Corrosion rate quantification of aluminum 5052 (Al), stainless steel 316L (SS) and high strength steel HY-80 (HY-80).

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Project Summary

The influence of biofilm on the corrosion rates of aluminum 5052 (Al), stainless steel 316L and high strength steel HY-80 will be investigated. These alloys were selected for evaluation because they are commonly used in the fabrication of marine equipment and fittings. HY-80 was specifically selected because it is used to construct United States Navy (USN) submarine hulls. The corrosion rate of a given metal in a marine environment is determined by a broad spectrum of physical, chemical and biological properties and interactions. [The] key factor to the alteration of conditions at a metal surface, and hence the enhancement or retardation of corrosion, is the biofilm (Edyvean and Videla 1991). Samples of these alloys, known as coupons, will be deployed in the surface waters of Puget Sound at three locations (Figure1) to evaluate corrosion rates in the presence of marine bacteria for the field component of the project. These coupons will be deployed and maintained at a depth of 5 m. The R/V *Thompson* draft is 5.18 m and the draft of surfaced USN submarines is approximately 6.1 m. The laboratory component of the project will evaluate corrosion rates in the absence of marine bacteria by immersing coupons in sterile seawater. Coupon sets will be removed from their respective environments after 1, 2, 4 or 6 weeks of exposure. Biocorrosion is rarely interpreted by a single mechanism or [seldom] caused by [a] single species of microorganisms (Videla 1996). Mass loss, electrochemical analysis and visual inspections will be used to quantify corrosion rates. A Scanning Electron Microscope (SEM) will be used for partial bacterial classification and to evaluate the variability between freshwater and seawater bacteria.

Introduction

Corrosion is the destructive result of chemical reaction between a metal or metal alloy and its environment (Jones 1996). Biological and corrosion types of fouling are mediated by microorganisms adhered to metal surfaces or embedded in a gelatinous organic matrix called biofilm (Characklis and Marshall 1990). Biofilm accumulation is the final result of several physical, chemical and biological processes that occur sequentially (Videla 1996). The two major components that compose a biofilm are the microbial cells and the Extracellular Polymeric Substances (EPS). The microbial species and their morphology as well as the EPS composition largely determine the physical properties of the biofilm. Thus, the biofilm can be considered as an organic polymer gel with living microorganisms trapped in it (Christensen and Characklis 1990). Corrosion of metals in an oxygenated aqueous environment is an electrochemical phenomenon in which the metal ions go into solution (anodic reaction), leaving electrons that combine with oxygen to produce hydroxyl ions (cathodic reaction). The two-component system (metal + solution) characteristic of abiotic corrosion changes to a three-component system (metal + solution + microorganisms) in biocorrosion, and the subsequent behavior of the metal/solution interface will be conditioned by the interaction between those three components (Videla 1996). Bacterial activity at metal surfaces may result in corrosion induction or corrosion inhibition (Potekhina et al. 1999) which is dependent on the type of bacteria and the attributes of the surrounding environment. Microorganisms are able to actively change the environment surrounding the metal surface to facilitate the corrosion process. Microbial participation in corrosion is seldom accomplished through a single mechanism or by a single species of microorganisms (Videla 1996).

If the change in coupon mass of a given alloy is greater in the presence of marine bacteria for a given period of time, then it can be concluded that the bacteria accelerated the corrosion rate of that alloy. Conversely, if the change in coupon mass of a given alloy is the same when in the presence and absence of marine bacteria for a given time period, then it can be concluded that the bacteria had no effect on the corrosion rate of that alloy. It may also be observed that the change in coupon mass of a given alloy is less in the presence than in the absence of marine bacteria which would lead to the conclusion that the bacteria decelerated the corrosion rate of that alloy.

Proposed Research

The field component of this project is designed to evaluate the corrosion rates of Al, SS and HY-80 in the presence of marine bacteria over different time periods. The lab component of this project is designed to evaluate the corrosion rates of Al, SS and HY-80 in the absence of marine bacteria over the same time periods as the field component.

Coupon Preparation

Coupon mass and dimensions will be determined to the greatest possible number of significant digits (G1-03. 2004). These measurements will be made using equipment provided by the UW Material Sciences Department.

SS and HY-80 coupons will be cleaned with a bleach-free scouring powder, followed by thorough rinsing in water and a suitable solvent, such as acetone. Since aluminum is a relatively soft metal, an ultrasonic method will be used to clean Al coupons (G31-72. 2004). The coupons will be air dried and weighed. Coupons will be weighed before and after the respective method of cleaning to determine if the mass of the coupon was altered.

Coupon Deployment

The coupons will be segregated into two different types of sets. Type one will consist of an Al and SS coupon and type two will consist of an Al, SS and HY-80 coupon. Coupon sets will be deployed in the surface waters of Puget Sound at three sites: Naval Submarine Base Bangor Delta Pier (NSB Delta Pier), John Wayne Marina (JWM) and the UW Oceanography Dock (UW Ocean Dock) (Figure 1). The deployment apparatus (Figure 2) is designed to maintain the coupons at a depth of 5 meters. The dowel rod in the deployment apparatus will prevent the coupons from physically contacting each other and thus prevent galvanic corrosion. Set type one coupons will be retrieved after 1, 2 and 4 weeks. Set type two coupons will be retrieved after 6 weeks. One Al and one SS coupon will be deployed at NSB Delta Pier and the UW Oceanography dock to be used for bacterial identification.

Coupon Identification

Individual coupons will be identified using a three digit alphanumeric label with the format $X_{\#}$-X-#. The first digit will identify the alloy and coupon set type, A for AL, S for SS and H for HY-80 with a numeral one or two subscript. The second digit will be used to identify the coupon deployment location, D for NSB Delta Pier, J for the JWM and W for the UW Oceanography dock. The final digit indicated the duration of coupon deployment in weeks. For example, S_1-D-1 indicates a SS coupon, set type one that will be deployed at the NSB Delta Pier for 1 week.

Coupon Analysis

The Al and SS coupons that are to be used for bacterial identification will be placed in a 2% formaldehyde solution for approximately 12 hours, than placed in an ethanol solution for biofilm preservation (Schrenk, M. pers. comm.). Biofilm samples will be analyzed with the UW

Biology Department's SEM. The SEM will be used for partial bacterial classification and to evaluate the variability between bacteria found in freshwater at the UW Oceanography dock and in seawater at the NSB Delta Pier.

Coupons not used for bacterial classification will be cleaned using an ultrasonic method followed by mechanical cleaning with a nylon brush. Coupons will be cleaned and weighed until there is no change in coupon mass after two subsequent cleaning cycles. Visual inspections of coupon surfaces will be conducted in accordance with ASTM G46-94.

Corrosion Rate Quantification

Change in coupon mass will be used to quantify corrosion rates using the following equation (G1-03. 2004):

Corrosion Rate = (K x W) / (A x T x D)
Where:
K = unit conversion constant
T = time of exposure (hrs)
A = area in (cm^2)
W = mass loss (g)
D = density of metal (g/cm^3)

The open-circuit potential or corrosion potential of a corroding metal can be measured by determining the voltage difference between the metal immersed in a corrosive medium and a suitable reference electrode (Videla 1996). Coupon corrosion potentials will be determined in accordance with ASTM G69-97. A high-impedence voltmeter will be used for measurement of the potential (G69-97. 2004). Equipment and materials for the open-circuit potential measurements will be provided by the UW Material Sciences Department. Corrosion rates will be calculated from coupon corrosion potential measurements in accordance with ASTM G102-89. Corrosion rate data will be used to generate a figure to evaluate and compare the alloys.

Project Budget

All funding for this project will be provided by the University of Washington's School of Oceanography (Table 2). No ship time is required for the completion of this project.

References

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ASTM G31-72. 2004. Standard practice for laboratory immersion corrosion testing of metals. ASTM Int.

ASTM G46-94. 2004. Standard guide for examination and evaluation of pitting corrosion. ASTM Int.

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ASTM G102-89.2004. Standard practice for calculation of corrosion rates and related information from electrochemical measurements. ASTM Int.

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Table 1. Project Budget

Category	Item (Quantity)	Source	Cost	Total Cost	Cost to Project
Coupon	Al (28)	Alabama Research & Development	$3.75	$105.00	$105.00
	SS (28)		$3.85	$107.80	$107.80
	HY-80 (6)		$35.00	$210.00	$210.00
Equipment	SEM	UW Biology Dept.			
	High Impedence Voltmeter	UW Material Sciences Dept.			
	10L Nisken Bottle	Pooled Equipment	$3.00/day	$3.00	$3.00
Deployment Apparatus	Wood	Open Purchase	≈$20.00	$20.00	$20.00
	Fishing Line		≈$5.00	$5.00	$5.00
	Float (45)		≈$0.50	$22.50	$22.50

Figures

Figure 1. A map identifying the coupon deployment sites in Puget Sound, Washington.

Figure 2. A schematic of the coupon deployment apparatus. 1 – Wood base that will be attached to pier. 2 – Fishing line used to attach coupons to wooden base. 3 – Wooden dowel used to maintain separation between coupons. 4 – Coupons.

Figure 3. A graph comparing the corrosion rates of Al, SS and HY-80 based on length of deployment. The left panel indicates alloy corrosion rates in the presence of marine bacteria and the right panel in the absence of marine bacteria. Corrosion rates are in mm per year (mpy).

Figure 1. Coupon deployment sites in Puget Sound, Washington.

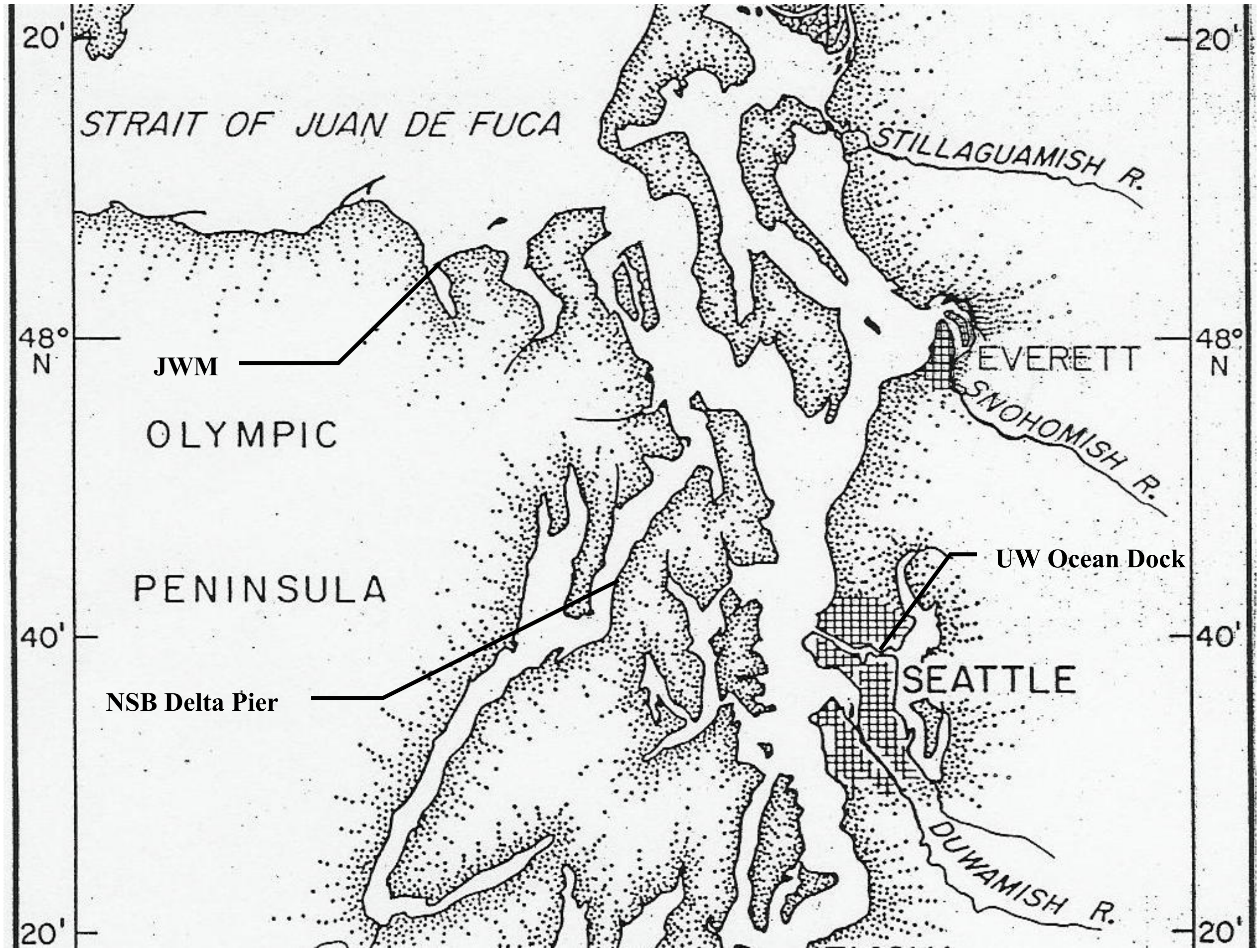

Figure 2. Schematic of coupon deployment apparatus.

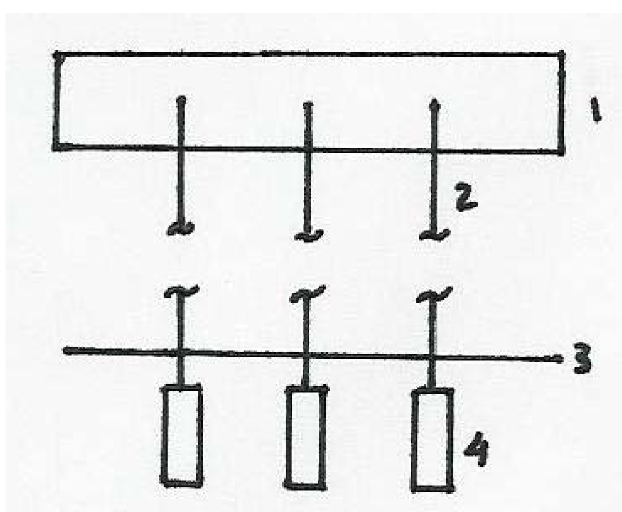

Figure 3. Left: Corrosion rates in the presence of bacteria. Right: Corrosion rates in the absence of bacteria.