MARINE CORROSION

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Abstract

This brief discussion will highlight the types of marine corrosion problems that are encountered in Naval service. Literally millions of parts are involved in the construction and use of Naval ships and all may be subject to the deleterious effects of seawater unless suitable precautions are taken. The important aspect of marine corrosion is to be aware of the limitations of materials and to understand the material/environment interactions in order to overcome such limitations.

1. Introduction

By way of introduction, I would like to consider the ramifications of dropping a piece of metal into seawater. There is, of course, a reactive surface and an electrolyte and therefore, we expect surface reactions; collectively known as corrosion. In straightforward terms, four (4) ingredients are essential for corrosion to occur:

- cathode
- anode
- electrolyte
- electrical connection between the anode and the cathode

If any of these ingredients are missing, the corrosion reactions will stop; conversely, if all four are present, one can be certain that corrosion reactions are occurring. While one half (the cathodic half) of the reactions may not be visible, the anodic reactions are usually evident and manifest themselves in various ways. For convenience, these can be categorized into the following groups:

- General Corrosion
- Localized Corrosion
- Erosion/Corrosion
- Galvanic Corrosion
- Stress Corrosion Cracking
- Corrosion Fatigue

These are the generally accepted forms of corrosion, although different names and subgroupings are also used. I will present examples of these forms of corrosion, but time does not permit discussion of the mechanisms and theories of each type.

2. Service Life Prediction

Of prime concern in an engineering sense is the rate of corrosion reactions since they affect the appearance, integrity or life of a component. It is important to distinguish corrosion rates from the more familiar corrosion potentials. Based on thermodynamic principles, the electromotive series has been devised to characterize the relative potential of chemical reactions involving the metal surface and the electrolyte. In seawater, this "galvanic" series is a useful guide in describing the "potential" for corrosion reactions; but says nothing about the rates at which the reactions will occur. In fact, metals like titanium would appear to be totally imcompatible with many alloys, and can only be used by virtue of their polarization resistance which inhibits cathodic surface reactions.

The field of electrochemistry is the realm in which these rate considerations can be investigated, and it is an active area for both a study of the phenomenon and for life prediction. It does, however, have severe limitations regarding service life prediction, because of environmental and metallurgical variables. What this says, of course, is that the rates of corrosion are significantly affected by conditions which, while they can be controlled in a laboratory test, cannot truly duplicate an exact service condition. These variables include changes in:

- temperature
- velocity/flow
- stress
- environment
- surrounding materials
- metallurgical conditions

The engineering objective is to control corrosion or to understand it sufficiently, and design to live with its effects.

3. Discussion

I will now discuss examples of various forms of corrosion as they impact Navy materials and components.

Piping mock-ups are useful to systematically define effects of velocity and galvanic corrosion. An example of a series of mock-ups, tested some years ago at the LaQue Center for Corrosion Technology (LCCT) in Wrightsville Beach, N.C., shown in Figure (1) helped to define flow velocity limits for copper-nickel systems. Data such as this is of interest at various locations in the piping system to focus on the "trouble" spots and develop confidence in the materials. Valve parts are often subject to localized attack due to high turbulence or special quiescent conditions. Figure (2) shows a Monel Ball from a valve in test for two (2) years.

Heat exchangers contain hundreds of feet of tubing and offer many possibilities for various forms of attack. Mud and silt may be ingested and contain sulfide producing bacteria. This, in turn, can modify surface films and cause general corrosion. Improper cleaning procedures of tubes drawn with organic lubricants can cause carbonaceous films on new tubes, which can effect corrosion performance in a matter of months.

Atmospheric corrosion is a major concern to shipboard service, where salt splash and spray are ever present. The degree of attack will be related to such factors as moisture, oxygen content, sulfur compounds and sodium chloride.

Localized corrosion, due to selective phase attack, occurs on certain aluminum and nickel aluminum bronze cast components. This can be a problem on any large casting such as valve tailpieces and is often difficult to detect upon surface examination. The microstructure consists of complex non-equilibrium phases, some of which are anodic to the matrix, and when continuous, will lead to an insidious leaching corrosion. The control of alloy chemistry and heat treatment will mitigate this form of corrosion to a considerable extent.

Aluminum exfoliation of hull materials, such as 5456, was a recurring problem until the advent of the new exfoliation resistant tempers, H116/117, in the early 1970's. The problem was localized preferential dissolution of the Mg_2Al_3 precipitates at the grain boundaries. The new thermo-mechanical processing treatments broke up the continuous precipitates and kept more of the magnesium in solid solution.

Many Navy ships, such as the PHM, operate at high speeds, and cavitation erosion resistance is essential. The foil material used is a 17-4 PH stainless steel, which was most successfully used on an earlier hydrofoil, PGH-2 TUCUMCARI. This alloy, however, is susceptible to pitting in service and requires cathodic protection. This localized pitting of 17-4 PH stainless steel is characteristic of most stainless steels unless they are allowed to repassivate by exposure to the air (oxygen). The 300 Series stainless steels are also most susceptible to this form of attack as illustrated by the specimen shown in Figure (3) after three (3) months in seawater.

Propeller materials are subject to corrosion/erosion caused by high velocities and cavitation environments. The propeller shown in Figure (4) is from a patrol gunboat and illustrates corrosion fatigue and erosion damage that have occurred on the bronze propeller. The materials used in propellers of high speed vehicles over the years include a range of stainless steels, nickel and copper base alloys as well as corrosion resistant titanium. In order to evaluate materials for these, and other high velocity applications, a series of special corrosion tests have been devised. These tests are good for comparing (ranking) the behavior of different materials in severe environments; but are virtually impossible to correlate with actual service conditions. The changes in, and sensitivity to, turbulence and other strong flow abnormalities are very difficult to model. Considerable interface with hydrodynamics is needed to advance this portion of corrosion technology, and for the present, material selection is largely based on emperical results.

One common area of corrosion encountered aboard ships is the accelerated galvanic corrosion caused by dissimilar metal contact in the presence of seawater. Shown in Figure (5) is an unsatisfactory method of mechanically joining aluminum to steel. The riveted overlapping surface would trap water in the joint, and this would cause corrosion of the aluminum, accelerated by the presence of steel and the rivets. The selection of fastener materials is important, with little data available on actual service performance. One study involved installing a series of bolts in panels of different materials. The bolts illustrated in Figure (6) were installed for six (6) months in a panel of 17-4 PH stainless steel. When sealant was used, galvanic corrosion attack on the aluminum bolt was not as severe as when sealant was absent. In at least one case (MP35N), crevice corrosion of the panel under the sealant was so extensive that the bolt was lost. Of concern also, of course, is the corrosion of the panel caused by the bolt. When, for example, steel bolts are used in aluminum panels, the aluminum will suffer galvanic corrosion and protect the bolts from attack.

The 2XXX and 7XXX aluminum alloys are among those materials susceptible to stress corrosion cracking in seawater and should never be used in marine service. Stress corrosion requires the presence of a flaw, a high stress concentration and an electrolyte (seawater). Normally, the Navy will not use SCC susceptible materials because of the catastrophic nature of the failure mode. While much has been learned about the nature of these materials (typically high in strength) and their design and analysis procedures, the continued reluctance stems from the sometimes ill-defined loading conditions and the possibilities of flaw (defect) growth during service.

Another prevalent form of corrosion is corrosion fatigue. Whenever structures are subjected to cyclic loading, cracking can occur, particularly in massive welded sections (e.g., hydrofoil struts/foils) or in rotating machinery components (e.g., pump impellers and shafts). The fact that components survive as well as they do is a tribute to careful design, analysis and above all, construction details to prevent stress concentrations.

4. Summary

What has been attempted in this brief discussion is to highlight the types of marine corrosion problems that are encountered in Naval service. Literally millions of parts are involved in the construction and use of Naval ships and all may be subject to the deleterious effects of seawater, unless suitable precautions are taken. This includes consideration, at the design stage, of the various means of corrosion protection: material selection, anodic or cathodic protection, barrier coatings, environmental control, and the design of surrounding components. The important aspect of marine corrosion is to be aware of the limitations of materials and to understand the material/environment interactions in order to overcome such limitations.

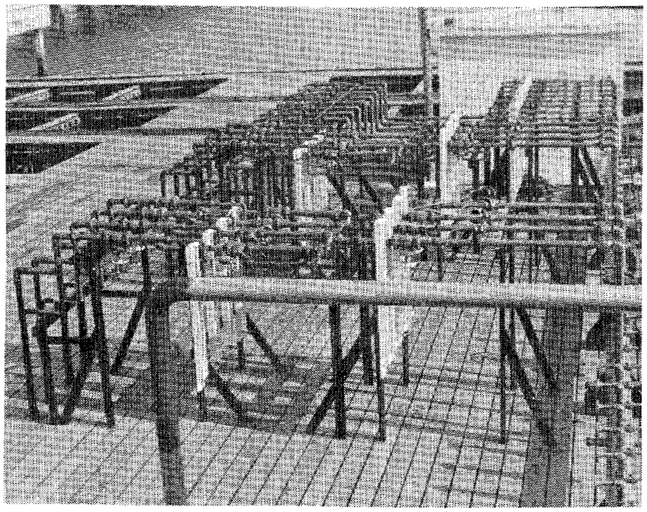
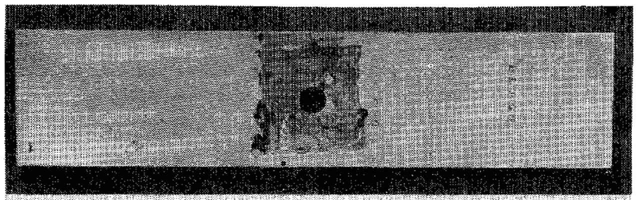


Figure 1. Piping Mock-up Tests

Figure 2. Monel ball after two years in test



CREVICE-CORROSION OF A 1/16 in. THICK TYPE 304 STAINLESS STEEL SPECIMEN EXPOSED TO SEA WATER

Figure 3.

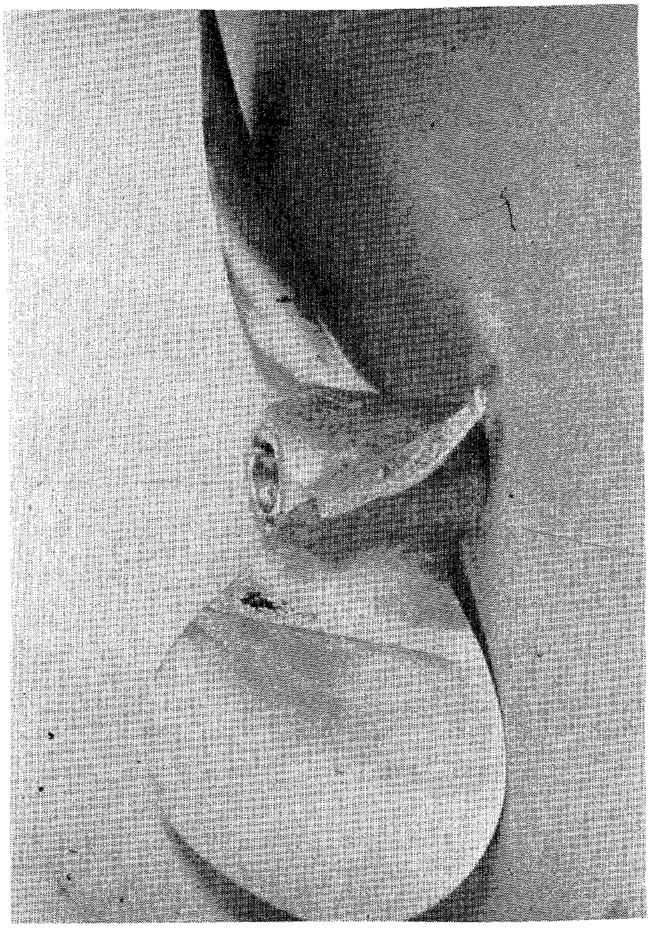


Figure 4. Propeller showing corrosion fatigue failure and erosion/corrosion damage

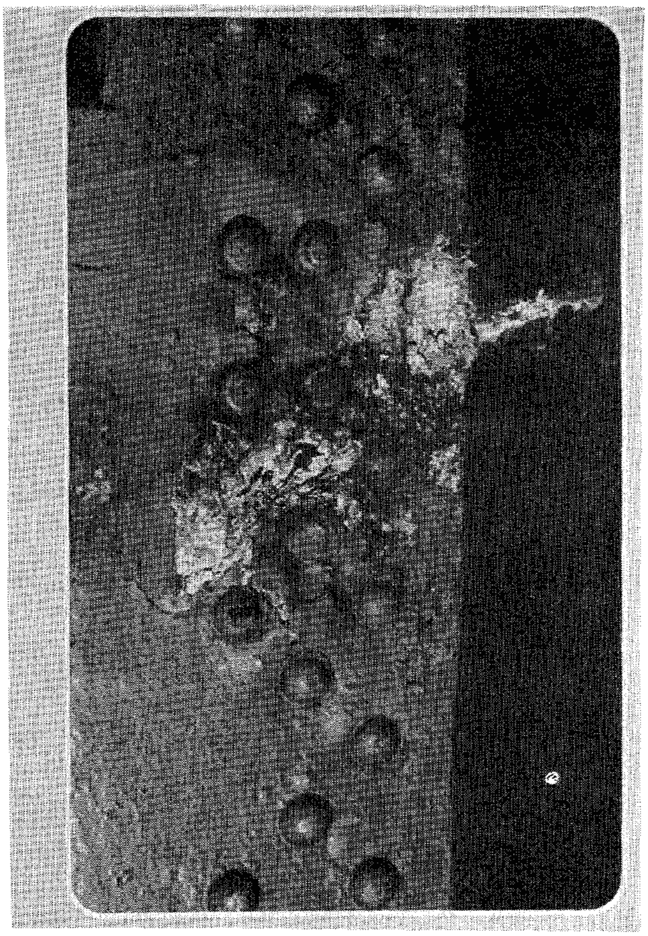


Figure 5. Corrosion of Aluminum at a riveted joint

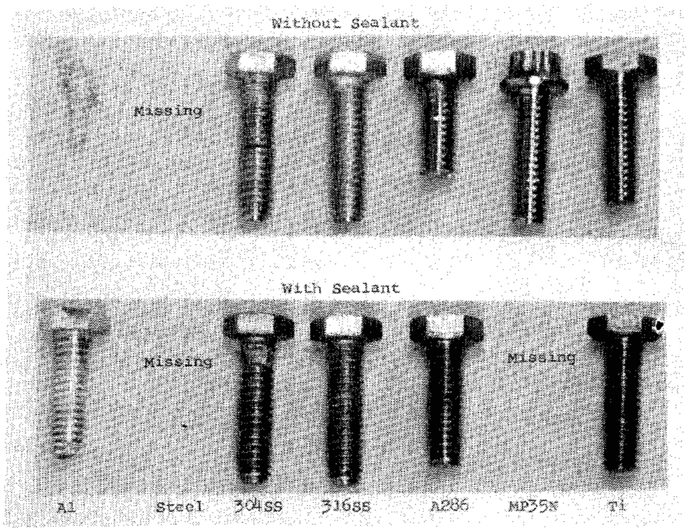


Figure 6. Corrosion attack of bolts in a 17-4PH stainless steel panel after 6 months' immersion in seawater