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Technical Note N-1037

CORROSION OF DSRV MATERIALS IN SEA WATER - SIX MONTHS EXPOSURE

By

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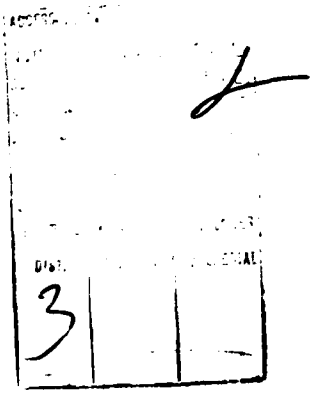
ABSTRACT

In order to provide information needed about specific corrosion problems involved with the design of the DSRV, a sea water exposure program was initiated to determine: (1) the galvanic and crevice corrosion on selected combinations of alloys; and (2) the efficacy of sealing compounds, paint systems and sacrificial anodes as protective measures.

Titanium alloy 6Al-4V and A-286 stainless steel fastened to anodized and painted 6061-T6 aluminum alloy caused the aluminum alloy to corrode galvanically at areas of paint failure.

Sacrificial anodes protected aluminum alloys and Type 321 stainless steel from corroding.

Sealing compounds DC780, PR1532, PR1527 and PR1422 were satisfactory sealants; however, DC93046, DC11 and sprayed PVC were unsatisfactory.



PREFACE

At the request of the Deep Submergence Special Projects Office, the Naval Civil Engineering Laboratory, in cooperation with Lockheed Missile and Space Company, undertook the task of evaluating painted and unpainted dissimilar metal couples, efficacy of zinc anodes and different seal seat finishes, weldments and the susceptibility of alloys to stress corrosion cracking.

Specimens were exposed in surface sea water at mean tide level at the Point Mugu exposure site. At mean tide level the specimens were exposed to the sea air during periods of low tide and were completely immersed in the sea water during periods of high tide.

This report contains the results of six months of exposure.

INTRODUCTION

The design of the Deep Submergence Rescue Vessels specified the use of many dissimilar alloys some of which would be in intimate contact with each other. Sometimes as many as three of four different alloys may be in contact with each other or in such a configuration that there would be an electrical path between all of them. Dissimilar metals in intimate (electrical or physical) contact with each other can result in two types of dangerous corrosion, galvanic and crevice, especially when immersed in sea water. Galvanic corrosion can be very rapid when the area of the cathodic (more noble) alloy is much larger than that of the anodic (less noble) alloy.

Because of the multitude of dissimilar metal combinations, a sea water test program was initiated to determine:

1. The effects of galvanic corrosion on selected combinations of alloys.

2. The efficacy of sealing compounds in preventing crevice corrosion.

3. The value of paint coatings for preventing galvanic corrosion.

4. The value of galvanic anodes in preventing corrosion, galvanic corrosion of dissimilar metal combinations, and corrosion in crevices.

Specimens simulating four conditions noted in the above paragraph were exposed at mean tide level at the Point Mugu site for evaluation. Typical specimens are shown in Figures 1 and 2. The specimen in Figure 1 is an anodized and painted 6061-T6 aluminum alloy panel to which is fastened six painted 6Al-4V titanium alloy strips with A-286 stainless steel fasteners.

There are five (5) different types of sealing compounds between the strips and the panel with no sealing compound underneath the sixth strip.

An aluminum alloy sacrificial anode attached to an AISI Type 321 stainless steel specimen is shown in Figure 2.

The characteristics of the sea water at the Point Mugu site and its geographical location are:

Latitude, North	34°06'
Longitude, West	119°07'
Temperature, °C	12-19
Oxygen, ml/l	3.9-6.6
Salinity, °/oo	33.51
pH	8.1
Current, Knots	Variable

This report discusses the results obtained after 176 days of exposure.

RESULTS AND DISCUSSION

The specimens were 6" x 12" with 1" x 5" strips attached to them. Their component parts, the protective systems, the sealing compounds for filling crevices and coating fasteners, and the results of visual examinations after exposure are given in Table 1. Each specimen is discussed below.

Specimen G1A

The entire specimen was heavily fouled with barnacles, mussels and tube worms.

The paint had failed along the edges of the panel portion of the specimen. The paint had also failed along the edges and at the corners of the strips and it was gone on 30 percent of the surface of one strip.

There was no failure of the sealing compounds atthe faying surfaces between the strips and the panel. Sealing compounds DC93046, DC11 and sprayed PVC were gone from the heads and nuts of the fasteners. The DC780 and PR1532 sealing compounds were intact on the heads and nuts of the fasteners and were judged to be much better than the other three sealing compounds.

The head of an anodized 6061-T6 aluminum alloy bolt and the nut were pitted but all the others were unattacked. The cadmium plated steel wahers underneath the nuts on strips No. 1, 4, 5 and 6 were severely corroded on their outer peripheries. The outside diameter in most cases was reduced from 3/8 inch to 1/4 inch; the washers originally were 3/8 inch outside diameter with a 3/16 inch inside diameter. Measurements with a volt-ohm meter before disassembling the specimen showed that there was an electrical conducting path of very low resistance between the bolts and strips and panel but there was a very high resistance

(no electrical conducting path) between the anodized fasteners and the cadmium plated washers. When steel and an aluminum alloy are in electrical contact, especially in sea water, a galvanic couple is created. In sea water which is an excellent electrolyte, the aluminum alloy in this couple is the more electronegative of the two and it will corrode at a rate which is much faster than its normal rate in an attempt to prevent the steel from corroding. The steel washers corroded at their normal rate in sea water after the cadmium coating had been removed by corrosion because the high electrical resistance of the anodic coating on the 6061-T6 aluminum alloy fasteners prevented the establishment of an electrical conducting path between the two alloys.

Specimen G2A

The entire specimen was heavily fouled with barnacles, mussels and tube worms.

The paint on about 1/6 of the area of the front side and 1/3 of the area of the back side of the panel had failed by flaking. The paint had also failed along the edges, at the corners and on much of the outer surfaces of the strips. When the strips were removed from the panel, the top coat of paint at the faying surface was stripped from the panel underneath all but No. 5 strip. No. 5 strip had been sealed with DC11 sealing compound which is essentially a grease with practically no adhesion

There were no failures of the sealing compounds.

There was no corrosion of the 5052 aluminum alloy rivets.

There was no corrosion at the faying surfaces of either the strips or the panel.

Specimen G3A

The entire specimen was heavily fouled with barnacles, mussels and tube worms.

The paint had failed where the specimens had been in contact with the insulators and the metal was attacked by pitting corrosion at the areas where the paint had failed. The paint had blistered and flaked around the nuts of the fasteners on strip No. 1. There were also paint failures and pitting corrosion on the back surface of the panel. There were paint failures along the edges and at the corners of the strips with corrosion at the denuded areas.

There were white corrosion products on the walls of the bolt holes of the strips and panel indicating that sea water had penetrated the crevices between these surfaces and the bolt sleeves.

There were no failures of sealants DC780, PR1532, DC93046 and sprayed PVC; there was good adhesion of all of them to the strips and panel except sprayed PVC. Sealing compound DC11 was gone from the ends of the fasteners and it had practically no adhesion.

There was no corrosion of the A-286 corrosion resistant fasteners except for one in strip No. 5 with the DC11 sealing compound. There was red rust on the sleeve, threaded end of the bolt and on the nut of this fastener.

There was no corrosion at the faying surfaces of the strips and panel nor were there any paint failures except around the bolt holes on strip No. 1 beneath which there was no sealing compound.

The pitting corrosion of the 6061-T6 aluminum alloy strips and panel at the areas of paint failures is attributed chiefly to galvanic corrosion because of the electrical contact with the A-286 corrosion resistant steel fasteners.

Specimen G4A

The entire specimen was heavily fouled with barnacles, mussels and tube worms.

The top coat of paint had peeled on nearly 50 percent of the front and back surfaces of the panel. The 6061-T6 anodized and painted panel had been attacked by pitting corrosion where it had been in contact with the insulators and the paint and anodized coating had been worn off. The paint had failed along the edges and at the corners of the 6Al-4V titanium alloy strips.

There were no failures of the sealing compounds. There was good adhesion of sealing compounds PR1527, PR1422 and DC93046 to the painted surface but no adhesion of sealing compounds DC11 and sprayed PVC.

There was no corrosion of the 6Al-4V titamium alloy fasteners.

At the faying surfaces the paint peeled from the panel when strips No. 2, 3, 4 and 6 were removed. There were no paint failures when strips No. 1 and 5 were removed.

The pitting corrosion of the anodized and painted 6061-T6 aluminum alloy panel was attributed to galvanic corrosion because of its electrical contact with the 6Al-4V titanium alloy strips and fasteners.

Specimen G5A

The entire specimen was heavily fouled with barnacles, mussels and tube worms.

The paint and anodic coating had failed along the edges and at the corners of the 6061-T6 aluminum alloy panel. There was severe pitting corrosion at the areas where the paint and anodic coating had failed. The paint had failed along the edges and at the corners of the 6Al-4V titanium alloy strips.

Sealing compounds DC93046, DC11 and sprayed PVC had failed around the heads of the bolts and the nuts on strips No. 4, 5 and 6.

There were no paint failures or corrosion at the faying surfaces of the strips and panel.

There was no corrosion of any of the A-286 corrosion resistant steel fasteners or of the cadmium plated steel washers under sealing compounds DC780 and PR1532 on strips No. 2 and 3. The cadmium plated steel washers underneath the nuts on strips No. 1, 4, 5 and 6 had corroded on their outer circumferences. The cadmium plated steel washers were in electrical contact with the A-286 corrosion resistant steel nuts and bolts thus forming a galvanic couple with the cadmium plated steel washers being the anodes. The cadmium plated steel washers, being the anode, would corrode at a faster rate than their normal rate.

The combination of alloys in this specimen creates a complicated galvanic situation composed of five different metals: cadmium, steel, anodized 6061-T6 aluminum alloy, 6Al-4V titanium alloy and A-286 corrosion resistant steel. The order of galvanic activity from anodic to cathodic potentials would be:

Cadmium - most anodic

6061-T6

Steel

A-286 steel

6Al-4V titanium alloy - most cathodic

Measurements with a volt-ohm meter showed very low resistance electrical contact between all metals of the specimen after recovery from test.

Before any paint failures occurred in the sea water exposure, the acting couple was composed of the bare A-286 nuts and bolts and the cadmium on the steel washers. The cadmium, being thin and of lesser area than the A-286 fasteners, corroded at a rapid rate and was soon consumed. After the cadmium was gone, the acting couple consisted of the A-286 fasteners and the bare steel washers, the latter were then sacrificed to provide protection to the fasteners. This couple continued to act until paint failures and anodic coating failures occurred on the edges of the aluminum panel and paint failures occurred on the titanium strips. When this occurred there was a four metal couple consisting of 6061-T6 aluminum alloy, steel, A-286 corrosion resistant steel and 6Al-4V titanium alloy. In this couple the 6061-T6 aluminum alloy being the most anodic alloy began to be sacrificed to protect the other three and in so doing began to pit. It is also possible that, even though the 6061-T6 aluminum alloy theoretically was being partially sacrificed to protect the steel washers, the steel washers were also being partially sacrificed to protect the 6Al-4V titanium alloy and the A-286 corrosion resistant steel. Hence, we have the situation where both the 6061-T6 aluminum alloy and the steel washers were being consumed at above average rates to afford protection to the A-286 corrosion resistant steel fasteners and the 6Al-4V titanium alloy strips.

Specimen G6A

The entire specimen was heavily fouled with barnacles, mussels and tube worms.

There were no paint failures on the glass reinforced plastic panel except where it had been worn away at the insulators. There were no paint failures on the 13V-11Cr-3Al titanium alloy strips or at the faying surfaces between the strips and the panel.

There was no corrosion of the 13V-11Cr-3Al titanium alloy strips at the faying surfaces.

There was corrosion of one of the silver plated A-286 corrosion resistance steel nuts on the 6Al-4V titanium alloy bolts.

Specimen G7A

The entire specimen was heavily fouled with barnacles, mussels and tube worms.

There were no paint failures on either the glass reinforced plastic panel or the 13V-11Cr-3Al titanium alloy strips.

There were no paint failures at the faying surfaces of the strips or panel.

There were rust stains under the heads and on the threads of the A-286 corrosion resistant steel bolts.

Specimen G8A

The entire specimen was heavily fouled with barnacles, mussels and tube worms.

The anodized coatings were gone from the 6061-T6 aluminum alloy panel and strips and their surfaces were etched; however, the anodic coating was intact on the faying surfaces of the strips and the panel.

There was no corrosion on either the Type 304 stainless steel or on the 70 nickel-30 copper 400 alloy rivets.

Although the zinc anode was covered with white corrosion products, less than ten percent of the zinc had been consumed.

Specimen G8E

The entire specimen was heavily fouled with barnacles, mussels and tube worms.

The surfaces of the 6061-T aluminum alloy panel had a dark grey color and were etched.

There was no discernible corrosion on the 13V-11Cr-3Al titanium alloy strips. There, also, was no corrosion on either the Type 304 stainless steel or the 70 nickel-30 copper 400 alloy rivets.

The faying surfaces of the panel underneath the strips were covered with white corrosion products and they were also etched. The faying surfaces of the strips were also covered with white corrosion products but they were not corroded; the white corrosion products were from the aluminum alloy panel.

The zinc anode was covered with a thick layer of white corrosion products, was pitted underneath the corrosion products, and about ten percent of it had been consumed. The zinc anode had effectively prevented pitting corrosion of the 6061-T6 aluminum alloy panel as well as galvanic corrosion of the panel but the zinc anode had not prevented corrosion of the faying surfaces of the aluminum alloy panel underneath the titanium alloy strips.

Specimen G9A

The entire specimen was considerably fouled with barnacles, mussels and tube worms.

There were no paint failures on the panel except where it had worn off at the insulators.

The titanium alloy strips were uncorroded.

There was no failure of the sealing compound e> pt where it had been abraded from the head of one screw.

The head of the screw from which the sealing compound had been abraded was rust stained and the rust stains extended along the shank underneath the head for about 1/2 inch. There was no corrosion on the other fasteners.

There were no paint failures or corrosion at the faying surfaces.

The Delrin strips, sleeves and washers performed as excellent insulators to prevent galvanic corrosion between the dissimilar metal panel, strips and fasteners.

Specimen No. 3

There was considerable fouling of the specimen with barnacles, mussels and tube worms.

The panel and weld bead were etched.

The aluminum anode was pitted and less than five percent had been consumed. The aluminum anode had effectively prevented pitting corrosion of the aluminum alloy specimens.

Specimen No. 5

The specimen was heavily fouled with barnacles, mussels and tube worms.

The specimen was uncorroded.

The aluminum anode had been about 75 percent consumed. It had effectively protected the specimen, including the weld bead and adjacent heat affected zones, from selective corrosion.

Specimen No. 10

The specimen was heavily fouled with barnacles, mussels and tube worms.

There were no paint failures, blisters or corrosion at the scribe marks on the anodized and painted 6061-T6 aluminum alloy specimen. However, there were a few areas where the paint had flaked along the edges of the specimen.

Specimen No. 11

The specimen was heavily fouled with barnacles, mussels and tube worms.

There were a few paint failures along the edges and at the corners of the specimen. There were a few small blisters and light rust stains along the scribe marks.

Specimen 718

The specimen was fouled with barnacles, mussels and tube worms.

There was no surface corrosion or any crevice corrosion at the intentionally created crevice at the transverse weld. There was no localized corrosion at or adjacent to either the transverse or the circular welds.

SUMMARY

Specimens composed of different combinations of alloys, fasteners, surface coatings, paint systems, sealing compounds and galvanic anodes were exposed at mean tide level in the Pacific Ocean to evaluate the efficacy of the protective systems for alleviating galvanic and crevice corrosion. The composite specimens simulated fabricating practices encountered in the construction of the first Deep Submergence Rescue Vessel (DSRV) for the Navy.

This report presents the results of the evaluation of a set of specimens removed after 176 days of exposure.

All the specimens were moderately to heavily fouled with barnacles, mussels and tube worms.

There were paint failures on all the 6061-T6 aluminum alloy panels and strips varying in degree from edge and corner failures to 30 percent of the surface area. In most cases, surface failures were due to peeling of the top coat of paint.

There were no paint failures or blisters along the scribe marks intentionally made on an anodized and painted 6061-T6 aluminum alloy specimen. However, there were rust stains and blisters along the scribe marks made on a painted HY140 steel specimen.

There were paint failures on the 6Al-4V titanium alloy strips.

There were no paint failures on the glass reinforced plastic (GRP) panels or on the 13V-11Cr-3Al titanium alloy strips.

There were no paint failures at the faying surfaces of the strips and the panels except the following: the top coat of paint was pulled from the panels when strips with or without the following sealing compounds were removed:

1. One strip with no sealant
2. One strip with sprayed PVC sealant
3. Two strips with PR1527 sealant
4. Two strips with PR1422 sealant
5. Two strips with DC93046 sealant

Three of the sealing compounds (DC93046, DC11 and sprayed PVC) failed by losing their adhesion to the heads of the bolts and the nuts. There were no failures of the other four sealing compounds - DC780, PR1532, PR1527 and PR1422.

The 5052 aluminum alloy rivets and 6Al-4V titanium alloy fasteners used to assemble the anodized and painted 6061-T6 aluminum alloy strips and the painted 6Al-4V titanium alloy strips to anodized and painted 6061-T6 aluminum alloy panels were not corroded.

The cadmium plated steel washers, both unprotected and where the sealing compounds had failed, were corroded on their outer peripheries; the outside diameters of some were reduced as much as 1/8 of an inch. There was no electrical contact between the cadmium plated steel washers and the anodized 6061-T6 aluminum alloy fasteners but there was electrical contact between the washers and the A-286 steel fasteners indicating the possibility of galvanic corrosion of the washers in the latter case but not in the former. The sealing compounds which did not fail, DC780 and PR1532, protected the cadmium plated steel washers from corroding.

An anodized 6061-T6 aluminum alloy nut and the head of the bolt were pitted underneath the cracked and split DC93046 sealing compound.

There was no corrosion on A-286 stainless steel nuts and bolts used to fasten painted 6Al-4V titanium alloy strips to an anodized and painted 6061-T6 aluminum alloy panel. However there were rust stains underneath the heads and on the threads of A-286 fasteners used to attach painted 13V-11Cr-3Al titanium alloy strips to a painted GRP panel. There were rust stains underneath a failure in the DC11 sealing compound on one (of 12) A-286 sleeve and bolt assmeblies used to fasten an anodized and painted 6061-T6 strip to a similar alloy panel.

There were white corrosion products from the 6061-T6 aluminum alloy strips and panels covering the outer surfaces of the A-286 sleeves of the fastener assemblies indicating that moisture had penetrated the interface between the two components.

There were rust stains on the heads of the 18 percent chromium - 8 percent nickel stainless steel bolts which were used to attach the 13V-11Cr-3Al titanium alloy strips to the anodized and painted 6061-T6 aluminum alloy panel.

There was no crevice corrosion of the Inconel 718 alloy.

Aluminum galvanic anodes protected both butt welded 7079 aluminum alloy and butt welded AISI Type 321 stainless steel from corroding.

Zinc galvanic anodes protected both unanodized and anodized 6061-T6 aluminum alloys except at the faying surfaces of the unanodized panel and strips. The faying surfaces were covered with thin layers of white corrosion products and were etched showing that the protective current was not affecting these surfaces.

The anodized and painted 6061-T6 aluminum alloy panels and strips were galvanically corroded at areas where both the anodized coating and the paint had been removed by: (1) A-286 stainless steel fasteners, (2) 6Al-4V titanium alloy strips and fasteners which had been bared at areas of paint failure, and (3) 6Al-4V titanium alloy strips and A-286 stainless steel fasteners which had been bared at areas of paint failure.

CONCLUSIONS

Paint coatings prevented galvanic corrosion of anodized 6061-T6 aluminum alloy coupled to more noble A-286 stainless steel and 6Al-4V titanium alloy as long as they remained intact.

The paint system protected the bare metal exposed at scribe marks on 6061-T6 aluminum alloy from corrosion but did not provide such protection to bare metal exposed at scribe marks on steel.

Sacrificial zinc anodes were satisfactory for preventing pitting, crevice and galvanic corrosion of anodized 6061-T6 aluminum alloy. They prevented pitting and galvanic corrosion of bare 6061-T6 aluminum alloy but did not completely prevent corrosion in the crevices between the aluminum alloy and a titanium alloy.

Sacrificial aluminum anodes were satisfactory for preventing corrosion of welded 7039 aluminum alloy and AISI Type 321 stainless steel.

Welded (TIG) 718 Inconel alloy was not susceptible to corrosion or crevice corrosion in sea water.

The anodic coating will protect 6061-T6 fasteners in sea water for about six months.

Cadmium plating is not a satisfactory protective coating for steel in sea water.

The 5052 aluminum alloy rivets, Type 304 rivets, nickel-copper 400 alloy rivets, and 6Al-4V titanium alloy fasteners are satisfactory for fabricating painted and galvanically protected aluminum alloy structures in sea water for a period of time of six months.

Unprotected A-286 fasteners will start to corrode within six months when exposed in sea water.

Silver plating is not a satisfactory protective coating for A-286 stainless steel nuts in sea water.

Sealing compounds DC780, PR1532, PR1527 and PR1422 were effective as sealants in crevices and for protecting the ends of fasteners whereas DC93046, DC11 and sprayed PVC sealing compounds were unsatisfactory for protecting the ends of fasteners.

This is an interim report; work on the program is continuing.

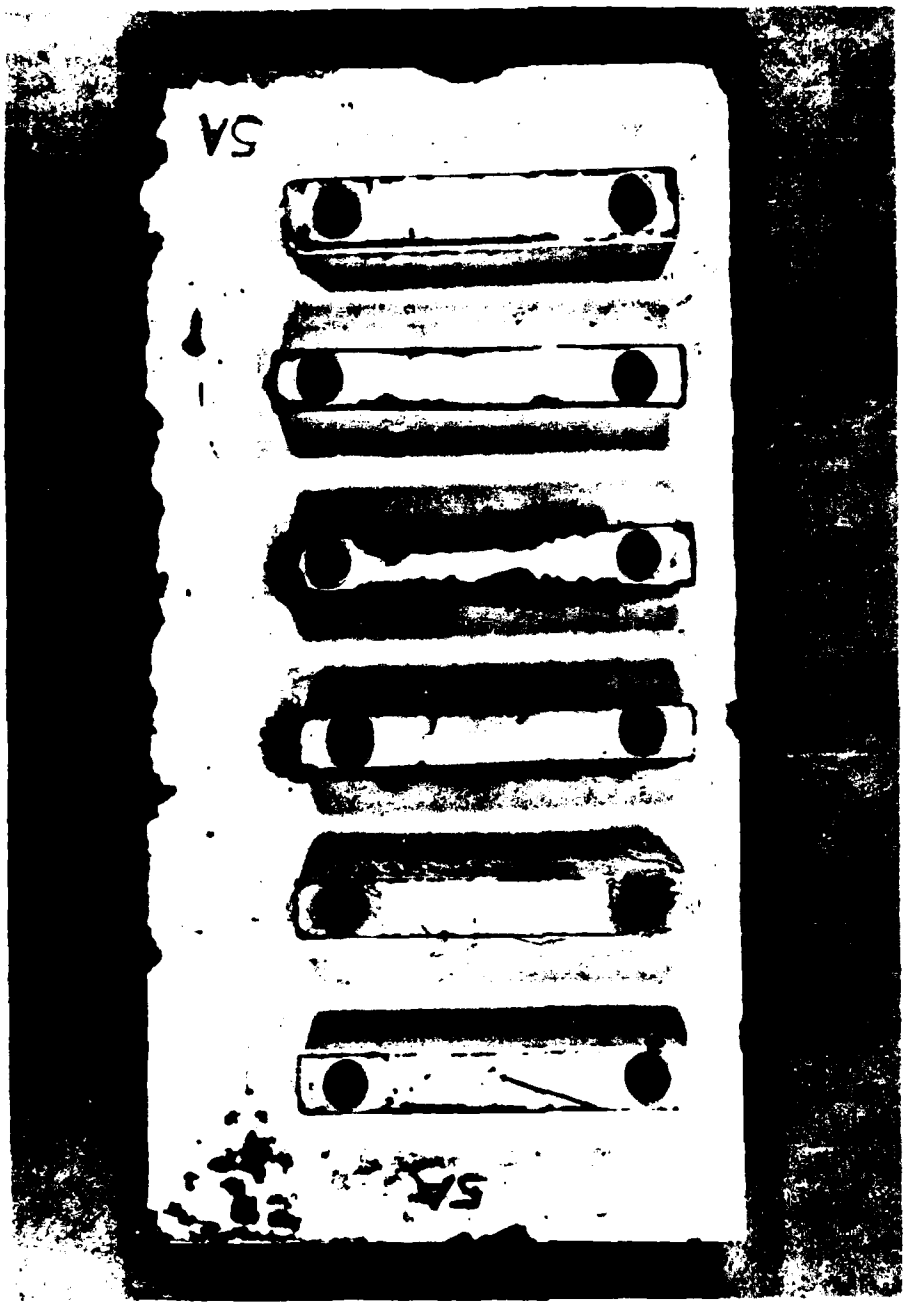


Figure 1. Painted titanium alloy strips bolted to an aluminum alloy panel with stainless steel bolts.

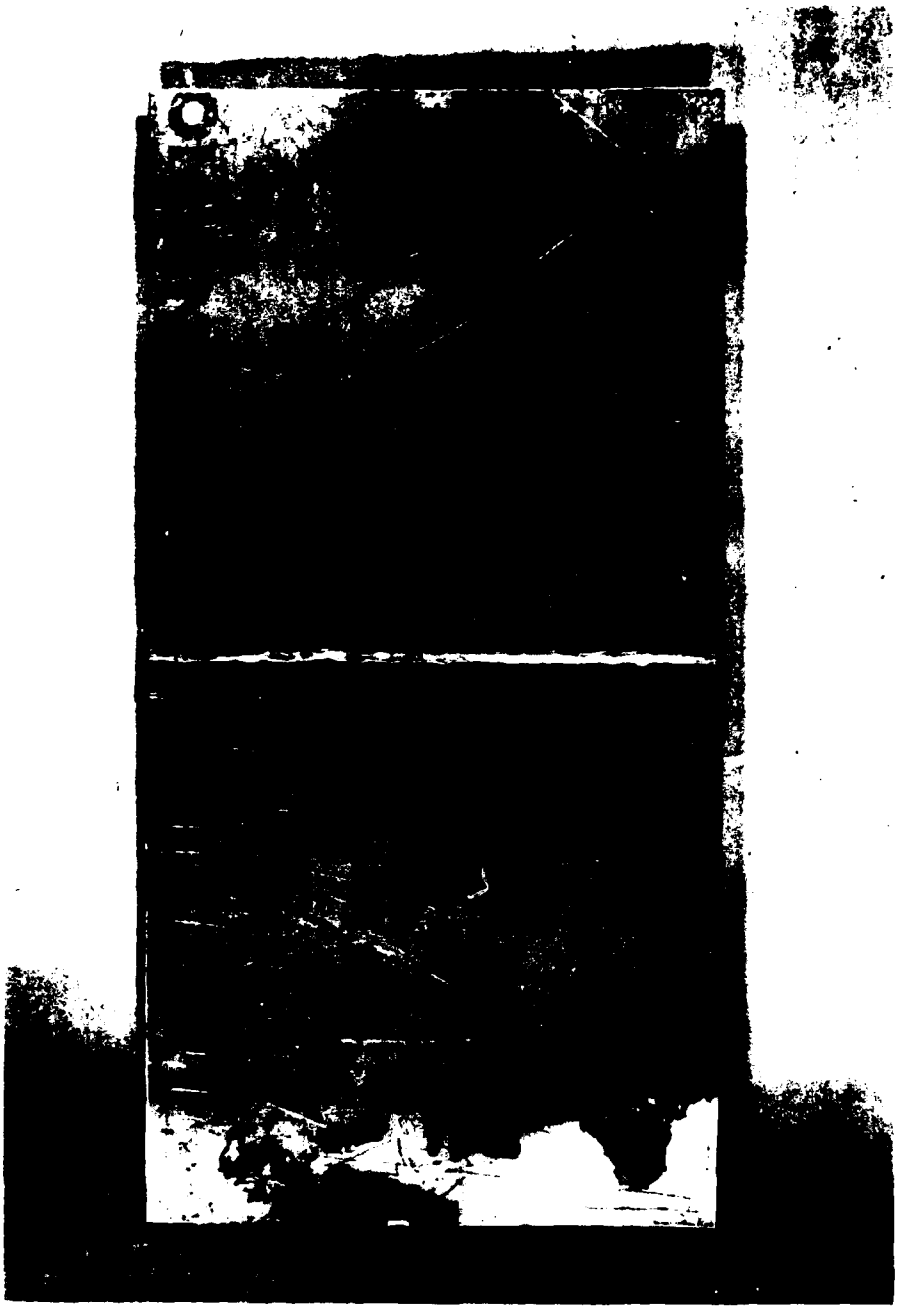


Figure 2. Aluminum alloy sacrificial anode in lower left corner of stainless steel specimen.

Table 1. Specimens After Six Months of Exposure in Tidewater

Specimen	Remarks
Panel G1A	6061-T6 anodized[1] and painted[2]; no electrical contact between fasteners and Cd plated steel washers; electrical contact between fasteners and panel.
Front[3]	Paint failures along edges of panel, much fouling
Back	Paint failures along edges of panel, much fouling
Strips	6061-T6 anodized[1] and painted[2]; HI-LOK 6061-T6 anodized fasteners, Cd plated steel washers
#1	Paint failure along edges and at corners, 30% of paint gone on surface of strip, much fouling
Sealant - None	
Fasteners	No corrosion of fasteners; edges of Cd plated steel washers corroded, OD decreased by 1/16 inch
Faying Surfaces	No paint failure
#2	Paint failure along edges and at corners, much fouling
Sealant - DC780	No failure, good adhesion
Fasteners	No corrosion on fasteners or on Cd plated steel washers
Faying Surfaces	No paint failure
#3	Paint failure along edges and at corners, much fouling
Sealant - PR1532	No failure, good adhesion
Fasteners	No corrosion on fasteners or on Cd plated steel washers
Faying Surfaces	No paint failure

Cont'd.

Table .. (Cont'd)

Specimen	Remarks
#4	Paint failure along edges and at corners, much fouling
Sealant - DC93046	Failures on bolt heads and nuts
Fasteners	Pitting on head of one bolt and on nut; Cd plated steel washers badly corroded, OD decreased by 1/8 inch
Faying Surfaces	No paint failure, good adhesion
#5	Paint failures along edges and at corners, much fouling
Sealant - DC11	Failures on bolt heads and on nuts
Fasteners	No corrosion on fasteners; Cd plated steel washers severely corroded, OD decreased by 1/8 inch
Faying Surfaces	No paint failure, no adhesion
#6	Paint failure at edges and at corners, much fouling
Sealant - PVC Spray	Failures on bolt heads and on nuts, no adhesion
Fasteners	No corrosion on fasteners; Cd plated steel washers severly corroded, OD decreased by 1/8 inch
Faying Surfaces	No paint failure
Panel G2A	6061-T6 anodized(1) and painted(2)
Front(3)	Paint flaked off 1/6 of area, much fouling
Back	Paint flaked off 1/3 of area, much fouling
Strips	6061-T6 anodized(1) and painted(2); 5052 rivets
#1	Paint failures along edges, corners and surfaces, much fouling
Sealant - None	
Fasteners	No corrosion
Faying Surfaces	Top coat of paint stripped from panel, no corrosion

cont'd.

Table 1. (Cont'd.)

Specimen	Remarks
#2	Paint failures along edges, corners and surfaces, much fouling
Sealant - PR1527	No failures, good adhesion
Fasteners	No corrosion
Faying Surfaces	Top coat of paint stripped from panel, no corrosion
#3	Paint failures along edges, corners and surfaces, much fouling
Sealant - PR1422	No failure, good adhesion
Fasteners	No corrosion
Faying Surfaces	Top coat of paint stripped from panel, no corrosion
#4	Paint failures along edges, corners and surfaces, much fouling
Sealant - DC93046	No failure, good adhesion
Fasteners	No corrosion
Faying Surfaces	Top coat of paint stripped from panel, no corrosion
#5	Paint failures along edges, corners and surfaces, much fouling
Sealant - DC11	No failure, no adhesion
Fasteners	No corrosion
Faying Surfaces	No corrosion
#6	Paint failures along edges, corners and surfaces, much fouling
Sealant - PVC Spray	No failure, no adhesion
Fasteners	No corrosion
Faying Surfaces	Top coat of paint stripped from panel, no corrosion
Panel G3A	6061-T6 anodized(1) and painted(2); electrical contact between fasteners and strips and panel
Front(3)	Paint failure and pitting corrosion at insulators, much fouling
Back	Paint failure and pitting corrosion, paint blistered and flaked around fasteners on strip No. 1, much fouling

cont'd.

Table 1. (Cont'd.)

Specimen	Remarks
Strips	6061-T6 anodized[1] and painted[2]; A-286 stainless steel fasteners with sleeves and crimp nuts
#1	Paint failures and pitting corrosion along edges and at corners. White corrosion products in bolt holes, much fouling
Sealant - None	
Fasteners	White corrosion products on sleeves, fasteners uncorroded
Faying Surfaces	Paint flaked around one bolt hole
#2	Paint failure and pitting corrosion along edges and at corners. White corrosion products in bolt holes, much fouling.
Sealant - DC780	No failure, good adhesion
Fasteners	White corrosion products on sleeves, fasteners uncorroded
Faying Surfaces	No paint failure
#3	Paint failure and pitting corrosion along edges and at corners. White corrosion products in one bolt hole, much fouling.
Sealant - PR1532	No failure, good adhesion
Fasteners	White corrosion products on one sleeve, fasteners uncorroded
Faying Surfaces	No paint failure
#4	Paint failure and pitting corrosion along edges and at corners. Paint blistered and flaked and pitting corrosion around bolt holes. White corrosion products in bolt holes, much fouling
Sealant - DC93046	No failure, good adhesion
Fasteners	White corrosion products on sleeves, fasteners uncorroded
Faying Surfaces	No paint failure
#5	Paint failure and pitting corrosion along edges and at corners. Heavy red corrosion products at one bolt hole. White corrosion products in other bolt hole, much fouling

cont'd.

Table 1. (Cont'd.)

Specimen	Remarks
Sealant - DC11	Gone from ends of fasteners, no adhesion
Fasteners	White corrosion products on one sleeve, red rust stains on other sleeve. Red rust stains on threads of one bolt.
Faying Surfaces	No paint failure. Red rust stains around one bolt hole.
#6	Paint failure and pitting corrosion along edges and at corners. White corrosion products in bolt holes, much fouling.
Sealant - PVC Spray	No failure, no adhesion
Fasteners	White corrosion products on sleeves, fasteners uncorroded
Faying Surfaces	No paint failure
Panel G4A	6061-T6 anodized[1] and painted[2]; electrical contact between panel, strip and fasteners
Front[3]	Top coat of paint peeled on much of panel, paint gone and panel pitted at insulators and at two corners, much fouling
Back	Top coat of paint peeled on much of panel, much fouling
Strip	Painted 6A1-4V; 6A1-4V fasteners and aluminum alloy washers potted in a sealing compound
#1	Paint failure along edges and at corners, much fouling
Sealant - None	
Fasteners	No corrosion
Faying Surfaces	No paint failure
#2	Paint failure along edges and at corners, much fouling
Sealant - PR1527	No failure, good adhesion
Fasteners	No corrosion, steel shells around nuts rust stained
Faying Surfaces	Paint peeled on panel

cont'd.

Table 1. (Cont'd.)

Specimen	Remarks
#3	Paint failure along edges and at corners, much fouling
Sealant - PR1422	No failure, good adhesion
Fasteners	No corrosion
Faying Surfaces	Paint peeled on panel
#4	Paint failure along edges and at corners, much fouling
Sealant - DC93046	No failure, good adhesion
Fasteners	No corrosion
Faying Surfaces	Paint peeled on panel
#5	Paint failure along edges and at corners, much fouling
Sealant - DC11	No failure, no adhesion
Fasteners	No corrosion
Faying Surfaces	Paint peeled on panel
#6	Paint failure along edges and at corners, much fouling
Sealant - PVC Spray	No failure, no adhesion
Fasteners	No corrosion
Faying Surfaces	Paint peeled on panel
Panel G5A	6061-T6 anodized(1) and painted(2); electrical contact between panel, strips and fasteners
Front(3)	Paint failure along edges, at corners and at insulators with severe pitting at areas of paint failure, much fouling
Back	Same as front
Strips	Painted 6A1-4V, A286 fasteners with Cd plated steel washers
#1	Paint failure along edges and at corners, much fouling

cont'd.

Table 1. (Cont'd.)

Specimen	Remarks
Sealant - None	
Fasteners	Edges of Cd plated steel washers corroded, bolts and nuts uncorroded
Faying Surfaces	No paint failure
#2	Paint failure along edges and at corners, much fouling
Sealant - DC780	No failure, good adhesion
Fasteners	No corrosion
Faying Surfaces	No paint failure
#3	Paint failure along edges and at corners, much fouling
Sealant - PR1532	No failure, good adhesion
Fasteners	No corrosion
Faying Surfaces	No paint failure
#4	Paint failure along edges and at corners, much fouling
Sealant - DC93046	Failed around nuts and washers
Fasteners	Edges of Cd plated steel washers corroded, bolts and nuts uncorroded
Faying Surfaces	No paint failure
#5	Paint failure along edges and at corners, much fouling
Sealant - DC11	Failed around nuts and washers
Fasteners	Edges of Cd plated steel washers corroded, bolts and nuts uncorroded
Faying Surfaces	No paint failure
#6	Paint failure along edges and at corners, much fouling
Sealant - PVC Spray	Failed around nuts and washers
Fasteners	Edges of Cd plated steel washers corroded, bolts and nuts uncorroded
Faying Surfaces	No paint failure
Panel G6A	Glass reinforced plastic (GRP) painted[2]

cont'd.

Table 1. (Cont'd.)

Specimen	Remarks
Front[3]	No paint failure, worn-off edges at insulators, much fouling
Back	No paint failure, much fouling
Strips	Painted[2] 13V-11Cr-3Al, 6Al-4V bolts with silver plated A-286 nuts, no sealants
#1	No paint failure, much fouling
Fasteners	No corrosion
Faying Surfaces	No paint failure, dirt accumulation
#2	No paint failure, much fouling
Fasteners	Threaded end of one screw rust stained, corrosion at pinholes in silver plating and on threads of one nut
Faying Surfaces	No paint failure, dirt accumulation
Panel G7A	Glass reinforced plastic (GRP) painted[2]
Front[3]	No paint failure, much fouling
Back	No paint failure, much fouling
Strips	Painted[2] 13V-11Cr-3Al, A-286 fasteners, no sealant
#1	No paint failure, much fouling
Fasteners	Rust stains under heads of bolts and on threads
Faying Surfaces	No paint failure, dirt accumulation
#2	No paint failure, much fouling
Fasteners	Rust stains under heads of bolts and on threads
Faying Surfaces	No paint failure, dirt accumulation

cont'd.

Table 1. (Cont'd.)

Specimen	Remarks
Panel G8A	6061-T6 anodized[1]; electrical contact between rivets, panel and strips; zinc anode attached
Front[3]	Anodized coating gone and panel etched, much fouling
Back	Anodized coating gone and panel etched, much fouling
Strips	6061-T6 anodized[1]; Type 304 stainless steel and nickel-copper 400 rivets
#1	Anodized coating gone, etched, much fouling
Fasteners	Type 304 rivets uncorroded
Faying Surfaces	Anodized coating intact
#2	Anodized coating gone, etched, much fouling
Fasteners	Type 304 rivets uncorroded
Faying Surfaces	Anodized coating intact
#3	Anodized coating gone, etched, much fouling
Fasteners	Type 304 rivets uncorroded
Faying Surfaces	Anodized coating intact
#4	Anodized coating gone, etched, much fouling
Fasteners	Nickel-copper 400 rivets uncorroded
Faying Surfaces	Anodized coating intact
#5	Anodized coating gone, etched, much fouling
Fasteners	Nickel-copper 400 rivets uncorroded
Faying Surfaces	Anodized coating intact

cont'd.

Table 1. (Cont'd.)

Specimen	Remarks
#6	Anodized coating gone, etched, much fouling
Fasteners	Nickel-copper 400 rivets uncorroded
Faying Surfaces	Anodized coating intact
Anode	Zinc anode covered with white corrosion products, less than 10 percent consumed
Panel G8E	6061-T6 bare, electrical contact with strips and rivets, zinc anode attached
Front(3)	Etched, discolored, dark gray, much fouling
Back	Etched, discolored, dark gray, much fouling
Strips	Bare 13V-11Cr-3Al; rivets Type 304 stainless steel and nickel-copper 400 alloy; no sealant
#1	No corrosion, much fouling
Fasteners	Type 304 rivets uncorroded
Faying Surfaces	White corrosion products, panel etched
#2	No corrosion, much fouling
Fasteners	Type 304 rivets, uncorroded
Faying Surfaces	White corrosion products, panel etched
#3	No corrosion much fouling
Fasteners	Type 304 rivets, uncorroded
Faying Surfaces	White corrosion products, panel etched
#4	No corrosion, much fouling
Fasteners	Nickel-copper 400 alloy rivets uncorroded
Faying Surfaces	White corrosion products, panel etched

cont'd.

Table 1. (Cont'd.)

Specimen	Remarks
#5	No corrosion, much fouling
Fasteners	Nickel-copper 400 alloy rivets uncorroded
Faying Surfaces	White corrosion products, panel etched
#6	No corrosion, much fouling
Fasteners	Nickel-copper 400 alloy rivets uncorroded
Faying Surfaces	White corrosion products, panel etched
Anode	Zinc anode covered with thick white corrosion products, pitted, about 10 percent consumed
Panel G9A	6061-T6 anodized(1) and painted(2); no electrical contact between fasteners and, strips and panel
Front(3)	No paint failure, except where due to wear at insulators, much fouling
Back	Same as front
Strips	Bare 13V-11Cr-3Al, 18-8 cap screws, silver plated nuts, delrin strips, sleeves and washers, DC 780 sealant
#1	No corrosion, much fouling
Sealant - DC780	No failure, good adhesion
Fasteners	No corrosion
Faying Surfaces	No paint failure, no corrosion
#2	No corrosion, much fouling
Sealant - DC780	Abraded off head of one screw
Fasteners	Rust stains on head of one screw, extended down shank from head for 1/2 inch
Faying Surfaces	No paint failure, no corrosion

cont'd.

Table 1. (Cont'd.)

Specimen	Remarks
Panel No. 3	7039 aluminum alloy, MIG welded, longitudinal butt weld, 5180 filter rod, Galvalum anode attached.
	Panel and weld bead etched, few pits on anode, much fouling
Panel No. 5	Type 321 stainless steel, TIG welded, transverse butt weld, 347 filler rod, Galvalum anode attached.
	No corrosion on panel or weld bead, anode about 75 percent consumed, much fouling
Panel No. 10	6061-T6 aluminum alloy, anodized(1) and painted(2); one X scribe mark through paint to bare metal on one side
	Some paint flaked, mostly along top edge, no corrosion or blisters at scribe marks, much fouling
Panel No. 11	HY140 steel, painted, double X scribe marks through paint to bare metal on one side.
	Some paint failures along edges and at corners, some light rust stains and a few small blisters along scribe marks, much fouling
Panel 718	Inconel 718 alloy, TIG welded without filler rod, transverse across top forming a 1-inch wide open lap joint forming a crevice, 3-inch diameter circular weld bead.

cont'd.

Table 1. (Cont'd.)

Specimen	Remarks
	No crevice corrosion, no surface corrosion, mottled by barnacles, much fouling

1. Chromic acid anodized

2. Paint system:
   Wash primer - phosphoneal, 1 coat
   Primer - 1 coat epoxy and 1 coat polyurethane
   Top coat - 2 coats, color coded polyurethane

3. Surface with strips attached to it.

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13. ABSTRACT

In order to provide information needed about specific corrosion problems involved with the design of the DSRV, a sea water exposure program was initiated to determine: (1) the galvanic and crevice corrosion on selected combinations of alloys and (2) the efficacy of sealing compounds, paint systems and sacrificial anodes as protective measures.

Titanium alloy 6Al-4V and A-286 stainless steel fastened to anodized and painted 6061-T6 aluminum alloy caused the aluminum alloy to corrode galvanically at areas of paint failure.

Sacrificial anodes protected aluminum alloys and Type 321 stainless steel from corroding.

Sealing compounds DC780, PR780, PR1527 and PR1422 were satisfactory sealants; however, DC93046, DC11 and sparyed PVC were unsatisfactory.

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