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OVERCOATING OF INORGANIC ZINC PRIMERS FOR UNDERWATER SERVICE

FINAL REPORT

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PROGRAM MANAGEMENT

On May 19, 1986 the program management of the Surface Preparation and Coatings Panel was transferred from Avondale Industries, Inc. (Avondale) to National Steel and Shipbuilding Company (NASSCO). With the transfer the panel number was changed from SP-023-1 to SP-3.

This report is the result of Task 3-82-2, performed under Avondale's Panel Program Manager Mr. John Peart. The printing and distribution was carried out under the new Panel Program Manager Mr. James Ruecker, NASSCO.

FOREWARD

The Maritime Administration under its National Shipbuilding. Research Program sponsored the present laboratory study. Avondale Shipyards, Inc., administered the program for the Maritime Administration with Mr. John Peart, formerly of the Avondale Shipyards, acting as the Technical Administrator. All of the experimental work described in this report took place at the Ocean City Research Corporation laboratory in Ocean City, New Jersey under the direction of Mr. George A. Gehring, Jr. and Mr. James A. Ellor.

The research study investigated the acceptability of overcoating inorganic zinc primers in underwater service. Of particular interest was the performance of inorganic zinc pre-construction primers. If it can be demonstrated that conventional topcoats are compatible with inorganic zinc pre-construction primers in underwater service, the requirement for removing the primer by abrasive blasting prior to coating of the underwater hull might be eliminated. This would result in a substantial cost savings. The overall objective of the National Shipbuilding Research Program is to reduce shipbuilding-related costs in U.S. shipyards.

EXECUTIVE SUMMARY

The shipbuilding industry has directed much effort toward ways of limiting escalating coating costs. A major portion of coating costs may be attributed to surface preparation. During construction, steel plate is normally protected with an inorganic zinc pre-construction primer. For the underwater portion of the hull, this primer is usually removed by abrasive blasting prior to final coating of the hull. If the requirement for removing the pre-construction primer could be eliminated, there would be a significant cost savings. As a result, Avondale Shipyards acting on behalf of the Maritime Administration under the National Shipbuilding Research Program authorized the Ocean City Research Corporation to undertake a laboratory study investigating the performance of selected marine coatings when applied over inorganic zinc primers in underwater service.

In general, the results of the study suggest that there are inorganic zinc pre-construction primers that can be overcoated for underwater service. The results encourage further tests to investigate the parameters affecting compatibility.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

INTRODUCTION

In new ship construction, the structural steel plate used to fabricate the hull is often protected with an inorganic zinc pre-construction primer. The pre-construction primer provides corrosion protection to the steel during fabrication. After fabrication, the general practice has been to remove the pre-construction primer on the underwater portion of the hull before application of any subsequent coats.* This is done to eliminate blistering and disbandment of the topcoat which can occur when inorganic zinc coatings are overcoated in underwater service (1), (2), (3), (4).

It has been reported that Japanese shipyards are now overcoating inorganic zinc pre-construction primers on the underwater portion of the hull without incurring subsequent blistering/disbondment problems. Reportedly, the Japanese are able to overcoat without problems because they are using pre-construction primers that have very low zinc levels and are less reactive, with less of a tendency to liberate hydrogen gas when contacted by water. The lower zinc levels do not provide comparable corrosion protection to those traditionally used in U.S. yards. However, the turn-around time for steel plate fabrication in the Japanese yards is supposedly lower than in U.S. yards (2-3 months vs. 6-9 months), and thus it is believed the additional corrosion protection is unnecessary.

Based on the reported practice in the Japanese shipyards, the Ocean City Research Corporation was authorized to undertake a study whose objectives were as follows:

- To determine whether it is necessary, for underwater marine service, to remove inorganic zinc pre-construction primers by abrasive blasting prior to the application of subsequent coatings.
- To compare the propensity of different inorganic zinc primers (pre-construction vs. full-coat) to cause topcoat blistering in underwater service.
- To evaluate the effect of different inorganic zinc primer weathering periods on topcoat blistering susceptibility.
- To determine to what extent cathodic protection will affect the performance of coatings applied over inorganic zinc primers.

The following report summarizes the results of the study.

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*The U.S. Navy does not permit overcoating of inorganic zinc primers for underwater service.

CONCLUSIONS

1. The results of the subject tests suggest that, depending on the degree of weathering prior to topcoating, there may be inorganic zinc pre-construction primers that can be over-coated for underwater service. After a weathering exposure of 7 days, three of the primers tested in this program (primers #l, #2 and #5 in Table 1) did not appear to increase the tendency for topcoat blistering or disbandment when compared to white-metal blasted control panels.

2. The Japanes-manufactured inorganic zinc pre-construction primer tested in the subject program showed a propensity to cause topcoat blistering. This is contrary to the manufacturer's claims.

3. Of the primers tested, the greatest tendency for topcoat blistering occurred over the 2-component full-coat inorganic zinc primer applied at the heaviest thickness (approximately 4 mils).

4. The results of the subject tests suggest that a longer weathering period (6Ø days versus 7 days) increases the susceptibility of the inorganic zinc primers to topcoat disbandment. This is contrary to the generally accepted notion.

5. Of the topcoats included in the test program, the MIL-P-24441 epoxy showed the least tendency toward blistering and disbandment.

EXPERIMENTAL APPROACH

General Test Plan

The general test plan comprised the evaluation of three different epoxy topcoats over each of five inorganic zinc primers. prepared test panels were exposed to three different test environments: (1) quiescent seawater immersion at a potential of -1.Ø volt vs. SCE, (2) quiescent seawater immersion at 15Ø°F, 25 psi, and (3) flowing seawater at 18 knots.

Coatings Selected For Testing

Table 1 describes each of the five inorganic zinc primers selected for testing. The test matrix included three pre-construction primers and two full-coat systems, among which was a Japanese pre-construction primer.

Table 2 describes the topcoats included in the test program -- a coal tar epoxy, a MIL-P-23236 epoxy, and a MIL-P-24441 epoxy. The coal-tar epoxy was included as a benchmark because of its wide use on the underwater portion of ship hulls. The MIL-P-23236 coating was selected because it is recommended as a tank coating over inorganic zinc primers. The MIL-P-24441 coating system was included since it is the standard U.S. Navy underwater hull coating.

Test Panel Preparation

The inorganic zinc primers were applied to ASTM A-36 steel panels, white-metal blasted to obtain a surface profile between 1-2 roils. The nominal panel dimensions were 6" x 12" x 1/8" thick for quiescent immersion testing and 5 1/4" x 7 1/2" x 1/2" thick for flow testing.

The inorganic zinc primers were applied by airless spray using an automated application system designed to provide close control of applied film thickness. The system utilized a fixed spray gun with apparatus for moving the test panel by the spray gun nozzle at a controlled speed. After coating, the dry film thickness on all test panels was determined using an Elcometer magnetic thickness gauge. The average dry film coating thicknesses of the respective inorganic zinc primers were as follows:

Primer #1 - 1.Ø mil

Primer #2 - Ø.7 mil

Primer #3 - Ø.8 mil

Primer #4 - 4.2 roils

Primer #5 - 2.1 roils

After application of the zinc primers, all test panels were weathered on the test fences at the OCRC Sea Isle test site. This test site provides a natural marine atmosphere and is located approximately 300 feet from the ocean. In order to evaluate the effect of different weathering times, one-half of the test panels were exposed for 7 days and the other half for a period of 60 days. After weathering, all test panels were lightly sanded with 600 grit silicon carbide paper to remove any zinc corrosion product (white rust).

After sanding, the test panels were topcoated with one of the three epoxy topcoats. The topcoat systems were applied in accordance with manufacturer's directions using hand-controlled airless spray equipment. After coating, all panels were inspected for "holidays" using a wet-sponge, 67.5 volt holiday detector. All holidays were suitably repaired. The panels were allowed to cure for 10 days before being placed into test.

After topcoating, the dry film thickness of all panels was again determined using the same equipment as described previously. The average dry film coating thicknesses of the respective topcoat systems were as follows:

Coal-tar epoxy - 9.6 mils (applied in 2 coats)

MIL-P-23236 - 11.0 mils (applied in 2 coats)

MIL-P-24441 - 9.2 roils (applied in 3 coats)

During application of the topcoats, some blistering problems were encountered. Depending on the particular primer over which the topcoat was being applied, small blisters or pinholes developed almost immediately after topcoating. This problem occurred even with the application, first, of a thin mist coat (0.25 to 0.5 mil) which was allowed to tack up before applying the full coat. The problem was most evident on zinc primers #4 and #5, the two full-coat inorganic zincs included in the program. Little or no blistering was observed over the thinner pre-construction primers. Those test panels where pinholing occurred during topcoating were lightly sanded and then recoated with a thin coat to-seal the pinholes.

As an experimental benchmark, the respective topcoats were also applied to white-metal blasted steel test panels. No application problems were encountered on these test panels.

Duplicate test panels of each coating system were prepared for each of the seawater immersion exposure tests. For the flow test, single panels were prepared. The total number of test panels prepared for exposure testing was 165.

Performance Testing

Three different types of exposure test were conducted in the study to evaluate the performance of the selected topcoats applied over the different inorganic zinc primers. These tests included: (1) quiescent seawater immersion at a potential of -1.Ø volt vs. SCE (2) quiescent seawater immersion at 25 psi, 15Ø°F and (3) seawater flow at 18 knots.

Seawater Flow At 18 Knots. A single test panel (5 1/4" x 7 1/2" x 1/2" thick) for each weathering/primer/topcoat condition was exposed in the OCRC natural seawater flow channel for a period of 6Ø days at a velocity of 18 knots. Both sides of each panel were scribed at the center (1" vertical scribe) with a razor knife.

After the first 3Ø days of test, the intentional scribe on those panels not evidencing any significant failure (disbandment area < 1 in^2) was modified. The original 1" vertical razor scribe—was widened to 1" x 1/4" rectangular holiday. All zinc primer within the,holiday area was removed to expose bare steel. Coatings which had disbonded over 1 in^2 were recoated with a MIL-P-24441 epoxy and left in test without a scribe.

The natural seawater flow channel is designed to permit velocity testing under flow conditions that are reasonably representative of the flow conditions that would exist over a major portion of a ship's hull -- fully developed parallel, turbulent, high Reynolds Number, seawater flow. The flow channel accommodates comparatively larger test panels, thus tending to minimize edge and/or boundary effects. The width of the channel cross section varies along the length permitting testing at different flow velocities simultaneously. Figure 1 shows the flow channel while Figure 2 shows the method by which test panels are typically mounted in the flow channel.

Seawater flow through the channel is accomplished using a double-suction centrifugal pump powered by a 1ØØ HP motor. The flow rate exceeds 5,ØØØ gpm and is measured using a calibrated 316 stainless steel orifice plate/differential pressure gauge set-up. The rate of seawater make-up into the channel can be adjusted to control seawater temperature to within ± 4.5°F and is maintained sufficiently high to avoid stagnation or concentration effects.

Quiescent Seawater Immersion @ -1.Ø volt. Duplicate test panels (6" x 12" x 1/8" thick) for each weathering/primer\topcoat condition were suspended in 1ØØ-gallon plastic tanks filled with fresh seawater. The seawater tanks were continually refreshed at a rate sufficient to effect a complete changeover 3 times a day. The seawater temperature was maintained at 7Ø°F.

A lead wire was attached to each test panel facilitating electrical connection to a zinc anode. Electrical coupling to a zinc anode maintained the test panels at a potential of -1.Ø volt versus a saturated calomel electrode. Prior to the start of test, each test panel received a 1/4" radial holiday directly in the center of one side. The test duration was 6 months.

Quiescent Seawater Immersion @ 25psi, 15Ø°F. Duplicate test panels were immersed in seawater maintained at 25 psi, 15Ø°F. Each test panel had a 1" vertical scribe centered on one side. The panels were mounted in PVC racks. The racks were then inserted into a 12-inch diameter PVC pipe which served as the test chamber. A pump provided seawater make-up while maintaining a positive pressure of 25 psi inside the pipe. The make-up flow was sufficient to effect a complete changeover once a day. The temperature was controlled at 15Ø°F with two thermosensors immersed in the test chamber which were electrically coupled through an appropriate temperature controller to a nichrome heating element wrapped around a titanium tube in the seawater supply line. The seawater was constantly circulated through the heating tube to maintain temperature. The test duration was 6 months.

Inspection/Evaluation Procedures

During the course of each of the three exposure tests, the test panels were periodically removed, visually inspected, and rated for blistering disbondment, and/or other forms of deterioration. At the conclusion of each test, the total extent of coating disbandment was determined by lifting all loose or disbonded coating with the point of a knife.

RESULTS AND DISCUSSION

Weathering Of Inorganic Zinc Primers Before Topcoating

Visual inspection of the inorganic zinc primed panels after the two different weathering exposures (7 days, 60 days) showed significant differences on only one primer (#1). For system #1, the panels exposed for 60 days exhibited extensive rust-through while those exposed for only 7 days showed no evidence of rust-through. This is shown in Figure 3. Of the three pre-construction primers, primer #1 had the lowest zinc loading in the dry film based on the manufacturers' specifications.

For the other four inorganic zinc primers, there were only slight, visually detectable differences between the 7-day and 60-day panels, with the 60-day panels exhibiting slightly more corrosion product (white rust).

Seawater Flow Test

Table 3 summarizes the extent of topcoat disbandment observed during the 60 days of seawater flow testing. In all, there were 15 separate instances where significant disbandment (greater than 1 in^2) occurred during the 60-day test. Of these, 6 occurred within the first 24 hours after start-up and 14 occurred within the first 30 days.

In theory, each side of a given test panel represented a duplicate exposure (considering the double-side exposure characteristics of the flow channel). Of the 12 test panels that exhibited disbandment failure during the test, failure on both sides occurred on only 3 test panels. Analysis of these results at 30 days raised concern about the seemingly poor replication. It was felt at this time that there might have been differences traceable to the knife-cut scribe initially made at the center on each side of each panel. All disbandment failures had initiated at the scribe. Thus, at this point, the intentional holiday was expanded from a knife-cut scribe to a 1" x 1/4" rectangular window which was felt would provide more uniformity. However, the lack of further failures (excepting the control) during the latter 30 days of the test precluded obtaining any further insight regarding this concern.

Where the topcoats did disbond, there was extensive rusting of the substrate (Figure 4). This observation suggests that the zinc primers tend to sacrifice rapidly once exposed to flowing seawater. Furthermore, it suggests that, at scribes or holidays, topcoats may be prone to underfilm lifting as the zinc coating dissolves. Topcoat disbandment due to dissolution of the zinc primer exposed at a holiday may decrease with time as the zinc corrosion products build up and plug the underfilm paths. The occurrence of such a phenomenon might account for the lack of further disbondment over the latter 30 days of the test.

Table 4 lists the total area of disbandment which occurred over each inorganic zinc primer. The data in Table 4 show that the least amount of topcoat disbandment occurred over primer #1 while the most disbandment occurred over primer #4. There was clearly a marked propensity for topcoat disbanding over primer #4 compared to other primers. Primer #4 is a 2-component, full-coat system which was applied at an average thickness of 4.2 roils (the heaviest applied thickness included in the study). It is noteworthy that the manufacturer of primer #1 does not recommend overcoating the primer for underwater service.

Of special interest was the comparative topcoat performance over primer #3, a Japanese pre-construction primer whose manufacturer suggests can be topcoated (without need of washdown or sandsweep) for underwater service. As is evident, significant disbondment occurred on two of the six test panels within 30 days. On both panels, some degree of disbandment was observed within 24 hours after start of the test.

Comparison of the disbandment results by topcoat shows that topcoat #3, the standard Navy hull coating (MIL-P-24441, Type I), exhibited the least amount of disbondment over 60 days. For this topcoat, disbandment occurred only on those panels primed with primer #4.

For three out of five primers, the total area of topcoat disbondment was greater on the panels weathered for 60 days versus 7 days. This observation is somewhat surprising -- in planning the study it had been felt that aging or weathering of the inorganic zinc primers would tend to reduce their inherent porosity (due to plugging of the pores with corrosion products) thereby reducing the tendency to blister and disbond. Additional data would be required however to establish that this observation is statistically significant.

Comparison of the results for all inorganic zinc primers versus the results obtained for the control panels indicates the only primer for which there is a clear-cut evidence of increased susceptibility to disbandment is primer #4.

Quiescent Seawater Immersion @-1.0 Volt

Of the 66 panels exposed in this phase of the test program, only four test panels exhibited blistering (excluding the area immediately around the holiday). The following summarizes the observed blistering after 6 months:

Inorganic Zinc Primer	Weathering Period	Topcoat	Description
#3	60-Day	#2	Few 1/32" blisters were observed on both of the replicate test panels

Inorganic Zinc Primer	Weathering Period	Topcoat	Description
#4	7-Day	#2	Medium 1/16''-1/8" blistering on single test panels
#4	60-Day	#2	Medium 1/32''-1/16" blistering on single test panel

The blistering described above was first detected after 3 months exposure. Figure 5 shows the blistering observed for topcoat #2/primer #4 after 6 months of testing. The blistering occurred at the zinc/topcoat interface.

The following summarizes the blistering observed immediately around the holiday after 6 months exposure:

Inorganic Zinc Primer	Weathering Period	Topcoat	Description
#1	7-Day	#1	Medium 1/64''-1/32" blistering
#1	7-Day	#2	Medium 1/64''-1/32" blistering
#1	60-Day	#1	Medium 1/64''-1/32" blistering
#1	60-Day	#2	Few 1/64''-1/32" blisters
#1	60-Day	#3	Few 1/32''-1/16" blisters
#2	7-Day	#1	Few 1/16" blisters
#2	7-Day	#2	Few 1/4" blisters
#2	60-Day	#1	Few 1/64''-1/32" blisters
#2	60-Day	#2	Few 1/32" blisters
#3	7-Day	#1	Few 1/64''-1/32" blisters
#3	7-Day	#2	Few 1/64''-1/32" blisters
Control		#2	Medium 1/64''-1/32" blistering

Blister formation at the holidays was first detected as early as one month into test. None of the panels which exhibited blistering at the holiday showed blistering elsewhere on the surface. This observation suggests that blistering outside the holiday area occurs by a different mechanism than that at the holiday.

Table 5 summarizes the extent of disbandment which occurred about the holidays over the 6-month test. There was only one case (topcoat #l/primer #3) where disbandment over an inorganic zinc primed panel was outside the disbandment range exhibited by the control panels. Comparing just the inorganic primers, there appeared to be more of a tendency for cathodic disbandment with primers #1, #2, and #3 than with primers #4 and #5 (the full-coat primers). As in the flow tests, the MIL-P-24441 epoxy topcoat system (topcoat #3) exhibited the least susceptibility to blistering and disbandment.

Quiescent Seawater Immersion @25 psi, 15Ø°F

Table 6 presents the results of the quiescent seawater immersion tests at 25 psi and 15Ø°F. The data in Table 6 show that topcoats applied over primer #4 were especially susceptible to rapid and extensive blistering. The results appeared to be insensitive to the length of weathering period. Figure 6 shows the appearance of topcoat #3 over primer #4 after a month in test.

Blistering also occurred quickly and extensively over primer #3 but only on those test panels where the primer was weathered for 6Ø days. A further examination of the data reveals that the topcoats applied on test panels weathered for 6Ø days were far more likely to blister than those applied on panels weathered for just 7 days. Eighty percent of the test panels weathered for 6Ø days exhibited blistering of the topcoat compared to forty percent of the panels weathered for 7 days.

Table 7 summarizes the extent of blistering observed within 1 inch of the intentional scribe. These results are consistent with the results for the general surface area. The heaviest topcoat blistering near the scribe was detected on those panels primed with primer #4 (both weathering periods) and primer #3 (60-day weathering period). Again, there was a greater tendency for blistering on those panels weathered for 60 days versus 7 days.

Table 8 lists the total area of topcoat disbandment adjacent to the scribe. As with the blistering observations, the worst topcoat disbandment occurred over primer #4 and primer #3 weathered for 60 days. The remainder of the test panels exhibited disbandment that was not significantly different than that of the control panels. Qualitatively, however, considering the disbonded area due to blistering, the only test panels where the topcoats performed as well as on the control panels were the panels primed with primers #1, #3, and #5 and weathered for 7 days.

All of the blistering/disbondment observed on the test panels originated at the zinc/topcoat interface. This is consistent with the results obtained in the other tests.

SUMMARY AND RECOMMENDATIONS FOR FUTURE WORK

The results of the study suggest that, for underwater service, certain inorganic zinc pre-construction primers can be overcoated without incurring subsequent blistering of the topcoat. These results encourage further tests investigating the parameters affecting compatibility.

Alternative zinc primer surface preparation methods should be evaluated. In the present test program, only a light sanding was tested. A sweep blast or a wash primer may be more effective in providing compatibility and still offer a significant cost savings in surface preparation.

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Table 1

GENERAL DESCRIPTION OF INORGANIC ZINC PRIMERS SELECTED FOR TESTING

Coating No.	Description
1	U.S. manufactured, single component, alkyl silicate type shop primer, 35% zinc in the dry film, recommended dry film thickness = Ø.6 - 1.Ø mil.
2	U.S. manufactured, 2-component, modified zinc silicate shop primer, 86% zinc in the dry film, recommended dry film thickness = Ø.6 - 1.Ø mil.
3	Japanese manufactured, 2-component shop primer, 50% zinc in the dry film, recommended dry film thickness = Ø.5 - Ø.7 mil.
4	U.S. manufactured, 2-component, full-coat primer, 60% zinc in the dry film, recommended dry film thickness = 3.Ø mils.
5	U.S. manufactured, 2-component, full-coat primer, 85% zinc in the dry film, recommended dry film thickness = 2.Ø mils.

Table 2

GENERAL DESCRIPTION OF TOPCOATS
SELECTED FOR TESTING

Coating No.	Description
1	Two-component, polyamide-cured high-build coal-tar epoxy, 67% volume solids, recommended application thickness = 5 mils (DFT)/coat.
2	Two-component, polyamide-cured epoxy, 56% volume solids, recommended application thickness = 5 mils (DFT)/coat. Meets MIL-P-23236, Type 1, Class 1.
3	Two-component, polyamide-cured epoxy, recommended application thickness = 2-3 roils (DFT)/coat. Standard U.S. Navy underwater hull coating meeting MIL-P-24441, Type 1.

Table 3

SUMMARY OF **60-DAY SEAWATER FLOW TESTS**

Inorganic Zinc Primer	Topcoat	Weathering Period	Side #1	Side #2	Total	Remarks
			Area of Disbandment, in^2			
#1	#1	7-day	0.00	0.00	0.00	
#1	#2	7-day	0.17	0.42	0.59	
#1	#3	7-day	0.00	0.00	0.00	
#1	#1	60-day	0.10	0.06	0.16	
#1	#2	60-day	0.10	0.31	0.41	
#1	#3	60-day	0.10	0.12	0.22	
#2	#1	7-day	2.06	5.56	7.62	Disbondment detected on side #2 @ 5 days; Disbondment detected on side #1 @ 15 days
#2	#2	7-day	0.02	0.00	0.02	
#2	#3	7-day	.56	.52	1.08	
#2	#1	60-day	0.00	0.0	0.00	
#2	#2	60-day	0.09	8.50	8.59	Disbondment detectd on side #2 @ 4 hours
#2	#3	60-day	0.04	0.08	0.12	
#3	#1	7-day	0.07	0.02	0.09	
#3	#2	7-day	0.00	21.0	21.0	Disbondment detected on side #2 @ 4 hours
#3	#3	7-day	0.04	0.04	0.08	
#3	#1	60-dav	0.00	5.00	5.00	

Table 3 (Cont'd)

Inorganic Zinc Primer	Topcoat	Weathering Period	Area of Disbondment, in^2 Side #1	Side #2	Total	Remarks
#3	#2	60-day	0.05	0.07	0.12	
#3	#3	60-day	0.06	0.09	0.15	
#4	#1	7-day	8.00	0.00	8.00	Disbandment detected on side #1 @ 12 days
#4	#2	7-day	12.00	0.13	12.13	Disbandment detected on side #1 @ 4 hours
#4	#3	7-day	2.00	2.30	4.30	Disbondrnent detected on sides #l and #2 @ 16 days
#4	#1	60-day	14.0	10.00	24.00	Disbandment detected on sides #l and #2 @ 16 days
#4	#2	60-day	1.22	0.14	1.36	
#4	#3	60-day	0.19	13.50	13.69	Disbandment detectd on side #2 @ 24 hours
#5	#1	7-day	0.91	0.00	0.91	
#5	#2	7-day	0.08	0.08	0.16	
#5	#3	7-day	0.00	0.00	0.00	
#5	#1	60-day	0.06	0.00	0.06	
#5	#2	60-day	20.00	0.00	20.00	Disbandment detected on side #1 @ 4 hours
#5	#3	60-day	0.00	0.11	0.11	

Table 3 (Cont'd)

Inorganic Zinc Primer	Topcoat	Weathering Period	Area of Disbondment, in^2 Side #1	Side #2	Total	Remarks
Control	#1		50.45	0.08	50.53	Disbondment detected on side #1 @ 46 days
Control	#2		7.18	0.16	7.34	Disbandment detected on side #1 @ 16 days
Control	#3		0.11	0.05	0.16	

Table 4

TOTAL AREA OF DISBANDMENT
AFTER 60-DAY SEAWATER FLOW TESTS

Inorganic Zinc Primer	Weathering Period	Area of Disbondment, in^2 Topcoat #1	Topcoat #2	Topcoat #3	Total
#1	7-day	0.00	0.59	0.00	0.59
#1	60-day	0.16	0.41	0.22	0.79
#2	7-day	7.62	0.02	1.08	8.72
#2	60-day	0.00	8.59	0.12	8.71
#3	7-day	0.09	21.0	0.08	21.17
#3	60-day	5.00	0.12	0.15	5.27
#4	7-day	8.00	12.13	4.30	24.43
#4	60-day	24.00	1.36	13.69	39.05
#5	7-day	0.91	0.16	0.00	1.07
#5	60-day	0.06	20.00	0.11	20.17
Control		50.53	7.34	0.16	58.03
	Total	96.37	71.72	19.91	

Table 5

AVERAGE AREA OF DISBONDMEMT AFTER 6 MONTH
QUIESCENT SEAWATER IMMERSION @ – 1.Ø VOLT

Inorganic Zinc Primer	Weathering Period	Average Area Of Disbondment, in^2 Topcoat #1	Topcoat #2	Topcoat #3	Total
#1	7-Day	Ø.47	Ø.31	Ø.23	1.Ø1
#1	6Ø-Day	1.Ø5	Ø.42	Ø.16	1.63
#2	7-Day	Ø	1.98	Ø	1.98
#2	6Ø-Day	Ø.56	Ø.34	Ø.Ø3	Ø.93
#3	7-Day	Ø.2Ø	Ø.74	Ø	Ø.94
#3	6Ø-Day	4.82	Ø.37	Ø.26	5.45
#4	7-Day	Ø	Ø	Ø	
#4	6Ø-Day	Ø	Ø	Ø	
#5	7-Day	Ø	Ø	Ø	
#5	6Ø-Day	Ø	Ø	Ø	
Control		Ø.53	2.17	Ø	2.7Ø
	Total	7.63	6.33	Ø.68	

Table 6

RESULTS OF QUIESCENT SEAWATER
IMMERSION TESTING @ 25 psi, 150°F

Primer #	Topcoat #	Weathering Period	Panel #	Comments
#1	#1	7-day	#1	Few 1/4" blisters after 6 months
#1	#1	7-day	#2	Few 1/16"-1/8" blisters after 6 months
#1	#2	7-day	#1	No blistering after 6 months
#1	#2	7-day	#2	No blistering after 6 months
#1	#3	7-day	#1	No blistering after 6 months
#1	#3	7-day	#2	No blistering after 6 months
#1	#1	60-day	#1	Few 1/16" blisters after 6 months
#1	#1	60-day	#2	Few 1/64" blisters after 1 month; few 1/8" blisters after 6 months
#1	#2	60-day	#1	Medium 1/32" blistering after 2 weeks; dense 1/32" blistering after 6 months
#1	#2	60-day	#2	Few 1/64" blisters after 3 months; dense 1/32"-1/16" blistering after 6 months
#1	#3	60-day	#1	Few 1/8" blisters after 6 month
#1	#3	60-day	#2	Few 1/32" blisters after 1 week; few 1/16"-1/8" blisters after 6 months
#2	#1	7-day	#1	Medium dense 1/64" blistering after 4 months; dense 1/64" and few 1/16" blisters after 6 months
#2	#1	7-day	#2	Medium dense 1/64" blistering after 4 months; dense 1/64" and few 1/8" blisters after 6 months
#2	#2	7-day	#1	No blistering after 6 months
#2	#2	7-day	#2	No blistering after 6 months
#2	#3	7-day	#1	Few 1/64"-1/32" blisters after 4 months; medium 1/32"-1/16" blisters after 6 months
#2	#3	7-day	#2	Few 1/64"-1/32" blistering after 1 month; medium dense 1/16" blistering after 6 months
#2	#1	60-day	#1	Medium dense 1/64" blistering after 3 weeks; dense 1/64"-1/32" blistering after 6 months
#2	#1	60-dayy	#2	Few 1/64" blisters after 2 months; dense 1/64"-1/32" blistering after 6 months
#2	#2	60-day	#1	No blistering after 6 months
#2	#2	60-day	#2	No blistering after 6 months
#2	#3	60-day	#1	Few 1/32"-1/16" blisters after 4 months; dense 1/32"-1/16" blistering after 6 months
#2	#3	60-day	#2	Few 1/32"-1/16" blisters after 3 weeks; dense 1/32"-1/16" blistering after 6 months
#3	#1	7-day	#1	No blistering after 6 months
#3	#1	7-day	#2	No blistering after 6 months
#3	#2	7-day	#1	No blistering after 6 months
#3	#2	7-day	#2	No blistering after 6 months

Table 6

RESULTS OF QUIESCENT SEAWATER
IMMERSION TESTING @ 25 psi, 150°F

(Continued)

Primer #	Topcoat #	Weathering Period	Panel #	Comments
#3	#3	7-day	#l	NO blistering after 6 months
#3	#3	7-day	#2	No blistering after 6 months
#3	#1	60-day	#1	Medium dense 1/32″ blistering after 2 weeks; dense 1/32″ blistering after 6 months
#3	#1	60-day	#2	Medium dense 1/64′′-1/32″ blistering after 3 weeks; dense 1/32″ blistering after 6 months
#3	#2	60-day	#1	Medium 1/16″ blistering after 1 week; dense 1/16′′-1/8″ blistering after 6 months
#3	#2	60-day	#2	Medium 1/16″ blistering after 1 week; dense 1/16′′-1/8″ blistering after 6 months
#3	#3	60-day	#1	Medium dense 1/32′′-1/16″ blistering after 3 weeks; medium 1/16″ blistering after 6 mont
#3	#3	60-day	#2	Few 1/32″- 1/16″ blistering after 2 months; medium 1/16′′-1/8″ blistering after 6 month
#4	#1	7-day	#1	Coating 20% disbonded after 2 weeks; coating 20% disbonded with few 1/16′′-1/8″ blisters after 6 months
#4	#l	7-day	#2	Few 1/64′′-1/32″ blisters after 1 month; few 1/32′′-1/16″ blisters after 6 months
#4	#2	7-day	#l	Medium 1/8′′-1/4″ blistering after 1 week; medium 1/4″ blistering after 6 months
#4	#2	7-day	#2	Medium 1/8′′-1/4″ blistering after 1 week; medium 1/4″ blistering after 6 months
#4	#3	7-day	#1	Coating 75% disbonded after 1 week; coating 100% disbonded after 6 months
#4	#3	7-day	#2	Coating 40% disbonded after 1 week and 6 months
#4	#1	60-day	#1	Few 1/8″ blisters after 2 weeks; few 1/4″ blisters after 6 months
#4	#1	60-day	#2	Few 1/8″ blisters after 3 months; few 1/8″ blisters and medium 1/64″ blistering after 6 months
#4	#2	60-day	#1	Few 1/16′′-1/8″ blisters after 1 week; dense 1/8′′-1/4″ blistering after 6 months
#4	#2	60-day	#2	Few 1/16′′-1/8″ blisters after 3 weeks; medium dense 1/16′′-1/8″ blistering after 6 months
#4	#3	60-day	#1	Few l/16′′-l/8° blisters after 1 week; few 1/8″ blisters after 6 months

Table 6

RESULTS OF QUIESCENT SEAWATER IMMERSION TESTING @ 25 psi, 150°F

(Continued)

primer #	Topcoat #	Weathering Period	Panel #	Comments
#4	#3	60-day	#2	Coating 70% disbonded after 1 week; coating 75% disbonded after 6 months
#5	#1	7-day	#1	No blistering after 6 months
#5	#1	7-day	#2	No blistering after 6 months
#5	#2	7-day	#1	No blistering after 6 months
#5	#2	7-day	#2	No blistering after 6 months
#5	#3	7-day	#1	No blistering after 6 months
#5	#3	7-day	#2	No blistering after 6 months
#5	#1	60-day	#1	Few 1/32″ blisters after 1 and 6 months
#5	#1	60-day	#2	Medium 1/32″ blistering after 1 and 6 months
#5	#2	60-day	#1	No blistering after 6 months
#5	#2	60-day	#2	Dense 1/32″ blistering after 1 week; dense 1/32′′-1/16″ blistering after 6 months
#5	#3	60-day	#1	Few 1/64′′-1/32″ blisters after 1 week; dense 1/32′′-1/16″ blistering after 6 months
#5	#3	60-day	#2	Few 1/64″ blisters after 5 months; few 1/32′′-1/16″ blisters after 6 months
Control	#1		#1	Few 1/16″ - 1/8″ blisters after 6 months
Control	#l		#2	Few 1/8″ blisters after 6 months
Control	#2		#1	Few 1/36″ - 1/16″ blisters after 6 months
Control	#2		#2	No blistering after 6 months
Control	#3		#1	No blistering after 6 months
Control	#3		#2	No blistering after 6 months

Table 7

EXTENT OF BLISTERING AT INTENTIONAL SCRIBE AFTER
6 MONTHS QUIESCENT SEAWATER IMMERSION @ 25psi, 150°F

Primer #	Topcoat #	Weathering #1	Panel #	Comments
#1	#1	7-Day		Few 1/8″ blisters
#1	#1	7-Day	#2	Few 1/16″ - 1/8″ blisters
#1	#2	7-Day		Medium dense 1/32″ blistering
#1	#2	7-Day	#2	Few 1/8″ blisters
#1	#3	7-Day	#1	No blistering
#1	#3	7-Day	#2	NO blistering
#1	#1	60-Day	#1	No blistering
#1	#1	60-Day	#2	Medium 1/16″ - 1/8″ blistering
#1	#2	60-Day	#1	Medium dense 1/32″ blistering
#1	#2	60-Day		NO blistering
#1	#3	60-Day	#1	Few 1/8″ - 1/4″ blisters
#1	#3	60-Day	#2	Medium dense 1/8″ - 1/4″ blister
#2	#1	7-Day	#1	NO blistering
#2	#1	7-Day	#2	No blistering
#2	#2	7-Day	#1	NO blistering
#2	#2	7-Day	#2	No blistering
#2	#3	7-Day	#1	Medium 1/8″ - 1/4″ blistering
#2	#3	7-Day		Medium dense 1/8″ blistering
#2	#1	60-Day	#1	Dense 1/32″ - 1/16″ blistering
#2	#1	60-Day	#2	Medium dense 1/8″ blistering
#2	#2	60-Day		No blistering
#2	#2	60-Day	#2	NO blistering
#2	#3	60-Day	#1	Few 1/16″ - 1/8″ blisters
#2	#3	60-Day	#2	Medium dense 1/8″ - 1/4″ blister
#3	#1	7-Day	#1	NO blistering
#3	#1	7-Day	#2	NO blistering
#3	#2	7-Day	#1	Few 1/32″ blisters
#3	#2	7-Day	#2	No blistering
#3	#3	7-Day	#1	No blistering
#3	#3	7-Day	#2	No blistering
#3	#1	60-Day	#1	Medium dense 1/32″-1/16″ blisteri
#3	#1	60-Day	#2	Few 1/16″ blisters
#3	#2	60-Day	#1	Dense 1/32″ blistering
#3	#2	60-Day	#2	Dense 1/8″ - 1/4″ blistering
#3	#3	60-Day	#1	Medium 1/16″ - 1/8″ blistering
#3	#3	60-Day		Few 1/16″ - 1/8″ blisters
#4	#1	7-Day	#1	Medium dense 1/8″-1/4″ blisterin
#4	#1	7-Day	#2	Medium dense 1/8″-1/4″ blisterin
#4	#2	7-Day	#1	Medium 1/4″ - 1/2″ blistering

Table 7

EXTENT OF BLISTERING AT INTENTIONAL SCRIBE AFTER
6 MONTHS QUIESCENT SEAWATER IMMERSION @ 25psi, 150°F

(Continued)

Primer #	Topcoat #	Weathering #1	Panel #	Comments
#4	#2	7-Day	#2	Few 1/4 " - 1/2" blisters
#4	#3	7-Day	#1	Coating disbonded
#4	#3	7-Day	#2	Coating disbonded
#4	#1	60-Day	#1	Dense 1/4" - 1/2" blistering
#4	#1	60-Day	#2	Mediun Dense 1/2" blistering
	#2	60-Day		NO blistering
#4	#2	60-Day	#2	Few 1/4" blisters
#4	#3	60-Day	#1	Coating disbonded
#4	#3	60-Day	#2	Medium Dense 1/4''-1/2" blistering
#5	#1	7-Day	#1	Medium 1/8" - 1/4" blistering
	#1	7-Day		Few 1/8" - 1/4" blisters
#5	#2	7-Day	#1	No blistering
#5	#2	7-Day	#2	No blistering
#5	#3	7-Day	#1	Medium 1/4" blistering
#5	#3	7-Day	#2	Medium 1/4" blistering
#5	#1	60-Day	#1	Few 1/8" - 1/4" blisters
#5		60-Day	#2	Medium 1/8" blistering
#5	#2	60-Day	#1	NO blistering
#5	#2	60-Day		NO blistering
#5		60-Day	#1	No blistering
#5	#3	60-Day	#2	NO blistering
Control	#1		#1	Few 1/8" - 1/4" blisters
Control			#2	Medium 1/8" blistering
Control	#2			NO blistering
Control	#2		#2	NO blistering
Control	#3			NO blistering
Control	#3		#2	NO blistering

Table 8

AVERAGE AREA OF DISBANDMENT AT THE INTENTIONAL SCRIBE
AFTER 6 MONTHS QUIESCENT SEAWATER IMMERSION @ 25 psi, 150°F

Inorganic Zinc Primer	Weathering Period	Disbonded Area, in^2 Topcoat #1	Topcoat #2	Topcoat #3	Total
#1	7-Day	1.55	0.78	0	2.33
#1	60-Day	0.62	0.78	0.31	1.71
#2	7-Day	0	0.31	0	0.31
#2	60-Day	0.16	0	0	0.16
#3	7-Day	0.16	0.31	0	0.47
#3	60-Day	0.62	36.43	0.31	37.36
#4	7-Day	0.31	0.16	70.68	71.15
#4	60-Day	0	0	35.34	35.34
#5	7-Day	0.31	0	0.31	0.62
#5	60-Day	0.78	0	0.16	0.94
Control		2.17	0	1.40	3.57
	Total	6.68	38.77	108.51	

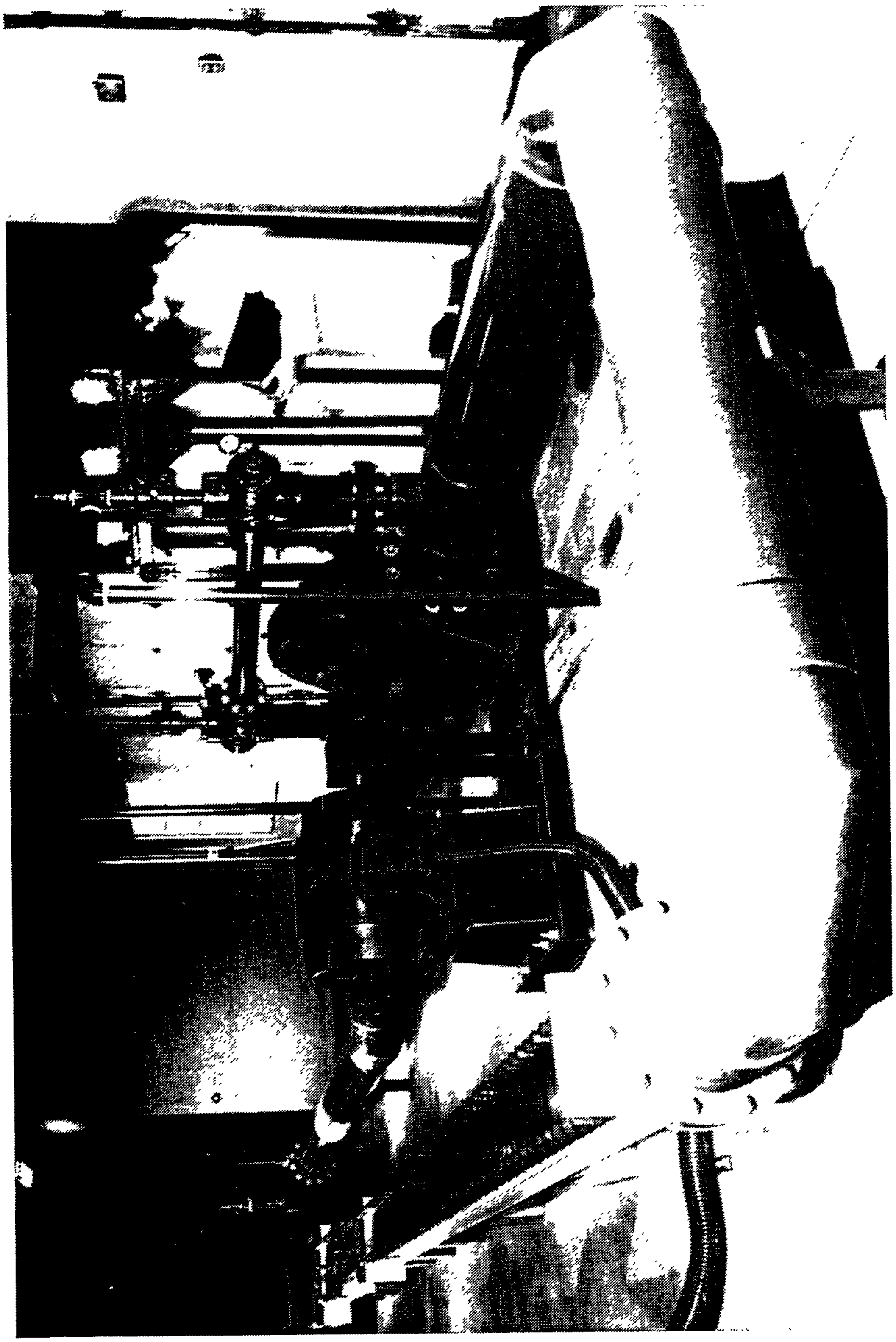
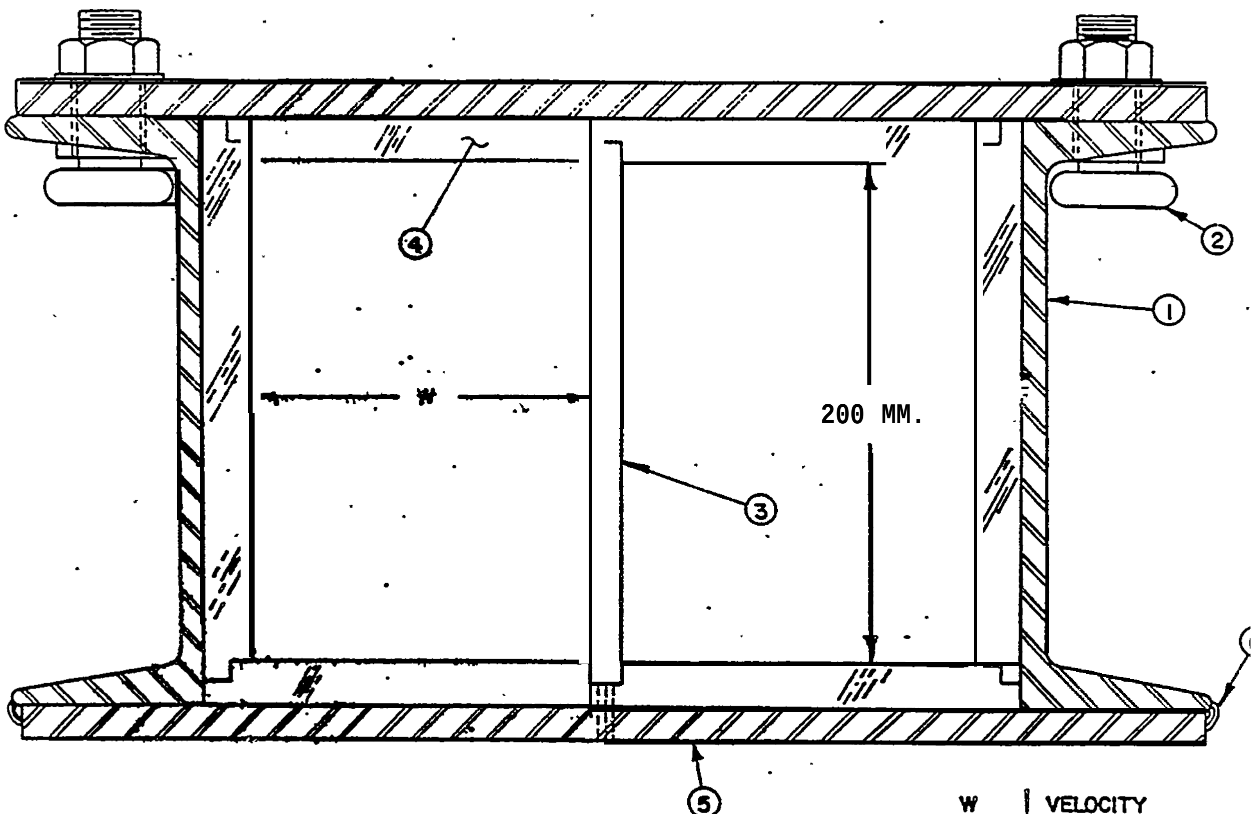


Figure 1 - Flow Channel



STEEL CHANNEL.

2 T-.BOLT

3 TEST PANEL

4 ACRYLIC PLATE

5 STEEL PLATE

6 WELD

W	VELOCITY
50 MM	18 M/SEC.
60. MM.	15 M/SEC.
75 MM.	12 M/SEC.
..100 MM.	9 M/SEC.
150 MM.	6 M/SEC.
300 MM.	3 M/SEC.

Figure 2 - Typical Test Panel Arrangement In The Flow Channel

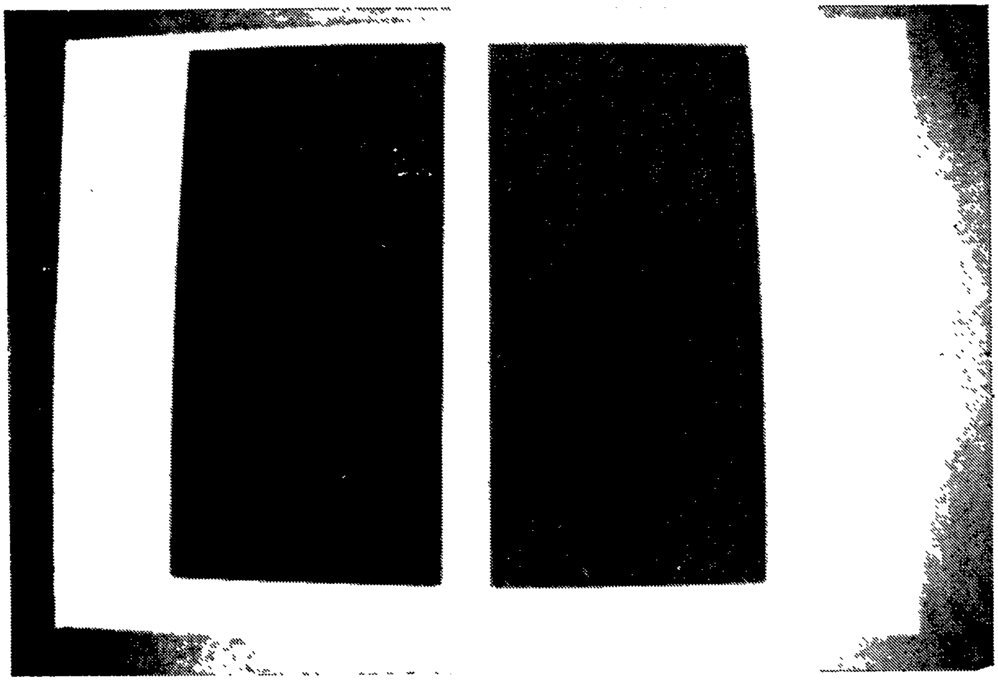


Figure 3 - Panel Topcoated With Primer #1 After 7-Days(Right) And 6Ø-Days (Left) Weathering Period

Figure 4 - Topcoat #2 Over Primer #4 After 3Ø Days Exposure To Flowing Seawater At 18 Knots

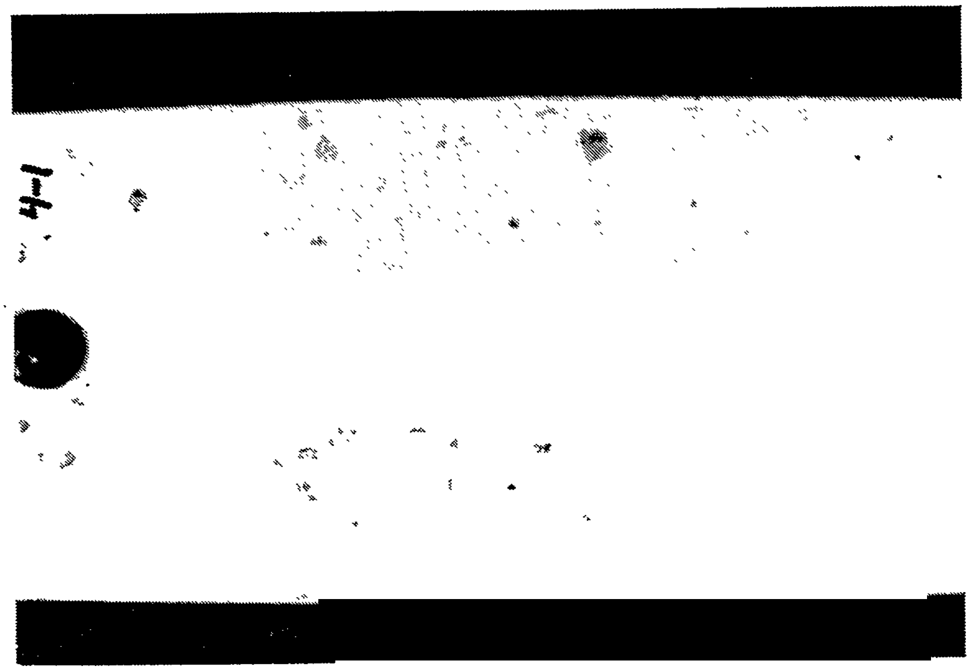


Figure 5 - Topcoat #2 Over Primer #4 Weathered For 7 Days After 6 Months Exposure In Quiescent Seawater At -1.0 Volt

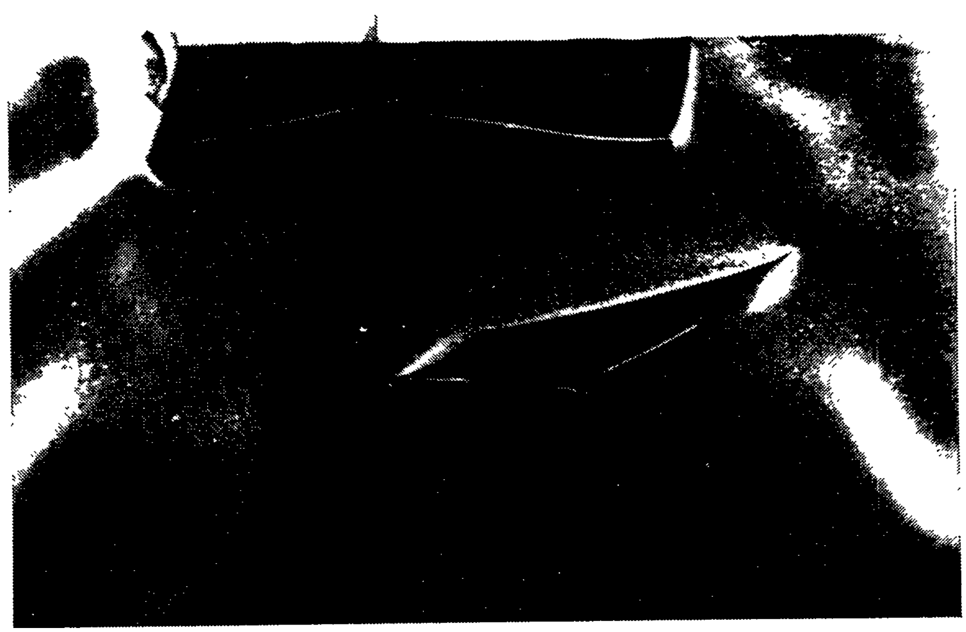


Figure 6 - Topcoat #3 Over Primer #4 (Weathered For 60 Days) After 1 Month Exposure In Quiescent Seawater At 25 psi, 150°F