEL
Ni-Cu 402	181	5	3.6	9	--	13	C,P	INCO[8]
	197	2340	0.4	--	--	--	U	INCO[8]
	123	5640	0.3	--	--	--	U	INCO[8]
Ni-Cu 406	181	5	7.5	50(PR)	--	50(PR)	C,P	INCO[8]
	197	2340	0.4	--	--	--	U	INCO[8]
	123	5640	0.4	--	--	9	C	INCO[8]
Ni-Cu 410, cast	181	5	1.3	16	--	14	C,P	INCO[8]
	197	2340	0.8	--	--	--	U	INCO[8]
	123	5640	0.6	--	--	--	U	INCO[8]
Ni-Cu K500	181	5	1.0	8	7	12	C,P	NCEL
	181	5	6.4	30(PR)	--	30(PR)	C,P	INCO[8]
	197	2340	0.4	--	--	--	U	INCO[8]
	123	5640	0.4	--	--	9	C	INCO[8]
Ni-Cu K500, welded, 134 electrode	181	5	0.9	12	9.3	--	P[4]	NCEL
Ni-Cu K500, welded, 64 electrode	181	5	1.1	8	5.6	--	P	NCEL
Ni-Cu 505 cast	181	5	0.7	--	--	--	NU	INCO[8]
	197	2340	0.3	--	--	--	U	INCO[8]
	123	5640	1.4	--	--	--	U	INCO[8]
Ni-Cu, 54-45	181	5	1.8	--	--	--	U	INCO[8]
	197	2340	0.8	--	--	--	U	INCO[8]
	123	5640	0.7	--	--	--	U	INCO[8]

Table 9. (cont'd)

Alloy	Exposure		Corrosion[1] Rate, MPY	Pit Depth, mils,		Crevice[2] Corrosion, Depth, Mils	Corrosion[2] Type	Source[3]
	Days	Depth, Feet		Max.	Avg.			
Ni-Cr-Fe 600	181	5	0.2	105	--	--	E,P[5]	NCEL
	181	5	1.7	50(PR)	--	50(PR)	C,P	INCO[8]
	197	2340	0.2	--	--	15	C	INCO[8]
	123	5640	<0.1	--	--	4	C	INCO[8]
Ni-Cr-Fe 600, welded, 62 electrode	181	5	<0.1	--	--	--	IP[6]	NCEL
Ni-Cr-Fe 600, welded, 82 electrode	181	5	<0.1	--	--	--	(7)	NCEL
Ni-Cr-Fe 600, welded, 182 electrode	181	5	1.3	--	--	--	(8)	NCEL
Ni-Cr-Fe 610, cast	181	5	1.8	180(PR)	--	23	P,C	INCO[8]
	197	2340	0.2	--	--	15	C	INCO[8]
	123	5640	0.3	--	--	4	C	INCO[8]
Ni-Cr-Fe 718	181	5	<0.1	--	--	--	NC	NCEL
Ni-Cr-Fe X750	181	5	1.4	50(PR)	--	50(PR)	C,P	INCO[8]
	197	2340	0.4	--	--	18	C	INCO[8]
	123	5640	<0.1	--	--	--	NC	INCO[8]
Ni-Cr-Fe 88	181	5	1.1	108	--	17	P,C	INCO[8]
	197	2340	0.3	--	--	17	C	INCO[8]
	123	5640	0.1	--	--	4	C	INCO[8]
Ni-Cr-Mo 3	181	5	<0.1	--	--	--	NC	INCO[8]
	197	2340	<0.1	--	--	--	NC	INCO[8]
	123	5640	<0.1	--	--	--	NC	INCO[8]
Ni-Cr-Mo 625	181	5	<0.1	--	--	--	NC	INCO[8]
Ni-Co-Cr 700	181	5	<0.1	--	--	--	NC	INCO[8]
	197	2340	<0.1	--	--	--	NC	INCO[8]
	123	5640	<0.1	--	--	--	NC	INCO[8]

Table 9. (cont'd)

Alloy	Exposure		Corrosion(1) Rate, MPY	Pit Depth, mils,		Crevice(2) Corrosion, Depth, Mils	Corrosion(2) Type	Source(3)
	Days	Depth, Feet		Max.	Avg.			
Ni-Fe-Cr 800	181	5	<0.1	--	--	--	NC	NCEL
	181	5	<0.1	--	--	--	NC	INCO(8)
	197	2340	<0.1	--	--	--	NC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)
Ni-Fe-Cr 804	181	5	<0.1	--	--	--	NC	INCO(8)
	197	2340	<0.1	--	--	--	NC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)
Ni-Fe-Cr 825	181	5	<0.1	--	--	33	C(9)	NCEL
	181	5	<0.1	--	--	--	NC	INCO(8)
	197	2340	<0.1	--	--	--	NC	NCEL
	197	2340	<0.1	--	--	--	NC	INCO(8)
	123	5640	0.0	--	--	--	NC	NCEL
	123	5640	<0.1	--	--	--	NC	INCO(8)
Ni-Fe-Cr 825, welded, 135 electrode	181	5	<0.1	--	--	--	NC	NCEL
Ni-Fe-Cr 825, welded, 65 electrode	181	5	<0.1	--	--	--	NC	NCEL
Ni-Fe-Cr 825, sensitized(10)	181	5	<0.1	--	--	--	NC	INCO(8)
	197	2340	<0.1	--	--	--	NC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)
Ni-Fe-Cr 825 Cb	181	5	<0.1	--	--	--	NC	INCO(8)
	197	2340	<0.1	--	--	--	NC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)
Ni-Fe-Cr 901	181	5	<0.1	--	--	--	NC	INCO(8)
	197	2340	<0.1	--	--	--	NC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)
Ni-Fe-Cr 902	181	5	2.2	--	--	26	C	NCEL

Table 9. (cont'd)

Alloy	Exposure		Corrosion(1) Rate, MPY	Pit Depth, mils,		Crevice(2) Corrosion, Depth, Mils	Corrosion(2) Type	Source(3)
	Days	Depth, Feet		Max.	Avg.			
Ni-Cr-Fe-Mo F	181	5	<0.1	--	--	--	NC	INCO(8)
	197	2340	<0.1	--	--	--	NC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)
Ni-Cr-Fe-Mo G	181	5	<0.1	--	--	--	NC	INCO(8)
	197	2340	<0.1	--	--	--	NC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)
Ni-Cr-Fe-Mo X	181	5	<0.1	--	--	--	NC	INCO(8)
	197	2340	<0.1	--	--	--	NC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)
Ni-Mo-Fe B	181	5	7.9	--	--	--	G	INCO(8)
	197	2340	<0.1	--	--	--	NU,ET	INCO(8)
	123	5640	2.3	--	--	--	U	INCO(8)
Ni-Mo-Cr C	181	5	<0.1	--	--	--	NC	NCEL
	181	5	<0.1	--	--	--	NC	INCO(8)
	197	2340	0.0	--	--	--	NC	NCEL
	197	2340	<0.1	--	--	--	NC	INCO(8)
	123	5640	<0.1	--	--	--	NC	NCEL
	123	5640	<0.1	--	--	--	NC	INCO(8)
Ni-Sn-Zn 23	181	5	3.7	37	--	27	P,C	INCO(8)
	197	2340	0.5	--	--	15	C	INCO(8)
	123	5640	2.6	--	--	25	C	INCO(8)
Ni-Cr 65-35	181	5	2.4	50(PR)	--	50(PR)	C,P	INCO(8)
	197	2340	<0.1	--	--	--	NC	INCO(8)
	123	5640	0.3	--	--	24	C	INCO(8)
Ni-Cr 75	181	5	1.5	50(PR)	--	50(PR)	C,P	INCO(8)
	197	2340	0.2	--	--	32(PR)	C	INCO(8)
	123	5640	<0.1	--	--	--	IC	INCO(8)

Table 9. (cont'd)

Alloy	Exposure		Corrosion[1] Rate, MPY	Pit Depth, mils,		Crevice[2] Corrosion, Depth, Mils	Corrosion[2] Type	Source[3]
	Days	Depth, Feet		Max.	Avg.			
Ni-Cr 80	181	5	2.6	50(PR)	--	50(PR)	C,P	INCO[8]
	197	2340	0.2	--	--	32(PR)	C	INCO[8]
	123	5640	<0.1	--	--	2	C	INCO[8]
Ni-Mo 2	181	5	4.7	5	--	--	P	INCO[8]
	197	2340	1.0	--	--	--	U	INCO[8]
	123	5640	1.2	--	--	--	G	INCO[8]
Ni-Si D	181	5	2.5	19	--	25	C,P	INCO[8]
	197	2340	0.2	--	--	25	C	INCO[8]
	123	5640	1.3	--	--	12	C	INCO[8]

1. MPY - mils penetration per year calculated from weight loss.
2. Corrosion Type

C - crevice	NC - no visible corrosion
E - edge	NU - non-uniform
ET - etched	P - pitting
EX - extensive	PR - perforated
G - general	SL - slight
I - incipient	U - uniform

3. Numbers refer to references at end of paper.
4. Also pitting in heat affected zone and on weld bead.
5. Two deep pits.
6. Incipient pitting only on weld bead.
7. Slight roughening of weld bead.
8. Weld bead perforated.
9. Corrosion under barnacles to 44 mils deep.
10. Heated for 1 hour at 1200°F.

Table 10. Changes in Mechanical Properties of Nickel Alloys After 6 Months of Exposure.

Alloy	Original Properties[1]			Percent Change After Exposure[2]								
				Surface, 181 Days			2,370 Feet, 197 Days			5,640 Feet, 123 Days		
	TS	YS	El	TS	YS	El	TS	YS	El	TS	YS	El
Ni 200	65.1	17.5	46.0	+0.8	+10.3	- 4.3	0.0	-10.0	- 4.1	-0.9	-16.0	-0.4
Ni-Cu 400	75.1	28.8	44.3	+2.1	+ 1.4	-10.8	+2.3	+ 1.2	- 0.7	+2.1	+ 1.4	+0.5
Ni-Fe-Cr 825	108.1	52.3	37.8	+0.7	- 2.1	- 7.4	+0.4	+ 3.9	- 5.8	+0.4	+ 3.8	0.0
Ni-Fe-Cr 902	98.9	40.3	43.2	-0.5	+ 5.7	-50.2	--	--	--	--	--	--
Ni-Mo-Cr C	120.8	60.0	43.0	+2.9	- 1.2	+14.7	+3.1	- 0.5	+18.1	+3.0	+ 4.5	-0.5

1. Original Properties
   TS - Tensile strength, KSI
   YS - Yield strength, KSI
   El - Elongation, percent in 2"
2. TS - Tensile strength
   YS - Yield strength
   El - Elongation

Table 11. 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(8)
Wrought Iron	0.02	0.06	0.13	0.01	0.13	--	--	--	--	--	2.5 Slag	NCEL
AISI 1010	0.12	0.50	0.004	0.023	0.060	--	--	--	--	--	--	NCEL
AISI 1010	--	0.34	0.01	--	0.02	0.04	0.02	--	--	0.03	--	INCO(8)
Copper Steel	--	0.40	0.01	--	0.02	0.01	0.03	--	--	0.28	--	INCO(8)
ASTM A36	0.20	0.55	0.010	0.020	0.064	--	--	--	--	--	--	NCEL
HSLA #1[1]	0.18	0.86	0.014	1.023	0.28	0.05	0.64	0.18	0.047	--	B-0.1028 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(8)
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(8)
HSLA #7	--	0.43	0.12	--	0.13	0.54	--	--	--	1.0	--	INCO(8)
HSLA #10	--	0.63	0.01	--	--	0.99	--	--	--	1.42	--	INCO(8)
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	NCEL
18% Ni-Maraging	0.02	0.10	0.005	0.007	0.14	17.92	--	4.78	--	--	Al-0.25 Co-8.75 B-0.003 Ti-0.94 Al-0.17	NCEL
1.5% Ni	Not recorded											INCO(8)
3.0% Ni	Not recorded											INCO(8)
5.0% Ni	Not recorded											INCO(8)
9.0% Ni	Not recorded											INCO(8)
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(8)

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

Table 12. Corrosion of Steels in Sea Water

Alloy	Exposed		Corrosion Rate, MPY(1)	Corrosion, Type (13)	Source(2)
	Days	Depth, Feet			
Armco Iron	181	5	6.9	U	INCO(8)
	197	2340	1.9	G	INCO(8)
	123	5640	3.1	U	INCO(8)
Wrought Iron	181	5	5.3	U	NCEL
	197	2340	2.0	U	NCEL
	123	5640	2.6	U	NCEL
AISI 1010	181	5	9.1	U	NCEL
	181	5	9.0	G	INCO(8)
	197	2340	1.5	U	NCEL
	197	2340	1.7	G	INCO(8)
	123	5640	3.0	U	NCEL
	123	5640	2.4	G	INCO(8)
Copper Steel	181	5	9.0	G	INCO(8)
	197	2340	2.0	G	INCO(8)
	123	5640	1.9	U	INCO(8)
ASTM A36	181	5	10.7	C,G(3)	NCEL
	197	2340	1.7	U	NCEL
	123	5640	3.1	U	NCEL
HSLA #1(4)	181	5	9.7	P,G(5)	NCEL
	197	2340	1.4	U	NCEL
	123	5640	2.9	U	NCEL
HSLA #2	181	5	6.8	P,G(6)	NCEL
	197	2340	1.4	U	NCEL
	123	5640	4.7	U	NCEL
HSLA #4	181	5	11.0	G	INCO(8)
	197	2340	1.4	U	NCEL
	197	2340	2.2	G	INCO(8)
	123	5640	3.6	U	NCEL
	123	5640	4.3	C, U(7)	INCO(8)
HSLA #5	181	5	8.9	U	NCEL
	181	5	11.0	G	INCO(8)
	197	2340	1.4	U	NCEL

Table 12. Corrosion of Steels in Sea Water (Cont'd)

Alloy	Exposed		Corrosion Rate, MPY[1]	Corrosion,[13] Type	Source[2]
	Days	Depth, Feet			
HSLA #5 (Cont'd)	197	2340	3.3	E,IP	INCO[8]
	123	5640	3.1	U	NCEL
	123	5640	6.0	E	INCO[8]
HSLA #7	181	5	11.0	G	INCO[8]
	197	2340	2.3	G	INCO[8]
	123	5640	3.5	C, U[8]	INCO[8]
HSLA #10	181	5	11.0	G	INCO[8]
	197	2340	2.1	G	INCO[8]
	123	5640	4.1	C, U[7]	INCO[8]
HSLA #12	181	5	8.5	P, U[9]	NCEL
HS #1[10]	181	5	9.9	U	NCEL
HS #2	181	5	8.2	U	NCEL
18% Ni, Maraging	181	5	5.4	P, U[1]	NCEL
	181	5	10.0	P[12]	INCO[8]
18% Ni, Maraging, heat treated	181	5	5.8	U	NCEL
18% Ni, Maraging, welded	181	5	5.1	U	NCEL
1.5 Ni Steel	181	5	11.0	G	INCO[8]
	197	2340	1.9	U	INCO[8]
	123	5640	3.5	U	INCO[8]
3 Ni Steel	181	5	11.0	G	INCO[8]
	197	2340	1.7	G	INCO[8]
	123	5640	3.4	U	INCO[8]
5 Ni Steel	181	5	8.0	G	INCO[8]
	197	2340	1.7	G	INCO[8]
	123	5640	2.8	U	INCO[8]
9 Ni Steel	181	5	10.0	IP	INCO[8]
	197	2340	1.9	G	INCO[8]
	123	5640	5.6	U	INCO[8]

Table 12. Corrosion of Steels in Sea Water (Cont'd)

Alloy	Exposed		Corrosion Rate, MPY[1]	Corrosion,[13] Type	Source[2]
	Days	Depth, Feet			
AISI Type 502	181	5	7.0	P[14]	NCEL
	181	5	13.0	G	INCO[8]
	197	2340	1.2	C,P[15]	NCEL
	123	5640	3.6	P[16]	NCEL

1. MPY-Mils penetration per year calculated from weight loss.
2. Numbers refer to references at end of paper.
3. Crevice corrosion to 8 mils.
4. HSLA signifies a high strength -low alloy steel.
5. Maximum pit depth 11 mils average 10.1.
6. Maximum pit depth 20 mils average 16.5.
7. Crevice corrosion to 9 mils.
8. Crevice corrosion to 4 mils.
9. Maximum pit depth 12 mils average 10.6.
10. HS signifies high strength steel.
11. Only 1 pit 22 mils deep.
12. Broad pits.
13. Types of corrosion:
    - C - Crevice
    - G - General
    - IP - Incipient pitting
    - P - Pitting
    - U - Uniform
14. Maximum pit depth 18 mils average 15.4.
15. Maximum pit depth 20 mils average 16.3, crevice corrosion to 13 mils.
16. Maximum pit depth 23 mils average 18.2.

Table 13. Effect of Exposure on Mechanical Properties of Steels.

Alloy	Original Properties[1]			Percent Change[2]								
				Surface, 181 Days			2,340 Feet, 197 Days			5,640 Feet, 123 Days		
	TS	YS	El	TS	YS	El	TS	YS	El	TS	YS	El
Wrought Iron	47.0	29.9	15.0	+ 6.8	- 7.7	+ 16.7	--	--	--	--	--	--
AISI 1010	54.1	36.3	42.3	+ 3.0	- 0.6	- 17.7	+2.1	+3.7	- 4.3	-0.9	-0.3	+ 1.2
ASTM A36	64.4	40.3	39.5	+ 1.1	- 1.2	- 19.0	+1.8	+4.1	- 1.3	-1.0	+1.6	+ 8.7
HSLA #1[3]	121.4	109.7	12.2	+ 1.1	+ 0.5	+ 13.1	+1.9	+1.6	+39.3	+0.2	+0.7	+41.8
HSLA #2	106.7	87.5	30.0	+ 0.9	+ 3.4	0.0	+3.5	+2.2	- 8.5	+1.3	-2.0	-12.3
HSLA #5	125.4	117.9	15.7	+ 5.9	+ 7.0	- 15.9	+2.3	+2.3	+ 1.6	+1.0	+1.5	- 1.3
HSLA #12	120.0	109.0	26.0	- 0.2	- 2.2	+ 3.8	--	--	--	--	--	--
HS #1[4]	145.0	140.0	22.0	- 2.0	- 2.9	+ 6.8	--	--	--	--	--	--
HS #2	194.0	186.0	15.0	- 3.8	- 4.7	+ 5.3	--	--	--	--	--	--
18 Ni Maraging	285.1	265.6	6.3	+10.4	+14.6	- 9.5	--	--	--	--	--	--
18 Ni Maraging, HT	320.7	315.4	2.5	- 7.3	- 8.5	+100.0	--	--	--	--	--	--
18 Ni Maraging, HT, Welded	169.6	150.7	8.3	+ 1.1	+ 3.2	- 27.7	--	--	--	--	--	--
Type 502	59.2	35.7	33.2	- 4.7	0.0	- 29.2	-1.1	-4.1	- 2.3	-2.0	+5.3	-33.6

1. Original Properties
   TS - Tensile strength, KSI
   YS - Yield strength, KSI
   El - Elongation, percent in 2 inches
2. TS - Tensile strength
   YS - Yield strength
   El - Elongation
3. HSLA - High Strength-Low Alloy Steel
4. HS - High Strength Steel

Table 14. Chemical Composition of Cast Irons.

Material	C	Mn	Si	Ni	Cr	Mo	Cu	Source [1]
Nickel	--	0.68	2.47	1.56	--	--	--	INCO (8)
Ni-Cr #1	--	0.73	1.64	1.66	0.60	--	--	INCO (8)
Ni-Cr #2	--	0.86	1.99	3.22	0.98	--	--	INCO (8)
Ductile #1	--	0.35	2.50	0.91	--	--	--	INCO (8)
Ductile #2	--	0.34	2.24	--	--	--	--	INCO (8)
Silicon	--	--	14.5	--	--	--	--	INCO (8)
Si-Mo	--	--	14.0	--	--	3.0	--	INCO (8)
Austenitic, Type 1	--	1.4	2.05	15.8	1.79	--	6.71	INCO (8)
Austenitic, Type 2	--	1.01	2.29	18.2	2.04	--	--	INCO (8)
Austenitic, Type 3	--	0.6	1.15	28.4	2.87	--	--	INCO (8)
Austenitic, Type 4	--	0.56	5.34	29.7	4.97	--	--	INCO (8)
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 (8)
Austenitic, Type D-2b	--	0.96	2.0	20.8	3.19	--	--	INCO (8)
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 (8)
Austenitic, Hardenable	Not Recorded							INCO (8)

1. Numbers refer to references at end of paper.

Table 15. Corrosion of Cast Irons in Sea Water.

Alloy	Exposed Days	Exposed Depth, Feet	Corrosion Rate MPY[1]	Corrosion Type[2]	Source[3]
Nickel	181	5	8.5	U	INCO[8]
	197	2340	2.2	G	INCO[8]
	123	5640	4.4	U	INCO[8]
Ni-Cr #1	181	5	6.7	U	INCO[8]
	197	2340	1.9	G	INCO[8]
	123	5640	4.3	U	INCO[8]
Ni-Cr #2	181	5	8.5	U	INCO[8]
	197	2340	1.9	G	INCO[8]
	123	5640	4.3	U	INCO[8]
Ductile #1	181	5	10.0	U	INCO[8]
	197	2340	1.9	G	INCO[8]
	123	5640	3.1	U	INCO[8]
Ductile #2	181	5	10.0	U	INCO[8]
	197	2340	2.3	G	INCO[8]
	123	5640	3.9	U	INCO[8]
Silicon	181	5	<0.1	E	INCO[8]
	197	2340	<0.1	NC	INCO[8]
	123	5640	<0.1	NC	INCO[8]
Si-Mo	181	5	<0.1	NC	INCO[8]
	197	2340	<0.1	NC	INCO[8]
	123	5640	<0.1	NC	INCO[8]
Austenitic, Type 1	181	5	4.1	U	INCO[8]
	197	2340	0.8	G	INCO[8]
	123	5640	1.8	G	INCO[8]
Austenitic, Type 2	181	5	5.8	U	INCO[8]
	197	2340	1.3	G	INCO[8]
	123	5640	2.4	G	INCO[8]
Austenitic, Type 3	181	5	5.0	U	INCO[8]
	197	2340	0.8	G	INCO[8]
	123	5640	1.9	G	INCO[8]

Table 15. (cont'd)

Alloy	Exposed Days	Exposed Depth, Feet	Corrosion Rate MPY(1)	Corrosion Type(2)	Source(3)
Austenitic, Type 4	181	5	3.8	U	NCEL
	181	5	3.4	U	INCO(8)
	197	2340	0.8	G	INCO(8)
	123	5640	1.8	G	INCO(8)
Austenitic, D-2	181	5	4.3	G	INCO(8)
	197	2340	1.2	G	INCO(8)
	123	5640	2.6	G	INCO(8)
Austenitic, D-2b	181	5	4.1	G	INCO(8)
	197	2340	1.4	G	INCO(8)
	123	5640	2.1	G	INCO(8)
Austenitic, D-2c	181	5	3.9	U(4)	NCEL
Austenitic, D-3	181	5	4.3	G	INCO(8)
	197	2340	0.9	G	INCO(8)
	123	5640	1.9	G	INCO(8)
Austenitic, hardenable	181	5	4.2	U	INCO(8)
	197	2340	2.8	G	INCO(8)
	123	5640	2.5	G	INCO(8)

1. MPY - Mils penetration per year as calculated from weight losses.
2. Symbols signify the following:
   - E - Etched
   - G - General
   - NC - No visible corrosion
   - U - Uniform
3. Numbers signify references at end of paper.
4. Interdendictic corrosion.

Table 16. Effect of Exposure in Sea Water on the Mechanical Properties of Cast Irons.

	Original[1] Properties			Percent[2] Change Surface, 181 Days		
Alloy	TS	YS	El	TS	YS	El
Austenitic, Type 4	22.8	20.1	2.3	+11.4	+7.4	+30.0
Austenitic, Type D2-C	46.8	41.7	4.7	-17.9	-8.0	-34.0

1. TS - Tensile Strength, SKI
   YS - Yield Strength, KSI
   El - Elongation, percent in 2 inches
2. TS - Tensile Strength
   YS - Yield Strength
   El - Elongation

Table 17. 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[8]
AISI Type 202	0.09	7.6	--	--	--	4.5	17.8	--	--	--	INCO[8]
AISI Type 301	0.11	1.17	0.025	0.021	0.34	6.73	17.4	--	--	--	NCEL
AISI Type 302	0.11	1.36	--	--	--	9.9	17.3	0.12	0.26	--	INCO[8]
AISI Type 302	0.06	1.05	0.020	0.013	0.60	18.2	9.33	--	--	--	NCEL
AISI Type 304	0.06	1.62	--	--	--	9.5	18.2	0.34	0.16	--	INCO[8]
AISI Type 304	0.06	1.73	0.024	0.013	0.43	10.0	18.8	--	--	--	NCEL
AISI Type 304 Sensitized[2]	0.06	1.62	--	--	--	9.5	18.2	0.34	0.16	--	INCO[8]
AISI Type 304 L	0.02	1.45	--	--	--	9.5	17.9	--	--	--	INCO[8]
AISI Type 304 L	0.03	1.24	0.028	0.023	0.68	10.2	18.7	--	--	--	NCEL
AISI Type 309	0.10	1.60	--	--	--	12.7	23.3	--	--	--	INCO[8]
AISI Type 310	0.04	1.78	--	--	--	20.9	25.3	--	--	--	INCO[8]
AISI Type 311	0.20	2.0	--	--	--	25	19	--	--	--	INCO[8]
AISI Type 316	0.05	1.73	--	--	--	13.2	17.2	2.60	--	--	INCO[8]
AISI Type 316	0.06	1.61	0.021	0.016	0.40	13.6	18.3	2.41	--	--	NCEL
AISI Type 316 Sensitized[2]	0.05	1.73	--	--	--	13.2	17.2	2.60	--	--	INCO[8]
AISI Type 316 L	0.02	1.78	--	--	--	13.6	17.7	2.15	--	--	INCO[8]
AISI Type 316 L	0.02	1.31	0.012	0.015	0.47	13.7	17.9	2.76	--	--	NCEL
AISI Type 317	0.05	1.61	--	--	--	13.6	18.7	3.30	--	--	INCO[8]
AISI Type 321	0.06	2.0	--	--	--	10.5	18.5	--	--	--	INCO[8]
AISI Type 325	0.03	0.7	--	--	--	23.5	9.0	--	--	--	INCO[8]
AISI Type 329	0.07	0.46	--	--	--	4.4	27.0	1.40	--	--	INCO[8]
AISI Type 330	0.20	--	--	--	--	34.5	15.0	--	--	--	INCO[8]
AISI Type 347	0.04	1.19	--	--	--	11.3	18.1	--	--	--	INCO[8]
AISI Type 410	0.13	0.4	--	--	--	0.2	12.1	--	--	--	INCO[8]
AISI Type 410	0.13	0.43	0.019	0.005	0.45	0.1	12.3	--	--	--	NCEL
AISI Type 430	0.06	0.4	--	--	--	--	17.7	--	--	--	INCO[8]
AISI Type 446	0.15	0.8	--	--	--	0.2	30.0	--	--	--	INCO[8]
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
20 Cb-3	--	--	--	--	--	34	20	2.3	3.4	--	INCO[8]
PH 14-8 Mo-SRH 950	0.037	0.36	0.004	0.002	0.34	8.12	14.21	2.25	--	1.21 Al	NCEL
PH 15-7 Mo-RH 1100	0.070	0.50	--	0.016	0.28	7.19	15.05	2.19	--	1.11 Al	NCEL

Table 17. (cont'd)

Alloy	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Other	Source[1]
17-7 PH-RH 1050	0.071	0.48	0.017	0.018	0.42	7.42	17.12	--	--	1.19 Al	NCEL
17-7 PH-TH 1050	0.071	0.48	0.017	0.018	0.42	7.42	17.12	--	--	1.19 Al	NCEL
17-4 PH-H 925	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(8)
18Cr-15Mn	--	15	--	--	--	0.5	18	--	--	--	INCO(8)
AM 350	--	--	--	--	--	4	17	3	--	--	INCO(8)
17Cr-7Ni	0.05	0.56	0.026	0.009	0.74	6.80	16.8	--	--	0.79 Ti 0.09 Al	NCEL

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

Table 18. Corrosion of Stainless Steels in Sea Water.

Alloy	Exposure		Corrosion Rate MPY(1)	Pit Depth		Crevice Corrosion Depth, Mils(2)	Corrosion Type(2)	Source(3)
	Days	Depth, Feet		Max.	Avg.			
AISI Type 201	181	5	<0.1	--	--	--	IC	INCO(8)
	197	2340	<0.1	--	--	4	C	INCO(8)
	123	5640	<0.1	--	--	--	IC	INCO(8)
AISI Type 202	181	5	0.6	50(PR)	--	50(PR)	C,P	INCO(8)
	197	2340	<0.1	--	--	--	IC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)
AISI Type 301	181	5	1.9	--	--	--	SE,T to PR	NCEL
	197	2340	0.3	--	--	--	C,P,T	NCEL
	123	5640	0.3	--	--	--	SLC,T	NCEL
AISI Type 302	181	5	0.9	--	--	--	E,C,T to PR	NCEL
	181	5	<0.1	15	--	7	C,P	INCO(8)
	197	2340	0.0	--	--	(PR)	SLT	NCEL
	197	2340	<0.1	--	--	--	IC	INCO(8)
	123	5640	0.0	--	--	--	SLC	NCEL
	123	5640	<0.1	--	--	--	NC	INCO(8)
AISI Type 304	181	5	1.7	--	--	--	E,T to PR	NCEL
	181	5	1.3	45	--	20	C,P	INCO(8)
	197	2340	0.2	--	--	11	C,T	NCEL
	197	2340	<0.1	--	--	--	IC	INCO(8)
	123	5640	<0.1	--	--	--	T	NCEL
	123	5640	<0.1	--	--	--	IC	INCO(8)
AISI Type 304 sensitized(4)	181	5	1.1	50(PR)	--	50(PR)	C,P	INCO(8)
	197	2340	0.6	--	--	50(PR)	C	INCO(8)
	123	5640	0.4	--	--	50(PR)	C	INCO(8)
AISI Type 304 L	181	5	0.6	--	--	--	E,T	NCEL
	181	5	<0.1	--	--	--	IC	INCO(8)
	197	2340	0.2	--	--	8	C,T	NCEL
	197	2340	<0.1	--	--	--	IC	INCO(8)
	123	5640	0.2	--	--	--	SLC,T	NCEL
	123	5640	<0.1	--	--	--	NC	INCO(8)

Table 18. (cont'd)

Alloy	Exposure Days	Exposure Depth, Feet	Corrosion Rate, MPY(1)	Pit Depth Max.	Pit Depth Avg.	Crevice Corrosion Depth, Mils(2)	Corrosion Type(2)	Source(3)
AISI Type 309	181	5	<0.1	--	--	33	C	INCO(8)
	197	2340	<0.1	--	--	--	IC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)
AISI Type 310	181	5	<0.1	--	--	--	IC	INCO(8)
	197	2340	<0.1	--	--	--	IC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)
AISI Type 311	181	5	0.5	28	--	50(PR)	C,P	INCO(8)
	197	2340	<0.1	--	--	--	IC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)
AISI Type 316	181	5	1.2	--	--	--	E,T to PR	NCEL
	181	5	<0.1	--	--	--	IC	INCO(8)
	197	2340	<0.1	--	--	--	NC	NCEL
	197	2340	<0.1	--	--	--	NC	INCO(8)
	123	5640	<0.1	--	--	--	SLE	NCEL
	123	5640	<0.1	--	--	--	NC	INCO(8)
AISI Type 316, sensitized(4)	181	5	0.8	7	--	38	C,P	INCO(8)
	197	2340	<0.1	--	--	8	C	INCO(8)
	123	5640	<0.1	--	--	--	IC	INCO(8)
AISI Type 316 L	181	5	0.3	--	--	--	E,T to PR	NCEL
	181	5	<0.1	--	--	25	C	INCO(8)
	197	2340	<0.1	--	--	18	C	NCEL
	197	2340	<0.1	--	--	8	C	INCO(8)
	123	5640	<0.1	--	--	--	SLC	NCEL
	123	5640	<0.1	--	--	--	NC	INCO(8)
AISI Type 317	181	5	<0.1	--	--	--	NC	INCO(8)
	197	2340	<0.1	--	--	--	IC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)
AISI Type 321	181	5	<0.1	--	--	2	C	INCO(8)
	197	2340	<0.1	--	--	--	IC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)

Table 18. (cont'd)

Alloy	Exposure Days	Exposure Depth, Feet	Corrosion Rate, MPY(1)	Pit Depth Max.	Pit Depth Avg.	Crevice Corrosion Depth, Mils(2)	Corrosion Type(2)	Source(3)
AISI Type 325	181	5	10.0	--	--	--	G	INCO(8)
	197	2340	2.8	12	--	--	P	INCO(8)
	123	5640	2.8	11	--	--	P	INCO(8)
AISI Type 329	181	5	<0.1	--	--	--	IC	INCO(8)
	197	2340	<0.1	--	--	--	NC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)
AISI Type 330	181	5	0.8	50(PR)	--	50(PR)	C,P	INCO(8)
	197	2340	<0.1	--	--	--	IC	INCO(8)
	123	5640	<0.1	--	--	--	IC	INCO(8)
AISI Type 347	181	5	0.9	50(PR)	--	50(PR)	C,P	INCO(8)
	197	2340	<0.1	--	--	--	NC	INCO(8)
	123	5640	<0.1	--	--	10	C	INCO(8)
AISI Type 410	181	5	2.1	--	--	40(PR)	C,T to PR	NCEL
	181	5	3.4	50(PR)	--	50(PR)	C,P	INCO(8)
	197	2340	0.2	--	--	10	E,T,C	NCEL
	197	2340	1.3	50(PR)	--	50(PR)	C,P	INCO(8)
	123	5640	0.2	--	--	--	SLC,T to PR	NCEL
	123	5640	1.9	50(PR)	--	--	P	INCO(8)
AISI Type 430	181	5	1.7	50(PR)	--	50(PR)	C,P	INCO(8)
	197	2340	0.4	30(PR)	--	30(PR)	C,P	INCO(8)
	123	5640	<0.1	--	--	--	IC	INCO(8)
AISI Type 446	181	5	0.3	50(PR)	--	50(PR)	C,P	INCO(8)
	197	2340	<0.1	--	--	--	IC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)

Table 18. (cont'd)

Alloy	Exposure		Corrosion Rate MPY(1)	Pit Depth		Crevice Corrosion Depth, Mils(2)	Corrosion Type(2)	Source(3)
	Days	Depth, Feet		Max.	Avg.			
20 Cb	181	5	<0.1	--	--	--	NC	NCEL
	197	2340	<0.1	--	--	--	SLC	NCEL
	197	2340	<0.1	--	--	--	IC	INCO(8)
	123	5640	<0.1	--	--	--	NC	NCEL
	123	5640	<0.1	--	--	--	NC	INCO(8)
20 CB-3	181	5	<0.1	--	--	--	IC	INCO(8)
PH 14-8 Mo-SRH 950, Butt weld	181	5	1.7	--	--	--	Tin HAZ to PR SE,T to PR, WPR	 NCEL
	197	2340	<0.1	--	--	--	IP,T	NCEL
PH 14-8 Mo-SRH 950, circular weld	181	5	3.1	--	--	--	SE,T to PR	NCEL
	197	2340	0.4	--	--	--	C,T	NCEL
PH 15-7 Mo-RH 1100, Butt weld	181	5	3.7	--	--	--	SE,T to PR	NCEL
	197	2340	0.2	--	--	--	T	NCEL
PH 15-7 Mo-RH 1100, circular weld	181	5	3.7	--	--	--	SE,T to PR	NCEL
	197	2340	0.6	--	--	--	C,T	NCEL
17-7 PH-RH 1050, Butt weld	181	5	3.2	--	--	--	SE,T to PR,Tin W	NCEL
	197	2340	0.6	--	--	--	Tedge HAZ	NCEL
17-7 PH-RH 1050, circular weld	181	5	2.9	--	--	--	SE,T to PR	NCEL
	197	2340	0.3	--	--	--	SCC in HAZ	NCEL
17-7 PH-TH 1050, Butt weld	181	5	2.7	--	--	--	SE,Tin to W (PR)	NCEL
	197	2340	0.2	--	--	--	C,T	NCEL
17-7 PH-TH 1050, circular weld	181	5	4.4	--	--	--	SE,T to PR	NCEL
	197	2340	0.4	--	--	--	C,T	NCEL
17-4 PH-H 925, Butt weld	181	5	3.2	--	--	--	SE,T to PR	NCEL
	197	2340	<0.1	--	--	--	NC	NCEL

Table 18. (cont'd)

Alloy	Exposure		Corrosion Rate MPY(1)	Pit Depth		Crevice Corrosion Depth, Mils(2)	Corrosion Type(2)	Source(3)
	Days	Depth, Feet		Max.	Avg.			
17-4 PH-H 925, circular weld	181	5	2.9	--	--	--	SE,T to PR	NCEL
	197	2340	<0.1	--	--	--	NC	NCEL
17Cr-14Ni-Cu-Mo	181	5	<0.1	3	--	--	P(one)	INCO(8)
	197	2340	<0.1	--	--	--	IC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)
18Cr-14Mn	181	5	4.9	50(PR)	--	50(PR)	C,P	INCO(8)
	197	2340	0.7	--	--	109	C,T	NCEL
	197	2340	<0.1	--	--	--	IC	INCO(8)
	123	5640	<0.1	--	--	--	NC	NCEL
	123	5640	<0.1	--	--	--	NC	INCO(8)
AM 350	181	5	<0.1	--	--	--	IC	INCO(8)
	197	2340	<0.1	--	--	--	IC	INCO(8)
	123	5640	<0.1	--	--	--	NC	INCO(8)
17Cr-7Ni	181	5	0.9	50	--	--	P,E,T to PR	NCEL
	197	2340	0.0	--	--	--	NC	NCEL
	123	5640	0.0	--	--	--	SLC	NCEL

1. MPY - Mils penetration per year calculated from weight loss.
2. Symbols for types of corrosion:
   - C - Crevice
   - E - Edge
   - HAZ - Heat affected zone
   - I - Incipient
   - NC - No visible corrosion
   - P - Pitting
   - PR - Perforated
   - S - Severe
   - SCC - Stress corrosion cracking
   - SL - Slight
   - T - Tunnel
   - W - Weld bead
3. Numbers refer to references at end of paper.
4. Heated for one hour at 1200°F, air cooled.

Table 19. Effect of Exposure in Sea Water on the Mechanical Properties of Stainless Steels.

Alloy	Original Properties (1)			Percent Change (2)								
				Surface, 181 Days			2,340', 197 Days			5640', 123 Days		
	TS	YS	EL	TS	YS	EL	TS	YS	EL	TS	YS	EL
AISI Type 301	174.7	124.9	27.0	- 4.6	- 0.8	-10.0	- 0.6	- 7.1	-15.6	+ 2.1	- 1.4	+0.5
AISI Type 302	93.3	43.5	54.2	+ 0.1	- 4.8	-10.9	- 3.3	-10.1	- 2.8	+ 3.7	- 3.7	+4.2
AISI Type 304	86.1	36.0	59.5	- 0.7	+ 1.9	-12.6	+ 0.6	+ 7.0	- 4.2	+ 2.4	+ 0.6	+8.0
AISI Type 304L	80.5	40.0	56.3	+ 1.3	+ 2.5	- 7.3	+ 1.0	+ 2.5	- 3.7	+ 4.7	+ 5.0	+8.4
AISI Type 316	81.6	36.5	55.3	+ 1.7	+13.7	- 7.8	+ 0.12	+12.6	- 3.8	+ 0.4	0	-0.2
AISI Type 316L	86.1	48.0	48.3	- 0.2	- 2.1	- 8.3	+ 0.9	- 2.5	+ 2.1	- 0.6	- 0.8	+1.0
AISI Type 410	79.5	48.8	30.5	+ 1.9	- 9.0	-13.1	+ 0.8	- 3.5	- 2.6	0	- 3.1	+8.3
20Cb	91.5	46.9	40.0	+ 1.5	+ 4.5	- 4.3	- 1.0	- 1.1	+ 3.8	+ 4.9	+18.7	-4.5
PH14-8 Mo-SRH 950 Butt weld	229.0	214.1	2.0	-23.4	-52.2	+100	--	--	--	--	--	--
PH15-7 Mo-RH 1100 Butt weld	191.6	183.2	3.0	-14.5	-54.0	+73.3	--	--	--	--	--	--
17-7 PH-RH 1050 Butt weld	206.7	196.7	4.6	-24.6	-59.9	- 2.2	--	--	--	--	--	--
17-7 PH-TH 1050 Butt weld	196.8	188.1	3.0	-21.7	-57.0	+66.7	--	--	--	--	--	--
17-4 PH-H 925 Butt weld	191.9	185.4	3.0	- 7.3	-10.7	+ 6.7	--	--	--	--	--	--
17 Cr-7 Ni	191.1	184.0	14.2	+ 3.9	+ 5.2	-38.0	+ 1.3	+ 2.3	-18.3	+10.9	+11.4	+7.04

1. TS - Tensile strength, KSI
   YS - Yield strength, KSI
   El - Elongation, percent in 2 inches
2. TS - Tensile strength
   YS - Yield strength
   El - Elongation

Table 20. 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(8)
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 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 21. Corrosion of Titanium Alloys in Sea Water.

Alloy	Exposure		Corrosion Rate, MPY(1)	Corrosion Type(2)	Source(3)
	Days	Depth, Feet			
Titanium	181	5	<0.1	NC	INCO(8)
	197	2340	<0.1	NC	INCO(8)
	123	5640	<0.1	NC	INCO(8)
75A	181	5	0.0	NC	NCEL
	197	2340	0.0	NC	NCEL
	123	5640	0.0	NC	NCEL
75A Circular weld	181	5	0.0	NC	NCEL
75A, Butt weld	181	5	0.0	NC	NCEL
Ti-0.15 Pd, Circular weld	181	5	0.0	NC	NCEL
Ti-0.15 Pd, Butt weld	181	5	0.0	NC	NCEL
5Al-2.5 Sn, Circular weld	181	5	0.0	NC	NCEL
	197	2340	0.0	NC	NCEL
	123	5640	0.0	NC	NCEL
5Al.2.5 Sn, Butt weld	181	5	0.0	NC	NCEL
	197	2340	0.0	NC	NCEL
	123	5640	0.0	NC	NCEL
6Al-4V	181	5	0.0	NC	NCEL
	197	2340	0.0	NC	NCEL
	123	5640	0.0	NC	NCEL
6Al-4V, Circular weld	181	5	0.0	NC	NCEL
	197	2340	0.0	NC	NCEL
	123	5640	0.0	NC	NCEL
6Al-4V, Butt weld	181	5	0.0	NC	NCEL
	197	2340	0.0	NC	NCEL
	123	5640	0.0	NC	NCEL
7Al-2CB-1Ta, Circular weld	181	5	0.0	NC	NCEL
7Al-2CB,1Ta, Butt weld	181	5	0.0	NC	NCEL
13V-11Cr-3Al, Circular weld	181	5	0.0	SCC(4)	NCEL
	197	2340	0.0	NC	NCEL
	123	5640	0.0	NC	NCEL
13V-11Cr-3Al, Butt weld	181	5	0.0	NC	NCEL
	197	2340	0.0	NC	NCEL
	123	5640	0.0	NC	NCEL

1. MPY - Mils penetration per year calculated from weight loss.
2. Symbols signify types of corrosion:
   NC - No visible corrosion
   SCC - Stress corrosion cracking
3. Numbers refer to references at end of paper.
5. Stress corrosion cracks, radially across unrelieved circular weld bead.

Table 22. Effect of Exposure in Sea Water on the Mechanical Properties of Titanium Alloys

Alloy	Original Properties(1)			Percent Change after Exposure(2)								
				181 Days, Surface			197 Days, 2340'			123 Days, 5640'		
	TS	YS	EL	TS	YS	EL	TS	YS	EL	TS	YS	EL
75A	87.2	70.1	29.7	+8.0	+9.4	-17.5	+5.16	+8.56	-10.8	+3.56	+5.0	-4.71
75A, Butt weld	101.0	84.0	25.0	+1.6	-1.3	-24.0	--	--	--	--	--	--
Ti-0.15 Pd, Butt weld	66.3	46.8	28.0	+2.7	+3.8	-32.9	--	--	--	--	--	--
6Al-4V	139.7	136.0	14.0	+3.3	+1.8	- 9.3	+3.44	+3.99	+5.71	--	--	--
6Al-4V, Butt weld	138.4	131.5	14.0	+3.4	-5.9	-28.6	--	--	--	--	--	--
5Al-2.5Sn, Butt weld	138.2	123.6	16.5	+3.6	+1.0	-20.0	--	--	--	--	--	--
7Al-2Cb-1Ta, Butt weld	111.1	99.8	17.5	+4.0	+1.3	-16.0	--	--	--	--	--	--
13V-11Cr-3Al, Butt weld	133.6	126.0	20.0	+5.1	+7.8	-36.0	--	--	--	--	--	--

1. TS - Tensile strength, KSI
   YS - Yield strength, KSI
   El - Elongation, percent in 2 inches
2. TS - Tensile strength
   YS - Yield strength
   El - Elongation

Table 23. Chemical Composition of Miscellaneous Alloys, Percent by Weight.

Material	Chemical Composition	Source[1]
Fe-Ni-Cr No. 1	43.5 Fe, 30.0 Ni, 20.0 Cr, 4.0 Cu, 2.5 Mo	INCO[8]
Fe-Ni-Cr No. 2	44.0 Fe, 30.0 Ni, 20.0 Cr, 3.5 Cu, 2.5 Mo	INCO[8]
Fe-Ni-Cr-Mo No. 1	54.0 Fe, 24.0 Ni, 19.0 Cr, 3.0 Mo	INCO[8]
Fe-Ni-Cr-Mo No. 2	50.0 Fe, 23.0 Ni, 21.0 Cr, 5.0 Mo, 1.0 Si	INCO[8]
Chemical Lead	99.9 Pb	INCO[8]
Antimonial Lead	94.0 Pb, 6.0 Sb	INCO[8]
Tellurium Lead	99 + Pb, 0.04 Te	INCO[8]
AZ31B Magnesium	96 Mg, 2.6 Al, 1.1 Zn, 0.4 Mn	INCO[8]
Tin	99.9 Sn	INCO[8]
Zinc	99.9 Zn, 0.09 Pb, 0.01 Fe	INCO[8]
Solder	67 Pb, 33 Sn	INCO[8]
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 24. Corrosion of Miscellaneous Alloys in Sea Water.

Alloy	Exposure		Corrosion Rate, MPY[1]	Corrosion Type[2]	Source[3]
	Days	Depth, Feet			
Fe-Ni-Cr, No. 1	181	5	0.5	C[4]	INCO[8]
	197	2340	<0.1	NC	INCO[8]
	123	5640	<0.1	NC	INCO[8]
Fe-Ni-Cr, No. 2	181	5	0.1	C[5]	INCO[8]
	197	2340	0.1	IC	INCO[8]
	123	5640	<0.1	NC	INCO[8]
Fe-Ni-Cr-Mo, No. 1	181	5	<0.1	NC	INCO[8]
	197	2340	<0.1	NC	INCO[8]
	123	5640	<0.1	NC	INCO[8]
Fe-Ni-Cr-Mo, No. 2	181	5	<0.1	NC	INCO[8]
	197	2340	<0.1	NC	INCO[8]
	123	5640	<0.1	NC	INCO[8]
Chemical Lead	181	5	0.8	U	INCO[8]
	197	2340	0.3	U	INCO[8]
	123	5640	0.8	U	INCO[8]
Antimonial Lead	181	5	1.2	U	INCO[8]
	197	2340	0.3	U	INCO[8]
	123	5640	0.8	U	INCO[8]
Tellurium Lead	181	5	1.0	U	INCO[8]
	197	2340	0.3	U	INCO[8]
	123	5640	1.1	U	INCO[8]
Magnesium, AZ31B	181	5	>40[6]	U	INCO[8]
	197	2340	[7]	--	INCO[8]
	123	5640	>59[7]	--	INCO[8]
Tin	181	5	8.3	P[8]	INCO[8]
	197	2340	1.8	C,P[9]	INCO[8]
	123	5640	0.5	G	INCO[8]
Zinc	181	5	4.5	P[10]	INCO[8]
	197	2340	2.3	P[11]	INCO[8]
	123	5640	6.7	P[12]	INCO[8]
Solder, 67Pb-33Sn	181	5	3.7	U	INCO[8]
	197	2340	0.5	U	INCO[8]
	123	5640	1.2	U	INCO[8]
Columbium, No. 1	181	5	0.0	NC	NCEL
Columbium, No. 2	181	5	0.0	NC	NCEL
Molybdenum	181	5	0.1	U	NCEL
Tantalum, No. 1	181	5	0.0	NC	NCEL
Tantalum, No. 2	181	5	0.0	NC	NCEL
Ta-60	181	5	0.0	NC	NCEL
Tungsten	181	5	0.3	U	NCEL

Table 24. (cont'd)

1. MPY - Mils penetration per year calculated from weight loss.
2. Sumbols for type of corrosion:
   C - Crevice
   G - General
   I - Incipient
   NC - No visible corrosion
   P - Pitting
   U - Uniform
3. Numbers refer to references at end of paper.
4. Crevice corrosion to 20 mils deep.
5. Crevice corrosion to 18 mils deep.
6. 95% corroded.
7. 100% corroded.
8. Perforated, 30 mils.
9. Crevice corrosion and crater pits to 2 mils deep.
10. Maximum pit depth 5 mils.
11. Maximum pit depth 2 mils.
12. Maximum pit depth 13 mils.

Table 25. Effect of Exposure in Surface Sea Water for 6 Months on the Mechanical Properties of Miscellaneous Alloys.

Alloy	Original Properties(1)			Percent Change(2) Surface, 181 Days		
	TS	YS	El	TS	YS	El
Columbium	113.7	102.4	12.3	-3.4	- 2.4	+ 1.6
Molybdenum	13.8	11.6	16.8	-2.2	+ 0.9	-13.7
Tantalum	48.8	36.6	48.7	-3.5	-10.9	- 4.5

1. TS - Tensile strength, KSI
   YS - Yield strength, KSI
   El - Elongation, percent in 1 inch
2. TS - Tensile strength
   YS - Yield strength
   El - Elongation

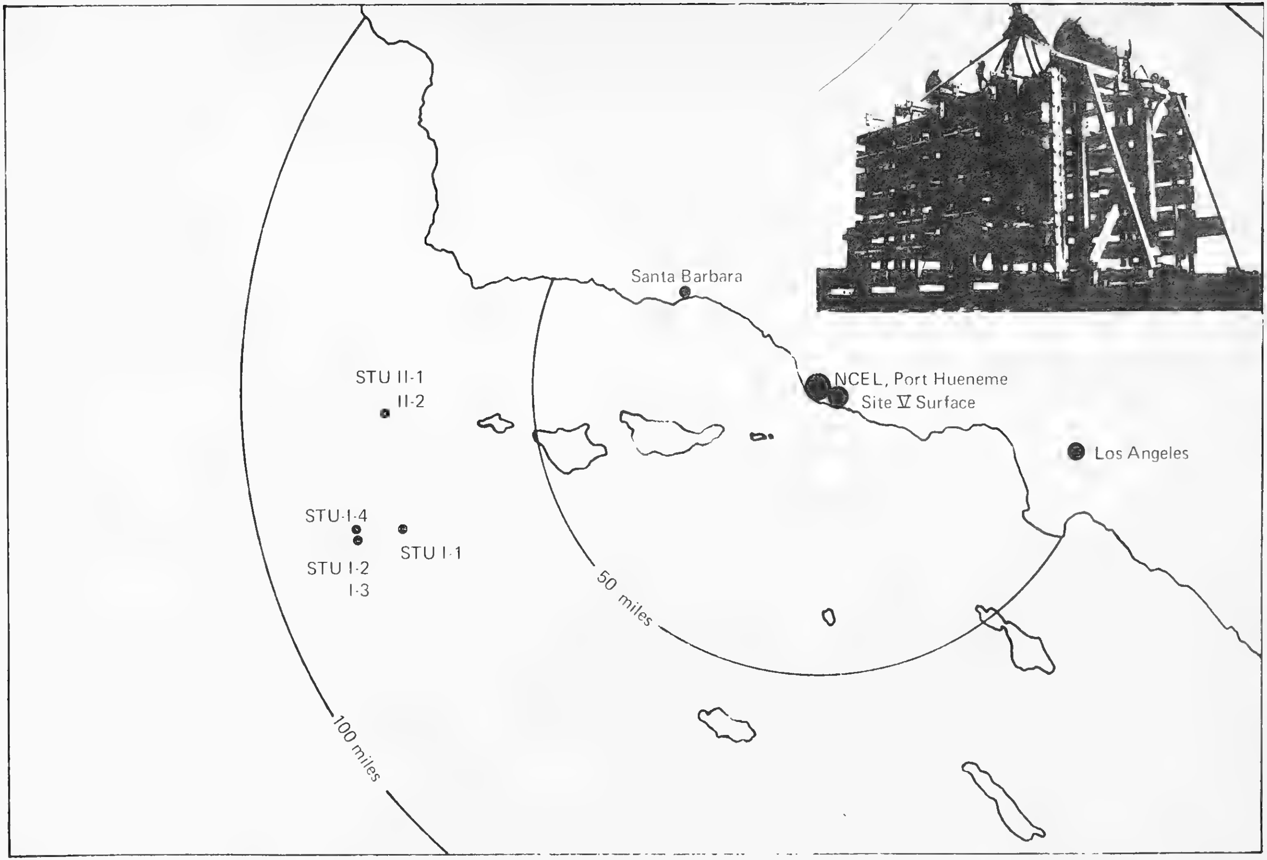

Figure 1. Area map showing STU sites off the Pacific Coast; STU structure in inset.

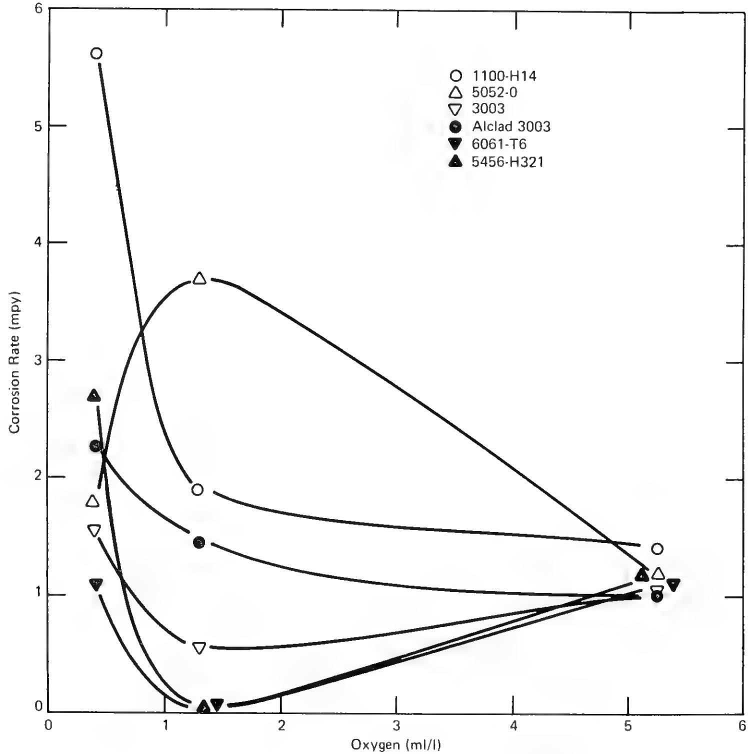

Figure 2. Aluminum alloys whose corrosion rates generally increased with a decrease in the oxygen concentration of sea water.

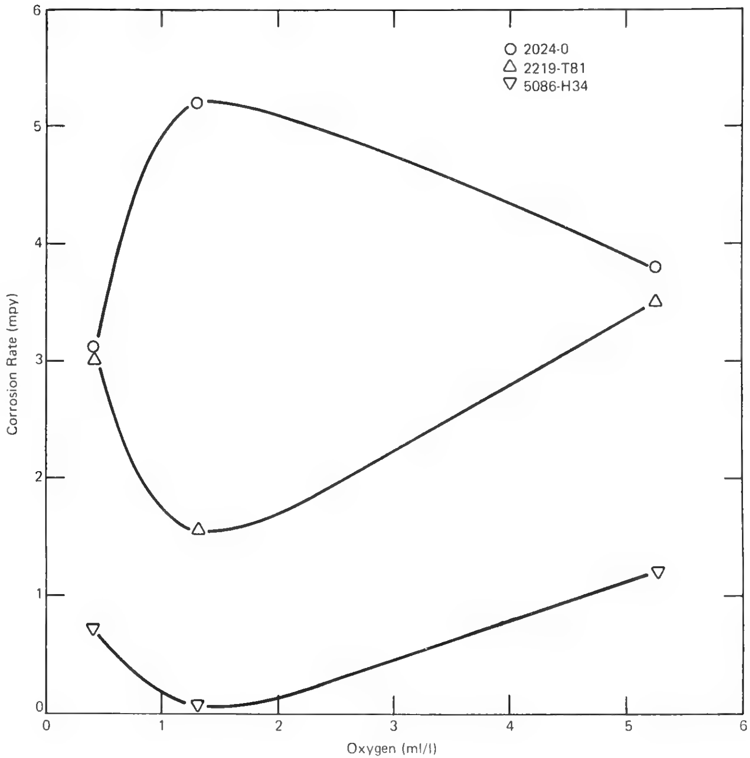

Figure 3. Aluminum alloys whose corrosion rates decreased with a decrease in the oxygen concentration of sea water.

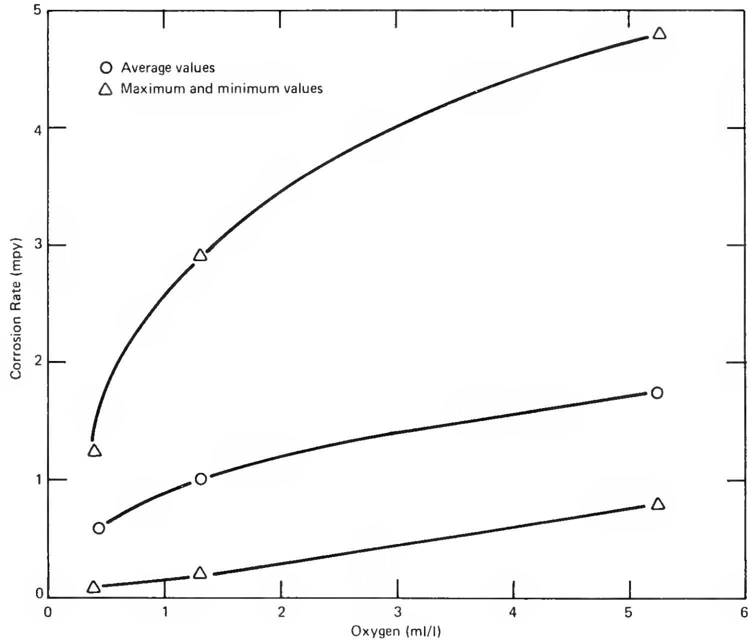

Figure 4. Corrosion rates of copper alloys versus oxygen concentration in sea water.

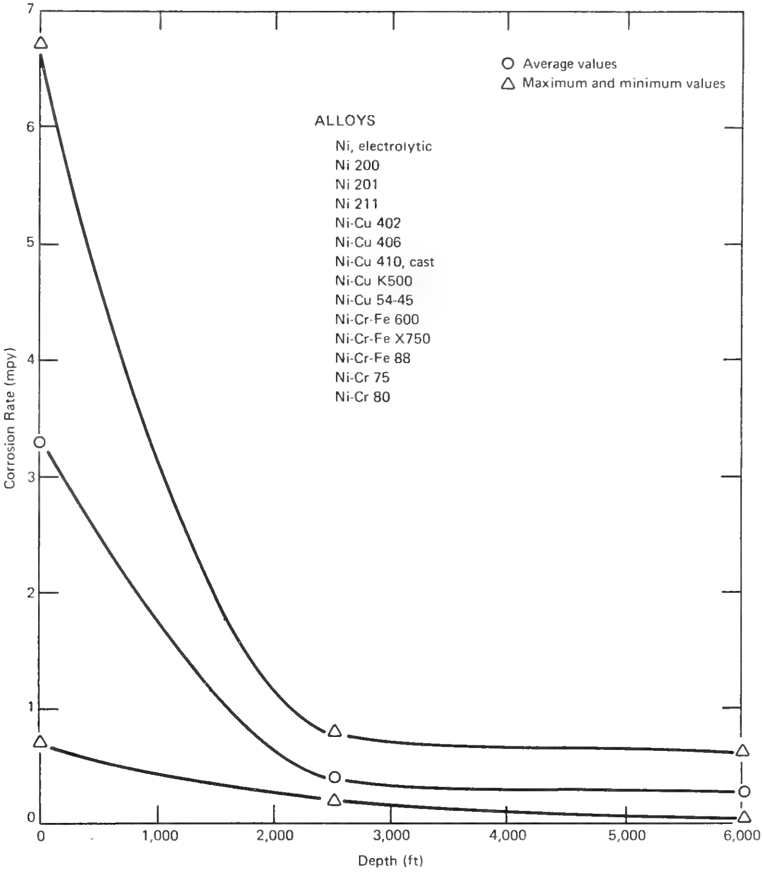

Figure 5. Decrease in corrosion rates of nickel alloys with increase in depth in sea water.

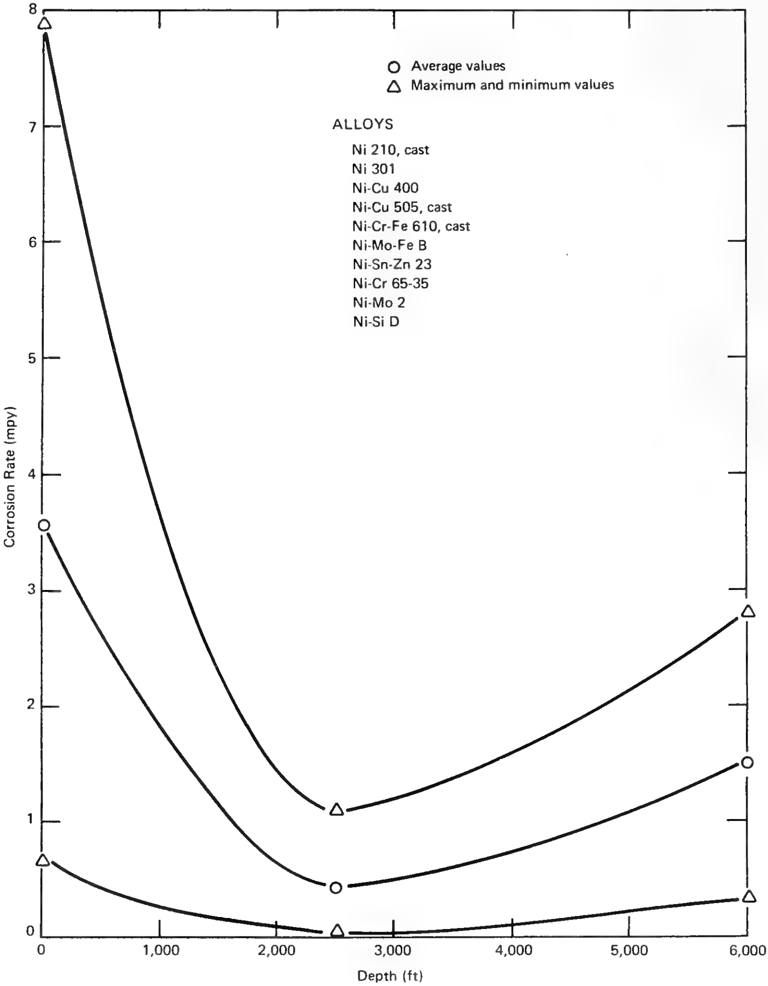

Figure 6. Effect of depth in sea water on corrosion rates of nickel alloys.

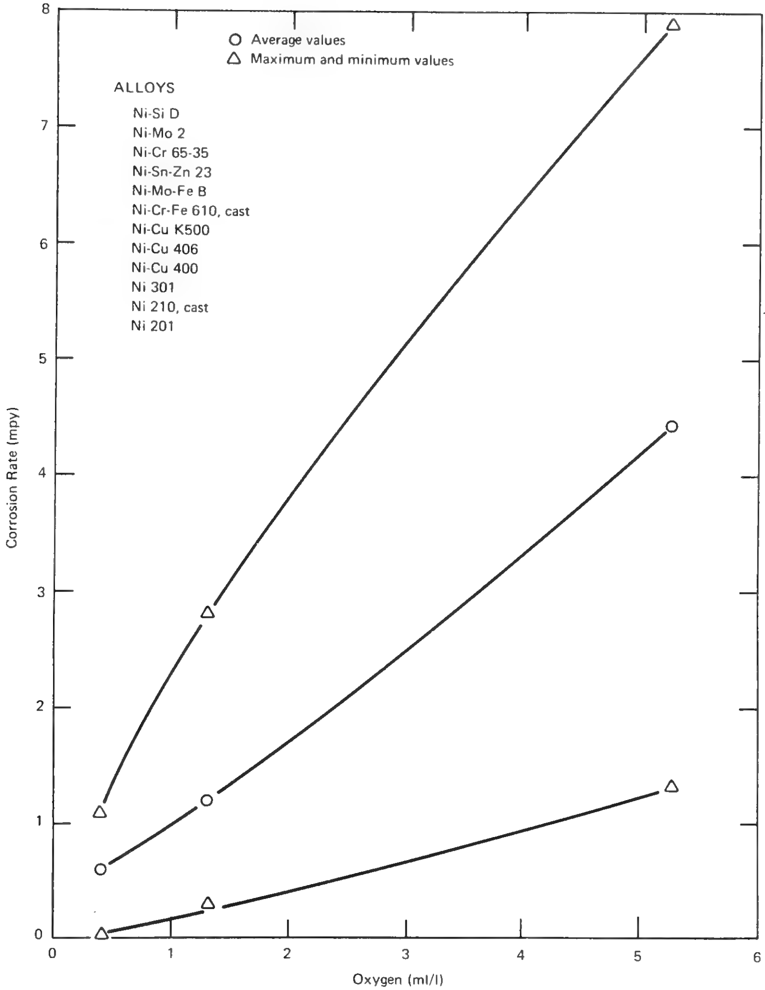

Figure 7. Decrease of corrosion rates of nickel alloys with decrease in oxygen content of sea water.

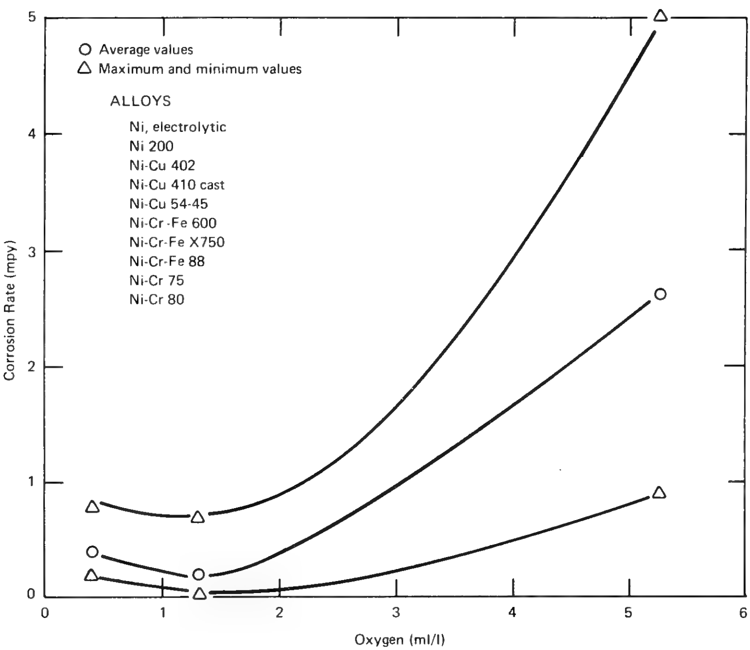

Figure 8. Effect of oxygen content of sea water on corrosion rates of nickel alloys.

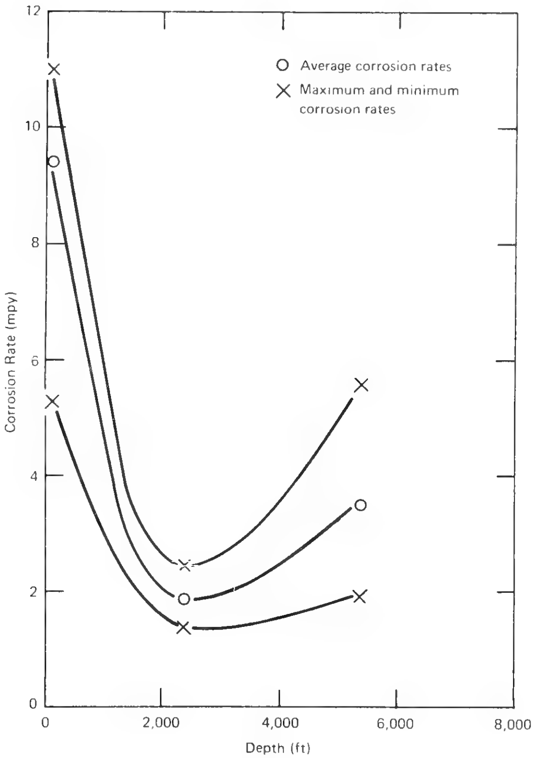

Figure 9. Effect of depth on the corrosion rates of steels.

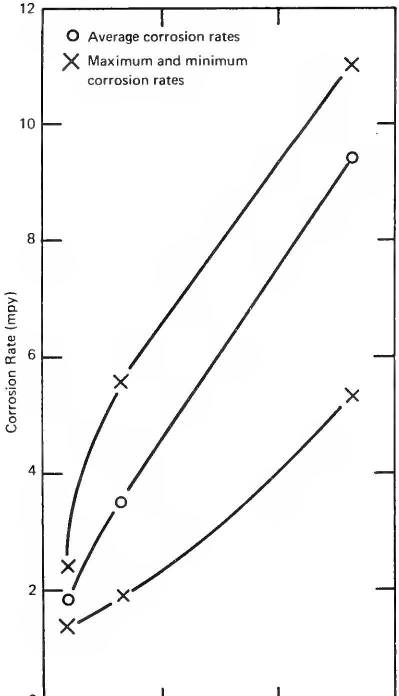

Figure 10. Effect of oxygen concentration in sea water on the corrosion rates of steels.

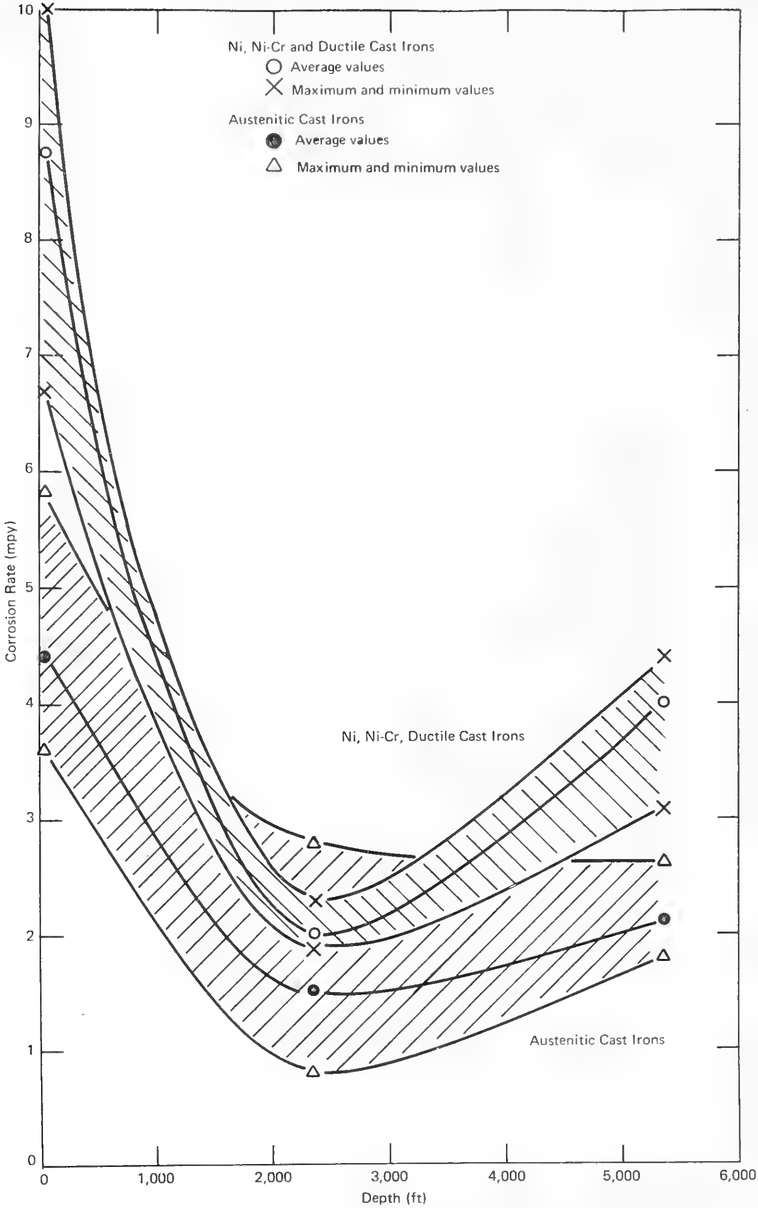

Figure 11. Effect of depth in sea water on corrosion rates of cast irons.

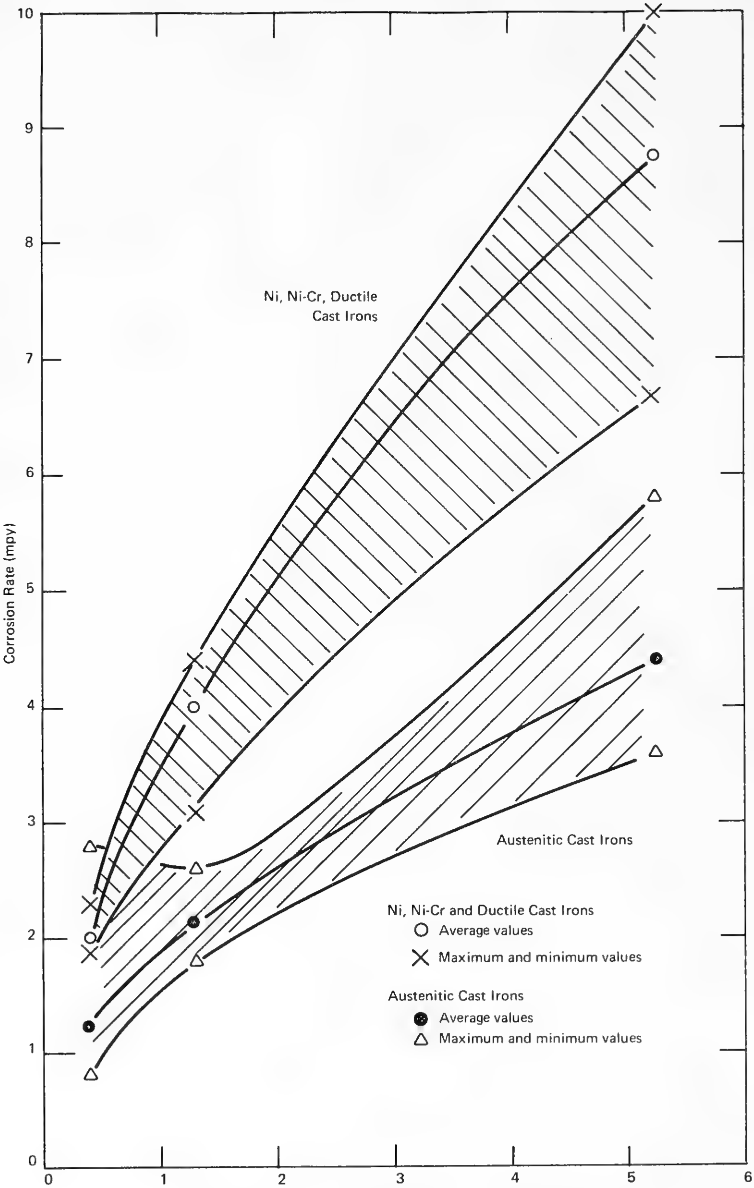

Figure 12. Effect of oxygen in sea water on corrosion rates of cast irons.

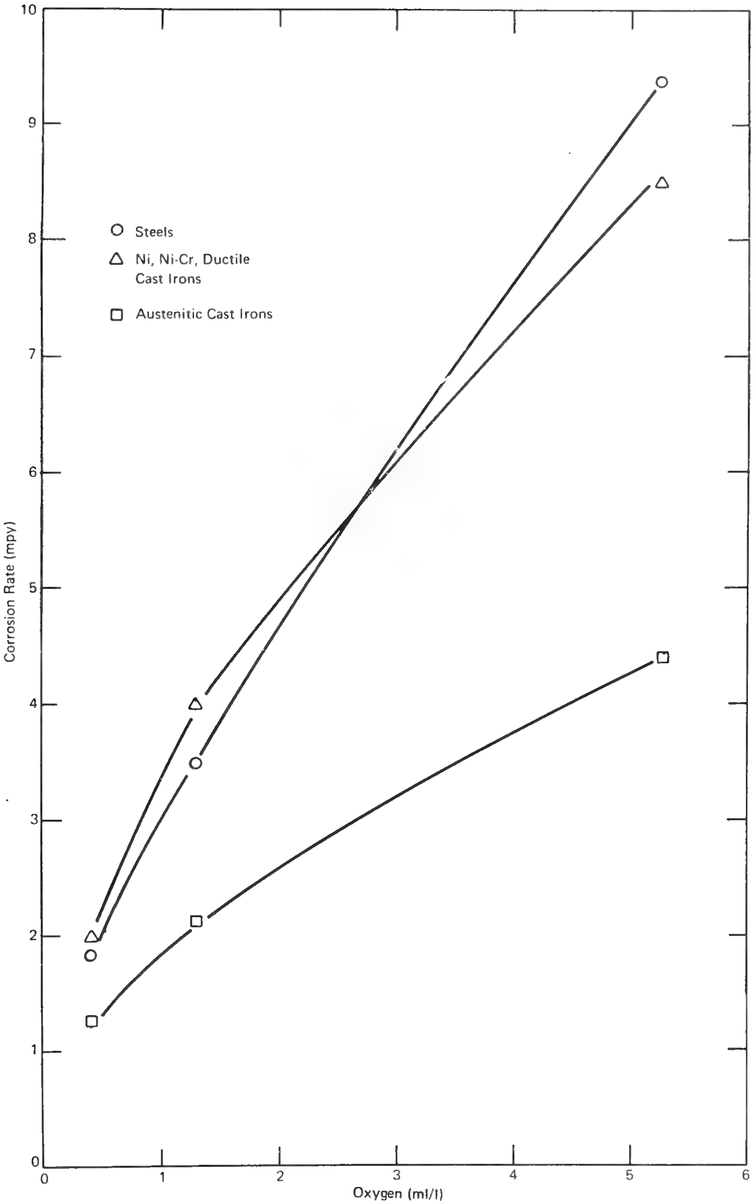

Figure 13. Effect of oxygen concentration of sea water on the corrosion rates of steels and cast irons.

Figure 14. Stress corrosion cracks in circular welded 13V-11Cr-3Al alloy after 181 days of exposure in surface sea water.

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13. ABSTRACT

A total of 880 specimens of 215 different alloys were completely immersed in surface sea water for six months to obtain data for comparison with deep ocean corrosion data.

Corrosion rates, types of corrosion, pit depths, and changes in mechanical properties were determined.

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

The corrosion rates of the copper base alloys, nickel base alloys, steels, and cast irons decreased as the concentration of oxygen in sea water decreased.

The copper base alloys, steels, cast irons, molybdenum, tungsten, leads and lead-tin solder corroded uniformly.

All the aluminum alloys were attacked by pitting and crevice corrosion and sea water was more aggressive at depth than at the surface. The effect of the oxygen concentration of sea water on the corrosion of aluminum alloys was inconsistent.

The stainless steels were attacked by crevice, pitting, edge and tunnel corrosion except types 310, 317 and 329, 20Cb, 20Cb-3 and AM350 on which there was only incipient crevice corrosion. Crevice corrosion was more severe in surface waters than at depth.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Corrosion						
Types						
Sea water						
Nickel alloys						
Titanium alloys						
Steels						
Cast iron						
Stainless steels						
Columbium						
Tantalum alloys						
Copper alloys						
Molybdenum						
Tungsten alloys						
Lead alloys						
Aluminum alloys						
Oxygen in sea water						