

EVALUATION OF NEW SURFACE PREPARATION
AND
COATING REPAIR TECHNIQUES IN BALLAST TANKS

JULY 1990

Prepared by
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in Cooperation with
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FOREWORD

This R&D project was performed under the National Shipbuilding Research Program. The project, as a part of this program, is a cooperative cost shared effort between the Maritime Administration, the United States Navy, and National Steel and Shipbuilding Company (NASSCO). The research and development work was accomplished by Associated Coatings Consultants under sub-contract to NASSCO. The overall objective of the program is improved productivity and therefore, reduced shipbuilding costs.

The study was undertaken with this goal in mind and has followed closely the project outline approved by the Society of Naval Architects and Marine Engineers (SNAME) Ship Production Committee.

Mr. Lynwood Haumschilt of NASSCO was the National Shipbuilding Research Program Manager of Panel SP-3, responsible for technical direction and publication of the final report. program definition and guidance was provided by the members of the SP-3 Surface Preparation and Coatings Committee of SNAME. Special thanks is given to Mr John Peart for providing technical direction of the test program.

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EXECUTIVE SUMMARY

Ship ballast tanks present special problems as concerns corrosion control. In addition, ballast tanks are one of the most costly areas in which to apply coatings in both new ship construction and ship maintenance. Being subjected to intermittent wet and dry cycles of aerated sea water places extreme demands on corrosion control methods. Harsh service environments are coupled with necessarily complex tank geometries, especially in Navy combatants where weight and hull designs dictate small, irregular tanks with difficult accessibility. The SP-3 Panel of SNAME recognized these problems and formulated a series of research and development projects to investigate alternate, cost effective corrosion control solutions.

The first project began in 1980 and was entitled "Cathodic Protection/Partial Coatings Verses Complete Coating in Tanks." A series of ballast tank mock-ups were constructed which duplicate ballast tank geometries. The tanks were also large enough to allow access for surface preparation and installation of the various corrosion control methods. The measures were not limited to protective coatings alone. Four approaches were originally selected for testing. These included:

- Completely coated tanks with high performance coating
- Partially coated tanks with cathodic protection
- Pre-construction primer with cathodic protection
- Soft coatings with cathodic protection
- Surface tolerant epoxy coatings (Added after three years)

The initial report published in 1982 and the project updates published in 1985 and 1987 demonstrated that, of the systems evaluated, the inorganic zinc pre-construction primer with zinc anode cathodic protection was the best performer, least expensive initially and least expensive over the 20 year economic life of the ship. After eight years of testing, this system continues to provide adequate corrosion protection. Partial coating with zinc anode cathodic protection out-performed complete coating and are also cost effective. Zinc anodes out-performed aluminum anodes but can result in increased ship weight. Soft coatings with cathodic protection failed in the first 90 days and was discontinued. The pre-construction primer with aluminum anodes failed after three years and was replaced by a rust tolerant, one coat epoxy system which, in turn, provided six years of protection.

Certain prerequisites were also found to be necessary to assure successful cathodic protection performance, e.g. tanks must be "pressed up" with salt water ballast.

In 1988, the project was re-directed to evaluate maintenance procedures and techniques. At that time the tanks had been under test for six years. Included in the new project were VOC compliant (340 grams/liter), surface tolerant epoxies from two suppliers, reformulated MIL-P-24441 VOC compliant epoxy, and a

technique common to the Japanese marine industry, namely the addition of zinc anode cathodic protection in lieu of complete coating removal and re-application.* Two coating systems from the original project were still providing adequate protection and, therefore, left undisturbed. The resultant test program consisted of:

- VOC compliant surface tolerant epoxy "A" over Power Tool Cleaned (SSPC SP-3) surface
- Completely coated tank (previously in service for six years) with added zinc anode
- Original partially coated tank with zinc anode (previously in service for six years)
- VOC compliant surface tolerant epoxy "A" over abrasive blasted surface
- VOC compliant surface tolerant epoxy "B" over abrasive blasted surface (previously in service for three years)
- Original inorganic zinc pre-construction primer with zinc anode (previously in service for six years)
- VOC compliant MIL-P-24441 epoxy over abrasive blasted surface
- Biodegradable soft coating over hand tool cleaned (SSPC SP-2) surface
- VOC compliant surface tolerant epoxy "B" over Solvent Cleaned (SSPC SP-1) and Hand Tooled Cleaned (SSPC SP-2) surface

After two years of testing (eight Years for some systems), all but one of the systems is providing protection. The biodegradable soft coating failed after one year and would have required replacement at that time. The VOC compliant surface tolerant epoxy "A" was essentially equal in performance both over the power tool cleaned and abrasive blast cleaned surface. The same was true for the epoxy "B" except for the bottom of the hand cleaned tank which had excessive dry film thickness. The coating in the bottom began to crack after one year and was delaminating at the end of two years. This apparently is a characteristic of high solids surface tolerant epoxies when applied at high dry film thickness.

In conclusion, this project continues to achieve all project goals. Identification has been made of ballast tank corrosion protection approaches which are effective in mitigating corrosion and yet save both new construction and operating dollars. It has been demonstrated that hand and/or power tool cleaning techniques may be adequate for some VOC compliant surface tolerant materials. It has also been demonstrated that cathodic protection can extend and compliment ballast tank coatings.

*John W. Peart and Benjamin S. Fultz, "A Survey Of Japanese Shipyard Applied Marine Coating Performance," November 1985

TABLE OF CONTENTS

<u>Foreword</u>	PAGE 2
<u>Disclaimer</u>	3
<u>Executive Summary</u>	4
<u>Table of Contents</u>	6
<u>List of Figures</u>	7
<u>List of Tables</u>	8
1. <u>Conclusions</u>	9
1.1 Project Results	9
1.1.1 Performance Results From Original Study	9
1.1.2 Performance Results Using New Techniques	10
1.2 Continued Research	11
2. <u>Project Plan of Action and Results</u>	12
2.1 Background Technical Information	12
2.1.1 High Performance Coating Systems	12
2.1.2 Partial Coating of Tanks Combined with Cathodic Protection	12
2.1.3 Pre-construction Primer Plus Cathodic Protection	12
2.1.4 VOC Compliant Surface Tolerant Epoxy Systems	13
2.1.5 Anodes Added to Existing Coated Tanks	13
2.1.6 Biodegradable Soft Coatings	14
2.2 Tank Test Results	14
2.2.1 Aluminum Anodes w/Partial Coatings	17
2.2.2 Completely Coated Tank	17
2.2.3 Zinc Anodes w/Partial Coatings	17
2.2.4 Aluminum Anodes w/Pre-construction Primer	18
2.2.5 Pre-construction Primer Only	18
2.2.6 Zinc Anode w/Pre-construction Primer	18
2.2.7 Surface Tolerant VOC Compliant Epoxy "A" Over Abrasive Blast Cleaned Surface	18
2.2.8 Surface Tolerant VOC Compliant Epoxy "A" Over Hand/Power Tool Cleaned Surface	19
2.2.9 Surface Tolerant VOC Compliant Epoxy "B" Over Abrasive Blast Cleaned Surface	19
2.2.10 Surface Tolerant VOC Compliant Epoxy "B" Over Hand/Power Tool Cleaned Surface	19
2.2.11 Previously Completely Coated Tank With Added Zinc Anode	20
2.2.12 VOC Compliant Version of MIL-P-24441	20
2.2.13 Biodegradable Soft Coating	20
2.2.14 Anode Performance	

Appendix A: Reprint of Economic Study Results from Initial Study

LIST OF FIGURES

Figure	Title	Page
2.1	Drawing Showing Details of Test Tank Assembly	15
2.2	Photo Showing Details of Test Tank Assembly	15
2.3	Photographs of Aluminum Anode/Partial Coatings After Six Years	22
2.4	Photographs of High Performance Coatings After Six Years	23
2.5	Photographs of Zinc Anode/Partial Coatings After Eight Years	24
2.6	Photographs of Zinc Primer/Aluminum Anode After Six Years	25
2.7	Photographs of Pre-construction Primer/Zinc Anode Eight Years	26
2.8	Photograph of Hand and Power Tool Cleaned Surface Prior To Surface Tolerant Epoxy "A" Application	27
2.9	Photograph of Epoxy "A" Over Tool Cleaned Surface After Two Years	28
2.10	Photograph of Epoxy "A" Over Blast Cleaned Surface After Two Years	29
2.11	Photograph of Epoxy "B" Over Tool Cleaned Surface After Two Years	30
2.12	Photograph of Epoxy "B" Over Blast Cleaned Surface After Five Years	31
2.13	Photograph of Coated Tank With Added Zinc Anode After Two Years (Eight Years Total)	32
2.14	Photograph of VOC compliant Version of MIL-P-24441 After Two Years	33
2.15	Photograph of Biodegradable Soft Coating After One Year	34

LIST OF TABLES		
Table	Title	Page
Table I	Corrosion Control Alternates Used in Tank Test	16
Table II	Test Site Sea Water Information	21
Table III	Anode Performance Summary	21

1. Conclusions

1.1 Project Results

This report includes the performance results of new approaches to surface preparation and coating repair techniques for preservation of in-service ships ballast tanks using VOC compliant coatings after two years of testing. Also included are the results from the original study "Cathodic Protection/Partial Coatings in Ballast Tanks" after six years of testing for those systems which were replaced or repaired and eight years for those systems which were not replaced.

1.1.1 Performance results from original study

The originally approved test program evaluated four corrosion control alternates (See Table I for systems tested). After three years of testing, an additional technique was added. These are:

- Ballast tanks completely coated with high performance coatings (Baseline)
- Ballast tanks partially coated with high performance coatings plus cathodic protection
- Ballast tanks completely coated with soft coatings plus cathodic protection
- Ballast tanks pre-construction primed plus cathodic protection
- Ballast tanks coated with a rust tolerant epoxy coating
- Both aluminum and zinc sacrificial anode systems were evaluated.

To test the proposed alternates, actual mock-up test tanks were constructed which duplicate ship ballast tank configurations. These tanks were then ballasted and deballasted for six (eight for some systems) years. At the end of each year, each alternate was graded. The present results of these tests are as follows:

- Pre-construction primer with a zinc anode far exceeded predicted performance. After eight years, this system continues to provide protection. Except for the overhead structure, there is no metal loss. This approach has proven to be a cost effective strategy for the protection of salt water ballast tanks.
- Pre-construction primer with aluminum anode failed after three years.
- Partial coatings with zinc anode continues to provide corrosion protection after eight years.
- Partial coatings with aluminum anode failed after six years.
- Zinc anodes out performed aluminum anodes.
- Soft coatings with cathodic protection failed after 90 days.
- Completely coated tanks with high performance epoxy exhibited more failure than anticipated after six years.

1.1.2 Performance results using new surface preparation and repair techniques.

After six years of testing, it was decided that the technical feasibility of reducing coating system repair costs utilizing more cost effective surface preparation, i.e., hand and power tool cleaning, combined with state-of-the-art coatings should be investigated with special emphasis given to VOC compliant coatings. The new project consisted of replacing failed coatings with two different manufacturer's surface tolerant epoxy systems. Each system was applied over both hand and abrasive blast cleaned steel surfaces. In addition, a biodegradable soft coating, a VOC compliant version of MIL-P-24441, and the addition of a zinc anode to the six year old completely coated tank were evaluated. In total, nine systems were tested. These include:

- VOC compliant surface tolerant epoxy "A" over Power Tool Cleaned (SSPC SP-3) surface
- Completely coated tank (previously in service for six years) with added zinc anode
- Original partially coated tank with zinc anode (no repair required).
- VOC compliant surface tolerant epoxy "A" over abrasive blasted surface
- VOC compliant surface tolerant epoxy "B" over abrasive blasted surface (previously in service for three years)
- Original inorganic zinc pre-construction primer with zinc anode (previously in service for six years)
- VOC compliant MIL-P-24441 epoxy over abrasive blasted surface
- Biodegradable soft coating
- VOC compliant surface tolerant epoxy "B" over Solvent Cleaned (SSPC-SP 1) and Hand Tooled Cleaned (SSPC-SP 2) surface

At the end of two years, the test results from the new surface preparation and repair techniques can be summarized as follows:

- The biodegradable soft coating failed after one year.
- Epoxy "A" was essentially equal in performance over both the hand and abrasive blast cleaned surfaces.
- Except for areas of excessive film thickness in the hand cleaned tank, Epoxy "B" performed as well over hand cleaned steel as over abrasive blasted steel.
- Excessive thicknesses of surface tolerant epoxies can result in premature coating failures.
- The addition of the zinc anode to the six year old completely coated tank extended system life without the necessity of coating repair or replacement. No new coating failure was detected.
- The VOC compliant version of MIL-P-24441 is providing good corrosion protection after two years. No blistering was detected. Most failures can be attributed to poor application.

1.2 Continued Research

The tank tests initiated as a part of this project should be continued for five additional years. At the present stage of the project, repairs should be made to those tanks which continue to demonstrate satisfactory performance. These include all the VOC compliant epoxy coated tanks and pre-construction primer with zinc anodes. The soft coating system should be replaced by a new system to be selected by Panel SP-3. Possible candidates include new versions of MIL-P-24441 or inorganic zinc coating with zinc anode cathodic protection.

The test tank configuration and site ballasting conditions of the test facility provide a unique, unequaled opportunity to predict service performance based on controlled tests. The continuation of this project coupled with the uniqueness of the test facility can be used to provide valuable performance data to the coating manufacturer, the engineering specifier, and end user of ship ballast tank corrosion control techniques. The testing facility can also be used to test new coating systems in a controlled test prior to actual in-service testing.

2. Project Plan of Action and Results

2.1 Background Technical Information.

The original study and test program published in May 1982 with updates in 1985 and 1987, contains a complete discussion of the pros and cons of each corrosion control technique and expected performance. Summarized below are the main points of that discussion.

2.1.1 High Performance Coating Systems

From collected data, high performance coating systems are projected to protect salt water ballast tanks for at least 10 years with 2% failure at 5 years and 5 to 10% failure at 10 years at which time the coating would be completely replaced. The tank which is completely coated with high performance coating duplicates this condition; however, this tank is performing worse than predicted. After six years, this tank had 10 to 20% failure with some localized failure to 50%; however, no measurable metal loss was detected after six years.

2.1.2 Partial Coating of Tanks Combined with Cathodic Protection

Anode systems can theoretically be designed to protect steel from corrosion without replacement for at least four years in uncoated tanks and eight years in coated tanks.

As a general rule, cathodic protection systems do not perform satisfactorily on overhead surfaces due to air pockets. These areas are then subject to severe corrosion. Another problem associated with the use of cathodic protection in salt water ballast tanks is created from the residual water and wet silt left on the tank bottoms after deballasting. This salt muck provides a path for steel corrosion, but since the cathodic protection system (anodes) is above the surface of the muck, no protection is afforded.

To rectify these problems, high performance epoxy coatings are generally applied to the overhead surfaces to include 6" to 24" down each bulkhead and frame plus the tank bottoms to include 6" to 24" above the bottom. During ballast, the protective coating system protects the steel and supplements the cathodic protection system, thereby reducing anode consumption. During the deballasted cycle, the coatings protect the high corrosion areas. Two test tanks duplicate partial coating of tanks, one being fitted with a zinc anode and the other with an aluminum anode.

The test program for partially coated tanks supports an anode life of six years for aluminum anodes and ten plus years for zinc anodes.

2.1.3 Pre-construction Primer Plus Cathodic Protection

Many shipyards automatically abrasive blast and prime structural

steel with inorganic zinc shop primers prior to fabrication. This primer is normally removed and replaced by a high performance coating system. If the tank coating system could be eliminated and the pre-construction primer left in place, many construction dollars could possibly be saved. Therefore, this approach was selected as a possible alternative for investigation. Sacrificial anodes were selected to provide the actual corrosion control mechanism. Inorganic zinc was selected as the pre-construction primer. Inorganic zinc primers provide the best shipbuilding handling and steel protection characteristics during construction. One major limiting factor of cathodic protection can be tank geometry. In these cases, zinc based primers actually compliment the cathodic protection system by protecting overheads, bottoms, and small pocket areas. This point has been substantiated by the test program.

2.1.4 VOC Compliant Surface Tolerant Epoxy Systems

With the advent of regulated air quality management for marine coating, many of the standard tank coating systems are no longer available. Coupled with this development are tighter controls over the use of abrasive blasting to clean steel and the resultant removal and disposal of abrasive residue. New state-of-the-art high solids epoxies are being introduced. Some of these materials are reported to be tolerant of poor surface preparation; therefore, two different manufacturer's coatings were selected to be applied over both abrasive blasted and hand tool cleaned steels. Since most of these materials have only been available for a short period of time-under six years-few actual field service histories are available. Past experience with high solids epoxies from foreign sources indicate that these materials may be brittle. This point was somewhat substantiated by this study. One coating failed as a result of excessive film thickness. As the tank bottom flexed during ballasting, the coating cracked due to reduced flexibility. The U.S. Navy has been actively involved in formulating new VOC compliant versions of MIL-P-24441. As new formulas become available, valuable performance test data can be obtained by testing these materials in this project.

2.1.5 Anodes Added to Existing Coated Tanks

Peart and Fultz found that the Japanese used anodes to extend the effective life of coating systems. During new construction ballast tanks are coated with a quality coating. After six to eight years, zinc anodes are added in lieu of coatings rework. This has been reported to extend coating life for an additional eight to ten years. By changing out anodes at regular intervals, the coating system can be extended to twenty plus years. The coating, even if twenty-five to fifty percent failed, reduces anode consumption as compared to a completely bare tank. As the anode cause calcareous deposits to build up on bare areas of failed coatings, anode demand is reduced and anode life extended. One time, i.e., initial tank lining, may be all that is required in ships ballast tanks.

2.1.6 Biodegradable Soft Coatings

One of the primary disadvantages of soft coatings is the potential for water contamination during deballasting operations. Biodegradable coatings have the potential to eliminate this problem; however, biodegradable may also mean that the coating can be destroyed in situ by biological attack. This project seems to bear out this point. The initial deballast after twenty days resulted in the discharge of a large volume of foul smelling gelatinous matter. This discharge continued with each cycle until the coating was depleted.

2.2 Tank Test Results

To verify the relative performance of each proposed alternate and the compatibilities between cathodic protection and coating systems, three ballast tank assemblies (4' X 4' X 10') were fabricated from 1/4" A-36 steel plate and shapes. Each assembly consisted of three separate test tanks. (See Figure 2.2). Each tank was constructed to duplicate ship ballast tanks as concerns structure and configuration (See Figure 2.1). One side of each tank was of bolted construction to allow access for inspection.

Table I contains information on each tank as to corrosion control alternate to include surface preparation, coating system description, anode type, etc.

Following tank fabrication and application/installation of each alternate, the tanks were ballasted and deballasted with fresh sea water. Table II contains data on the sea water used.

Each ballast cycle consisted of 20 days full and 10 days empty. Records were kept on sea water resistivity and cathodic protection half cell potentials. Due to a delay in the test program, the tanks were dry for nine months after the first year; therefore, the actual test period is greater than eight years.

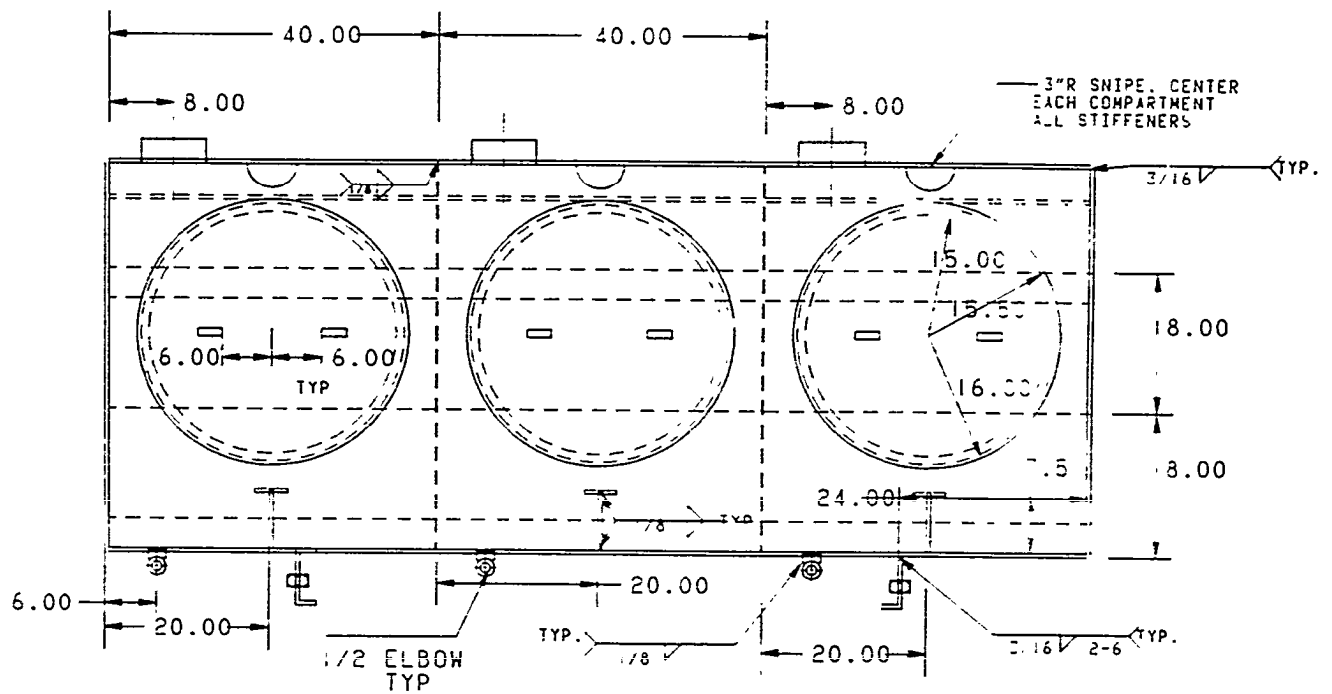


Figure 2.1: Drawing Showing Details of Test Tank Assembly



Figure 2.2: Photograph of Test Tank Assembly

Table I**Corrosion Control Alternates Used In Tank Test**

Surface Preparation	Coating System	Anode Type	System Age
SP10	Two Coat Epoxy (MIL-P-23236) Partially coated	Aluminum Alloy (Galvalum III)	Failed after 6 years
SP10	Two Coat Epoxy (MIL-P-23236) Completely coated	None initially Zinc (MIL-A-18001H)	8 years Anode added @ 6 years
SP10	Two Coat Epoxy (Mil-P-23236) Partially coated	Zinc (MIL-A-18001H)	8 years
SP10	Inorganic zinc pre-construction primer	Aluminum (Galvalum III)	Failed after 3 years
SP10	Inorganic zinc pre-construction primer	None	Failed after 1 year
SP10	Inorganic zinc pre-construction primer	Zinc (MIL-A-18001H)	8 years
SP2/SP3	Surface tolerant VOC compliant epoxy "A"	None	2 years
SP10	Surface tolerant VOC compliant epoxy "A"	None	2 years
SP1/SP2	Surface tolerant VOC compliant epoxy "B"	None	2 years
SP10	Surface tolerant VOC compliant epoxy "B"	None	5 years
SP10	VOC compliant MIL-P-24441	None	2 years
SP1/SP2	Biodegradable soft coating	None	Failed after 1 year

2.2.1 Performance of Aluminum Anode with Partial Coatings

At the completion of six years ballasting and deballasting, the coating system on the tank bottom totally failed. The top of the bottom stiffener flanges had 10% failure (ASTM Rust Grade 4) and the flange edges were scaling and exfoliating.

The coating portion of the side quadrants has 10% failure (ASTM Rust Grade 4). The tank top had less than 1% failure except for the corners which had 10% failure. See Figure 2.3.

The aluminum anode was completely consumed. The calcite deposit which had formed on the un-coated steel was porous and loose. Some areas had detached with heavy rust deposits visible at the exposed areas. Heavy calcite deposits were still present at welds and in corners. It was also noted early in the experiment that the deposit formed by the aluminum anode was more coarse and less tenacious than the zinc produced deposit. This system was considered a failure at the end of six years; however, there was no significant metal loss except for the edges of some of the structural members. The decision was made to replace this coating with a new coating system.

2.2.2 Performance of Completely Coated Tank.

Figure 2.4 is a graphic representation of the performance of the paint system in this tank. Scaling was present on the bottom and the bottom stiffener flanges. One quadrant in the bottom was 90% failed, and the other three bottom quadrants were 50 % failed. The sides were approximately 1% failed and the back was less 1% failed. The overhead stiffener flange was scaling but the flat surface failure was judged to be an ASTM Rust Grade 9 (0.03% failure). The overall breakdown of the coating is judged to be between fifteen and twenty five percent with some localized areas to thirty percent. As stated earlier this system performed less than expected. There was no metal loss except for minor flange faces. The coating system was basically in tack and considered to be a good candidate to test the validity of the Japanese technique of adding zinc anode cathodic protection in lieu of coating repair or replacement.

2.2.3 Performance of Zinc Anode with Partial Coatings

At six years, the color of the bare portion of the tank surface was primarily the color of the calcareous deposit. Removal of the deposit revealed tight black oxide under the film. Where the deposit had been removed, a new deposit had formed. The calcareous deposit in this tank is more dense and tenacious than that formed with the aluminum anode; however, the deposit was observed to be more porous than previously reported. No metal loss was observed in this tank. There was some minor scaling on the tank bottom but no red rust was observed. The balance of the coating system had less than 1% failure.

Because of the excellent condition of this tank after six years,

the decision was made to continue testing this system without modification or repair.

After two additional years (eight years total) there is no significant change in this system except for some zinc anode depletion. See Figure 2.5.

2.2.4 Aluminum Anode with Pre-construction Zinc Primer

Early in the test cycle, the aluminum anode seemed to protect the zinc coating and even built up a calcareous deposit on bare welds and other damaged areas. At the end of three years, the calcareous coating was depleted. After five years, the inorganic zinc coating was depleted. The measured anode potential was still sufficient to protect the steel; however, the anode was almost depleted. Rust scale was visible on the overhead surfaces, but there was no appreciable metal loss on the tank sides. This became a candidate tank for a replacement coating system.

2.2.5 Performance of Pre-construction Primer Only

Initially, a calcareous deposit was formed on welds and damaged areas; however, with time this deposit disappeared (approximately 9 months). At the end of the twelfth cycle, all of the zinc primer was used up and the steel was just beginning to rust. After thirty-six ballast cycles, the tank was beginning to lose metal. Heavy, uniform rust was present. This coating was replaced after three years with a rust tolerant epoxy coating (see paragraph 2.2.9).

2.2.6 Performance of Zinc Anodes with Pre-construction Primer

This continues to be the most significant finding of the test project. A calcareous deposit formed on all the surfaces after the second cycle. These deposits are still present after eight years. Figure 2.7 are photographs of this system. Note the deposits on the weld area. The primary failure is limited to scaling on the overhead area primarily due to air pockets. Some areas on the tank flat bottom subjected to erosion from the ballast water filling operation are beginning to corrode. Except for the overhead, there is essentially no change from the last grading period. The anode is showing progressive consumption but at a slow pace.

2.2.7 Performance of Surface Tolerant VOC Compliant Epoxy "A" Applied Over Abrasive Blast Cleaned Steel.

With the exception of the bottom one-third of the back, the overall performance of this coating system is less than three percent failure after two years. The bottom one-third of the back has thirty percent failure. The overhead and flat bottom has less than one percent failure. The top stiffener has approximately fifty percent failure. There is no metal loss in this tank. As with most tanks which have previously been in service, replacement coatings seem to fail earlier than coatings initially

applied during new construction. A partial cause for this premature failure could be salt contamination.

2.2.8 Performance of Surface Tolerant VOC Compliant Epoxy "A" Applied Over Hand Tool Cleaned Steel

After two years, the coating system applied in this tank over a combination power and hand tool cleaning techniques seems to be performing as well as or better than the same system applied over abrasive blast cleaned steel. There is some coatings breakdown along the lower section at the interface between the previously coated and bare steel areas. This condition is not unusual when applying a new coating over the feathered edge of an old coating. The new coating has a tendency to lift the old coating. The back and sides of the tank have from one to three percent failure. The top has less than one percent failure, and the bottom has less than one percent except for some stiffner edges which are beginning to fail. Figure 2.8 is a photograph of the degree of hand and power tool cleaning prior to coating application.

2.2.9 Performance of Surface Tolerant VOC Compliant Epoxy "B" Applied Over Abrasive Blast Cleaned Steel

The original pre-construction primer only system was replaced by a one coat rust tolerant epoxy coating system which had previously been tested and shown to have promise in another MarAd sponsored research project (Rust Compatible Coating). The tank required abrasive blasting prior to coating application because of the heavy rust scale which had formed in this tank. This system has been under test for five years.

The system is beginning to show significant failure. The top of the tank has twenty-five to fifty percent breakdown. One side of the tank has an area of total failure. This spot originally appeared as pinhole rust at the first grading period and has become progressively worse. The opposite side has one to three percent failure, and the back has less than one percent failure. The flat bottom has five to ten percent failure. This system should be repaired or replaced.

2.2.10 Performance of Surface Tolerant VOC Compliant Epoxy "B" Over Hand Tool Cleaned Steel

After one year of testing, the back, sides and overhead were judged to be an ASTM rust grade 9. The bottom is divided into four quadrants because of the structural configuration. The coating in right front quadrant had cracked and totally failed. The left front and right rear quadrants showed no sign of failure. The left rear quadrant had twenty-five percent failure. The failures occurred in areas of excessive film thickness (30 plus mils). The coating on the left side of the bottom stiffner had cracked and blistered. The balance of the structure had no failure.

After two years, there was no major change in the system

performance except for the bottom which had progressively deteriorated. Discounting the failure in the bottom, this system which is very similar to the surface tolerant Epoxy "B" is performing equally good over both hand tool cleaned and abrasive blast cleaned steel.

2.2.11 Completely Coated Tanks With Aged Coating System And Added Zinc Anode

No new coatings failure was noted. Calcareous deposits had formed over the areas of failed coatings. Very little anode consumption could be detected.

2.2.12 VOC Compliant Version of MIL-P-24441

After two years the left side of the tank has less than one percent failure. The back and right side have from one to three percent failure primarily located in the bottom one-third. Most of the discoloration in the back resulted from coating failure in the difficult to reach area behind the stiffener which then bled down across the intact coating. The edges of some stiffeners are beginning to fail. No blistering was noted. Most of the failures can be attributed to poor application on edges and difficult to reach areas.

2.2.13 Biodegradable Soft Coating

The soft coating totally failed after one year; however, some small areas still had some coating. After two years these areas were still visible. The primary failure mode of this vegetable oil based material appeared to result from biological attack. Initially the coating was a bright yellow which rapidly changed to black after ninety days. At each deballast cycle, a black, foul smelling mass flowed out of the tank. If the coating were replaced at one year or less intervals in conjunction with a high pressure water wash, the system may provide adequate protection. This would limit it's use to barges and ships with a reduced ballasting cycle.

2.2.14 Anode Performance

From the original study, the calculated service life for both zinc and aluminum anodes in partially coated tanks was five years. To attain a five year life, it was determined that a twenty pound aluminum or a fifty pound zinc anode was required. These weights were then selected for test. The aluminum anode lasted for six years prior to total consumption. The zinc anode lost twenty-six pounds in six years which is significantly better than forecasted. Based on present consumption rates, the zinc anode should last for ten years.

In addition to weight requirements, anode size and shape, i.e., exposed surface area, are also important when establishing cathodic protection requirements. One way is to think of the weight as being stored potential and exposed surface area as providing

current density. For this reason it is not practical to just install a smaller zinc anode and expect the same level of protection as an equal weight aluminum anode. The smaller, equal weight, zinc anode would not have the proper current density and therefore, would not provide the required protection.

For ships with weight control concerns, it may be necessary to use lighter weight aluminum anodes and replace them at five to six year intervals.

Table II

Test Site Sea Water Information
Water Resistivity ranged from 26 to 29 ohms/cm

	SPRING		SUMMER		FALL		WINTER	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Water Temperature (0c)	17.0	20.0	26.5	30.0	17.0	30.5	14.5	25.0
pH	6.5	7.5	7.6	8.3	6.7	8.1	7.2	8.2
Oxygen (Dissolved)	5.8	8.5	4.2	7.8	4.2	7.6	5.2	9.4
Salinity (parts per 1000)	17.5	29.0	21.5	35.5	6.0	33.0	8.5	27.0

TABLE III
Six Year Anode Performance Summary

<u>Tank System</u>	<u>Anode Type</u>	<u>Beginning Weight (lbs)</u>	<u>End Weight (lbs)</u>	<u>Actual Loss (lbs)</u>
Partial Coating	Aluminum (Galvalum III)	20	-0-	20
Partial Coating	Zinc (MIL-A-18001H)	50	24	26
Primer Only	Aluminum (Galvalum III)	20	-0-	20
Primer	Zinc (MIL-A-18001H)	50	31.5	18.5

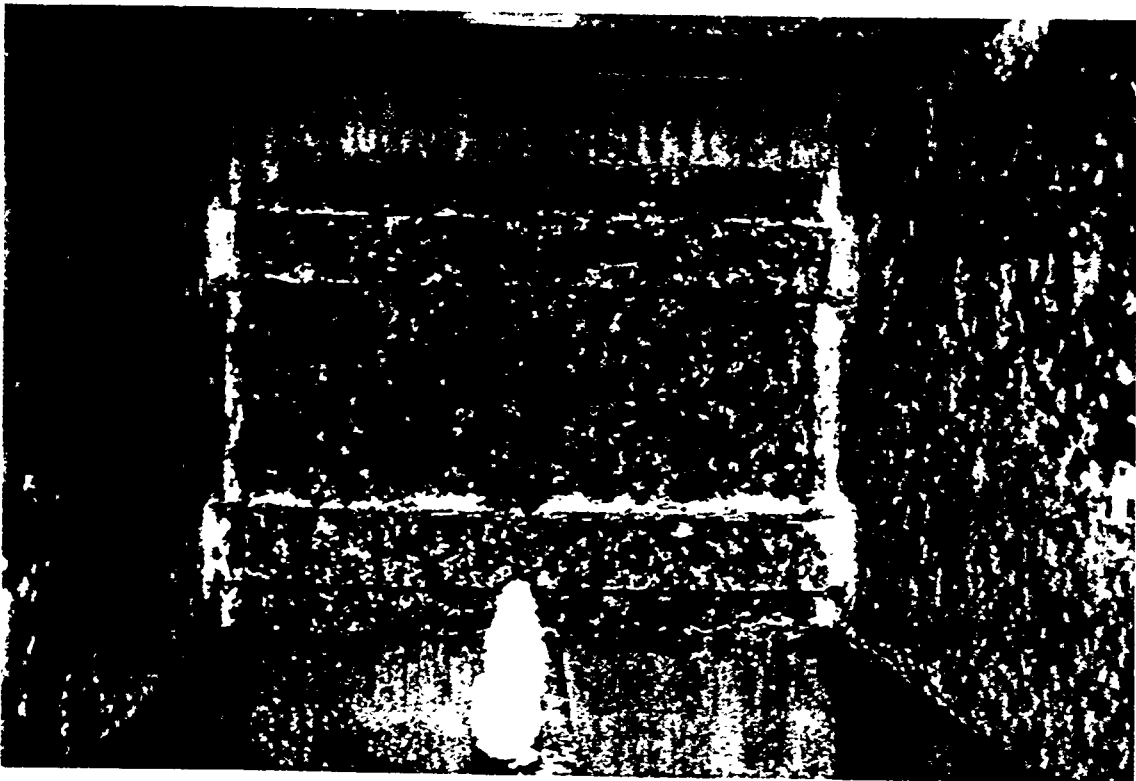
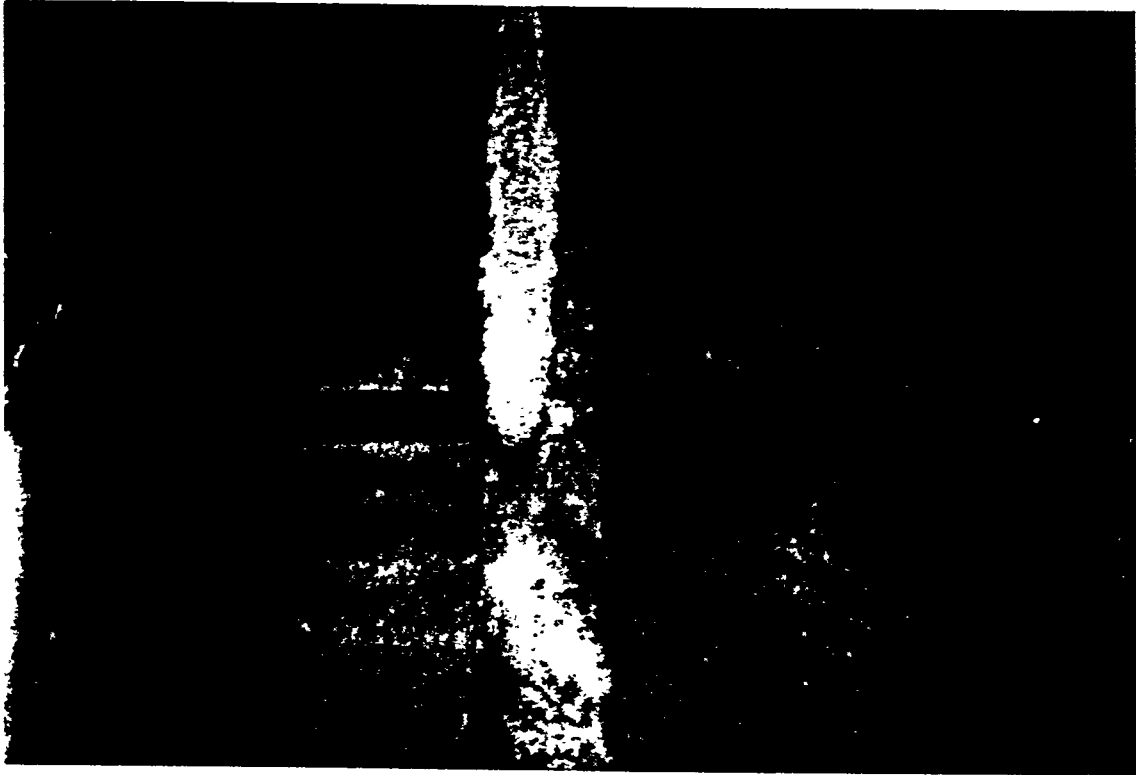


Figure 2.3: Aluminum Anode/Partial Coating After Six Years

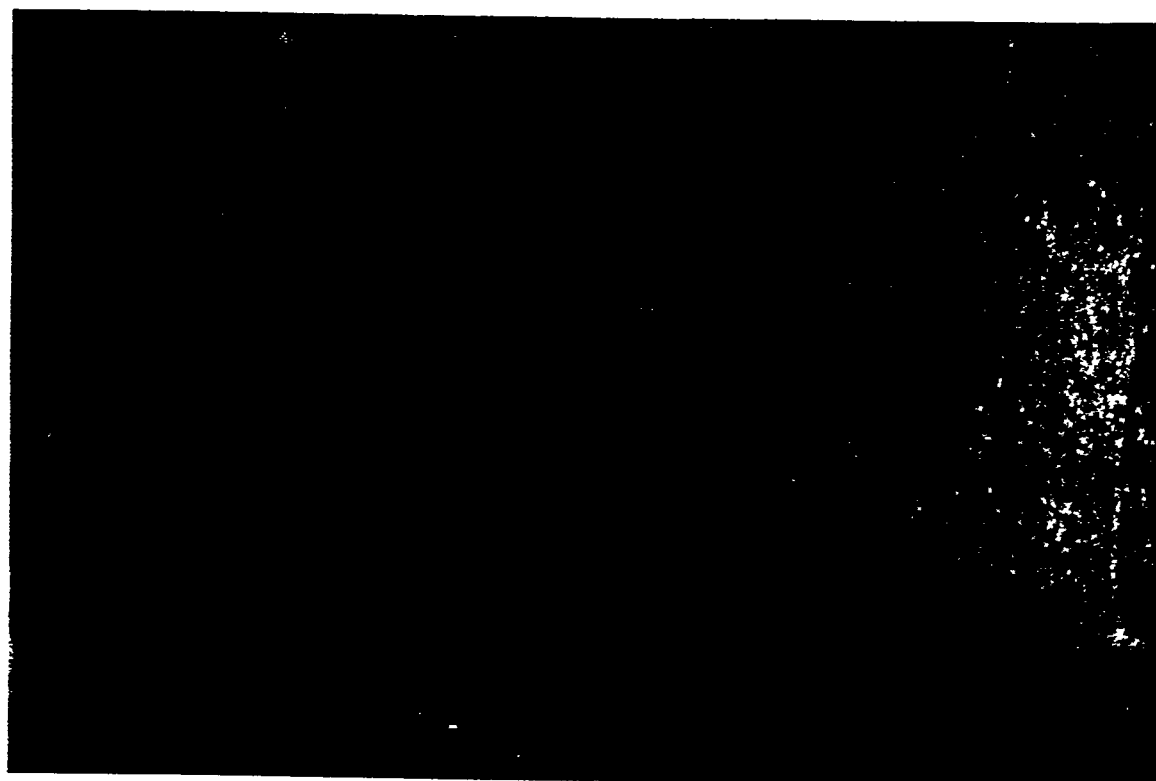
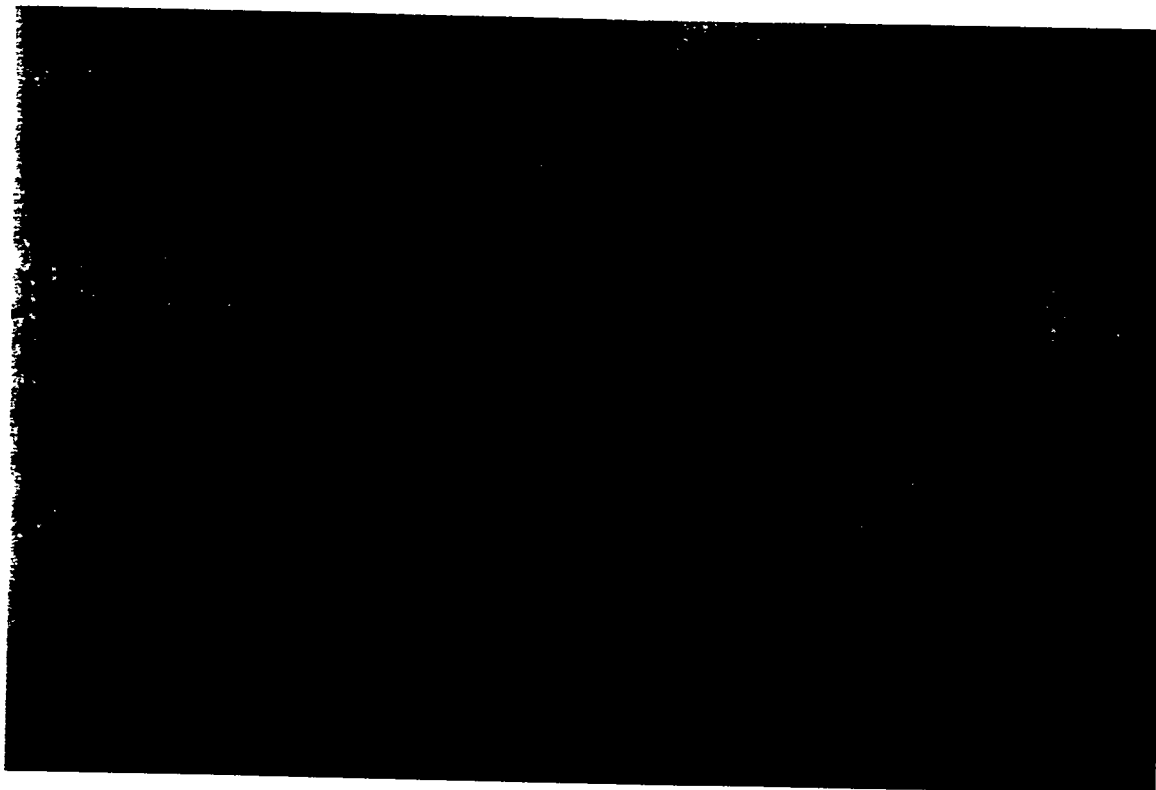


Figure 2.4: High Performance Coating After Six Years

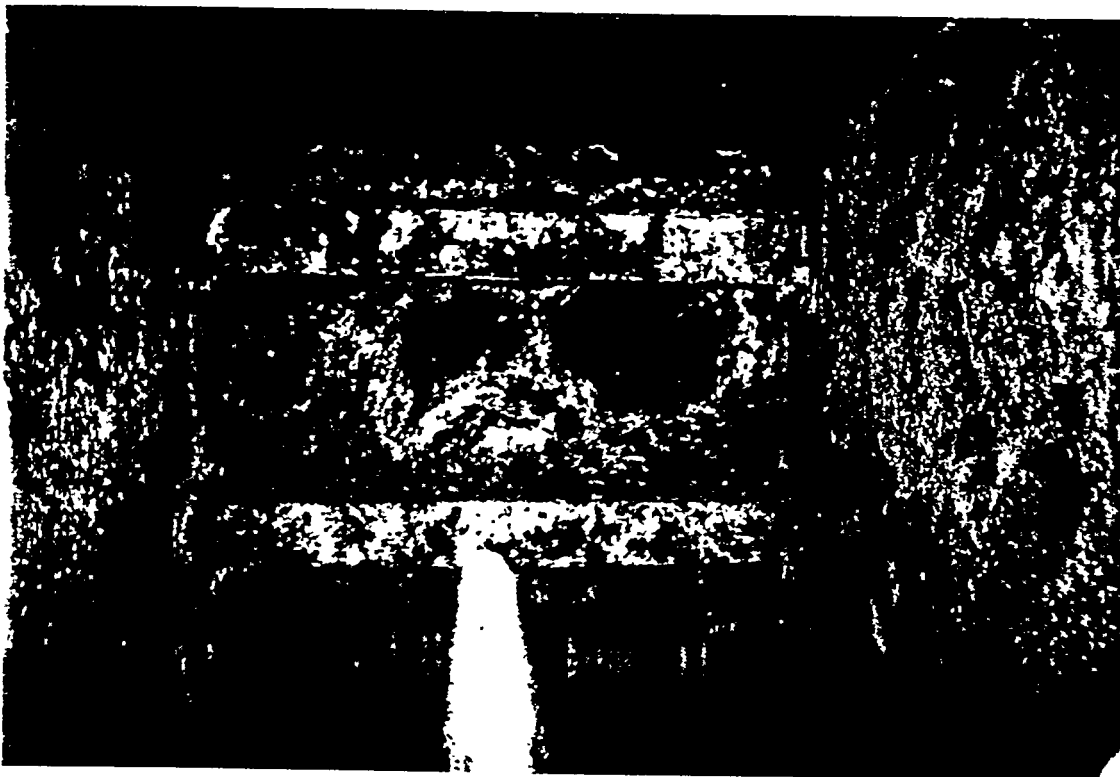
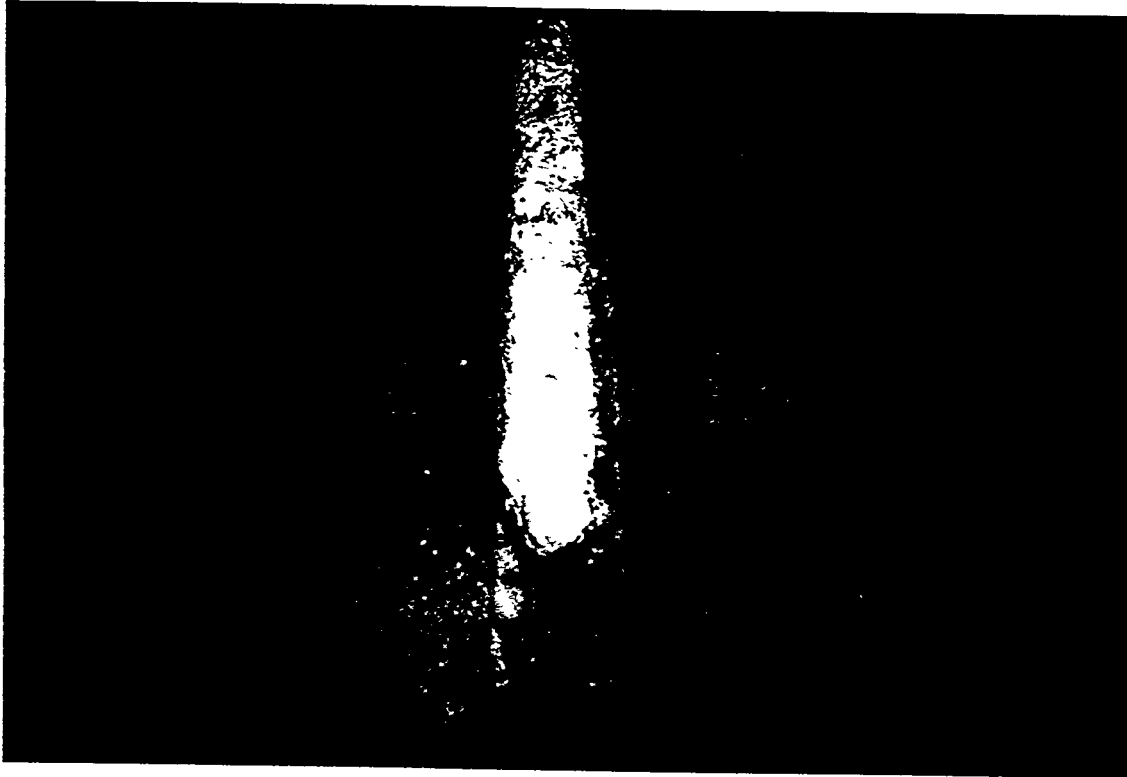


Figure 2.5: Zinc Anode/Partial Coating After Eight Years

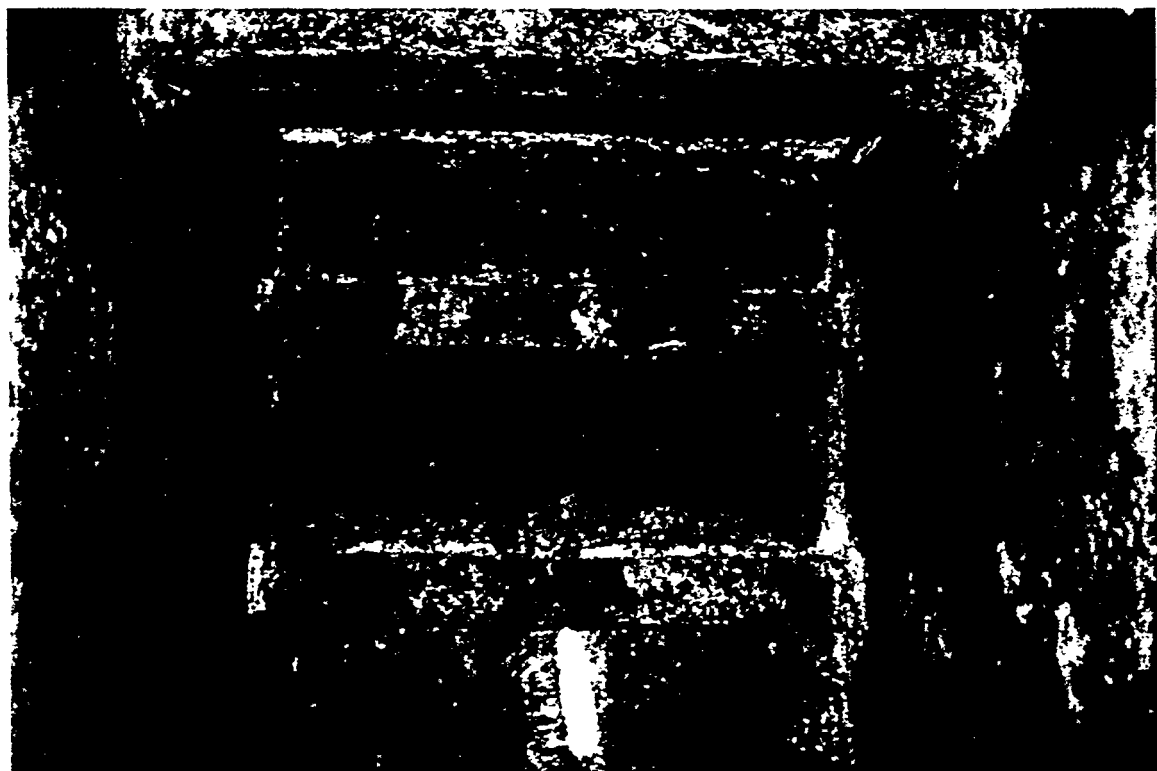


Figure 2.6: Zinc Primer Aluminum Anode After Six Years

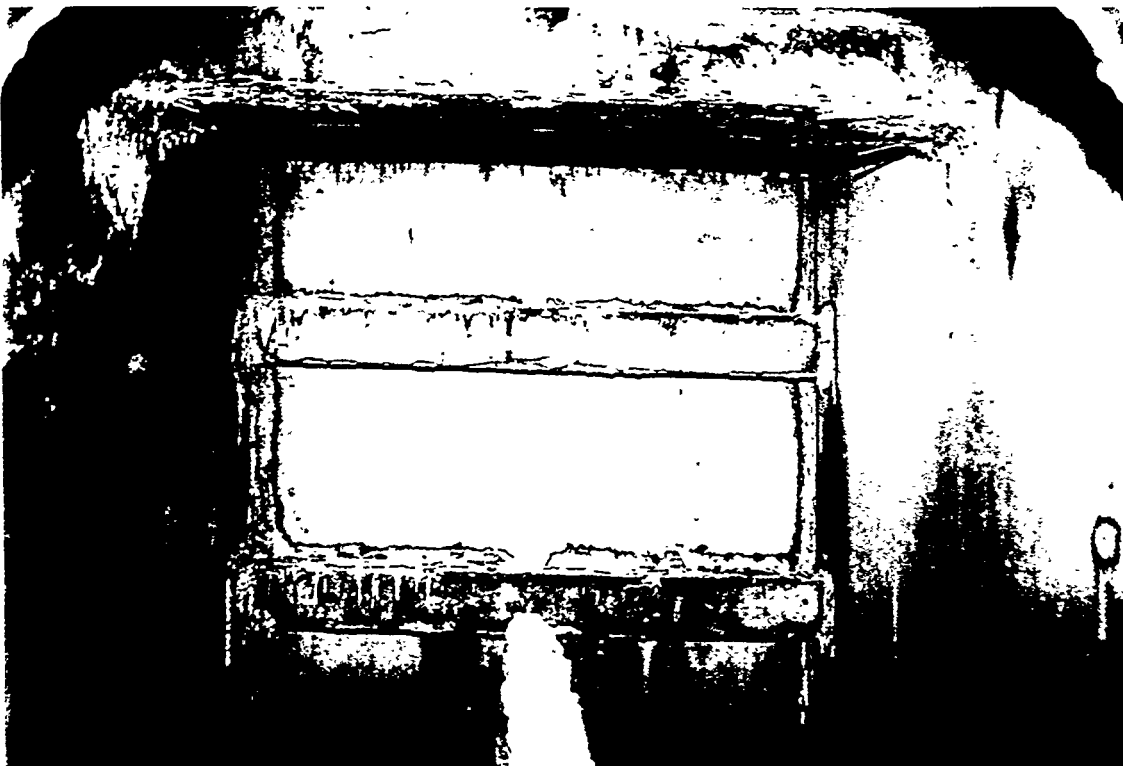
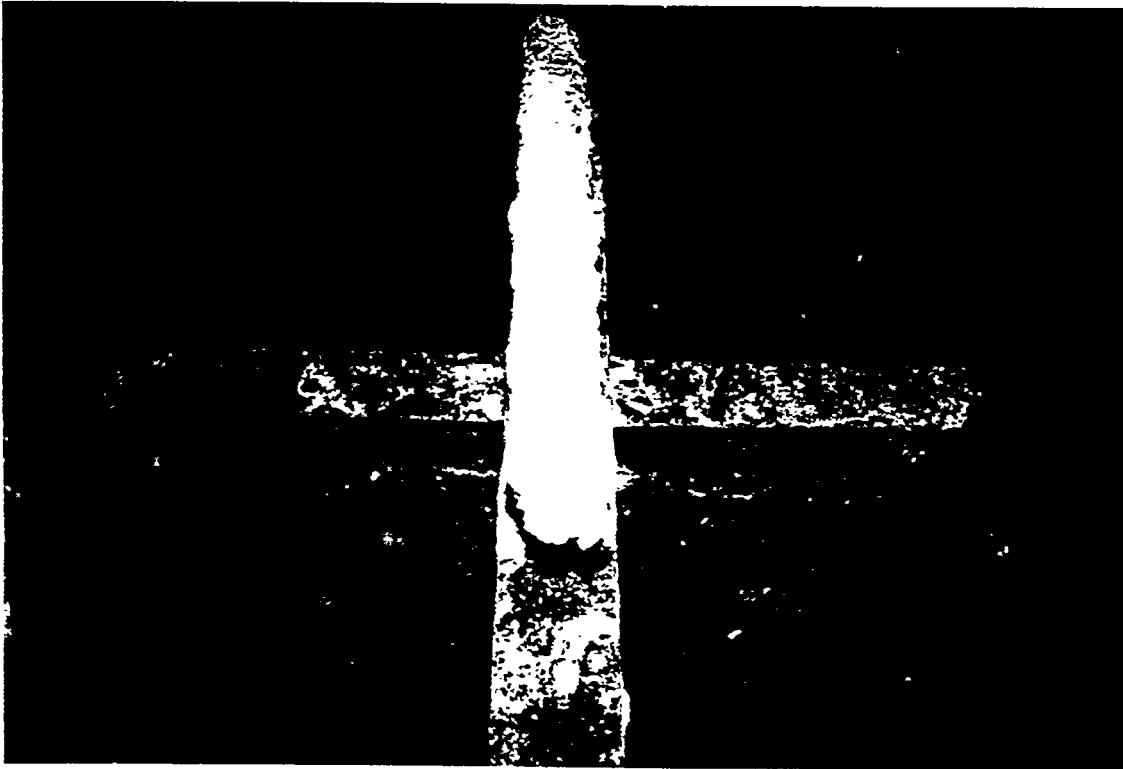


Figure 2.7: Pre-construction Primer/Zinc Anode After Eight Years

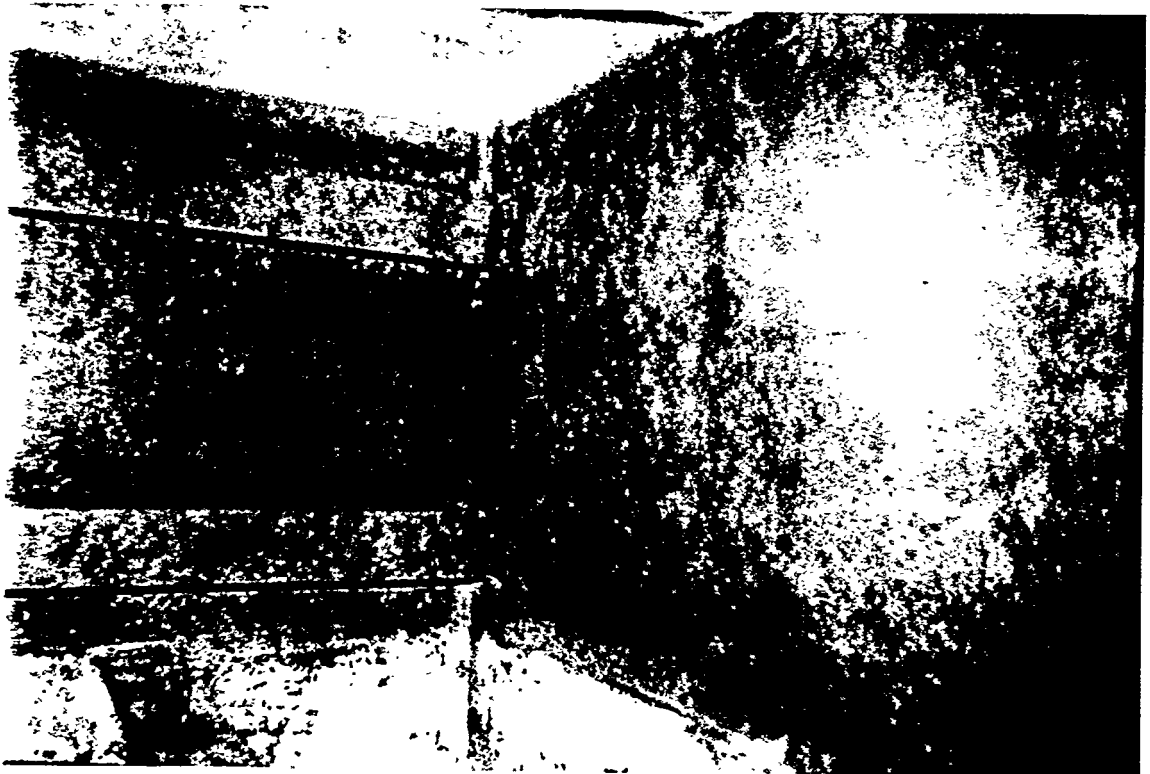
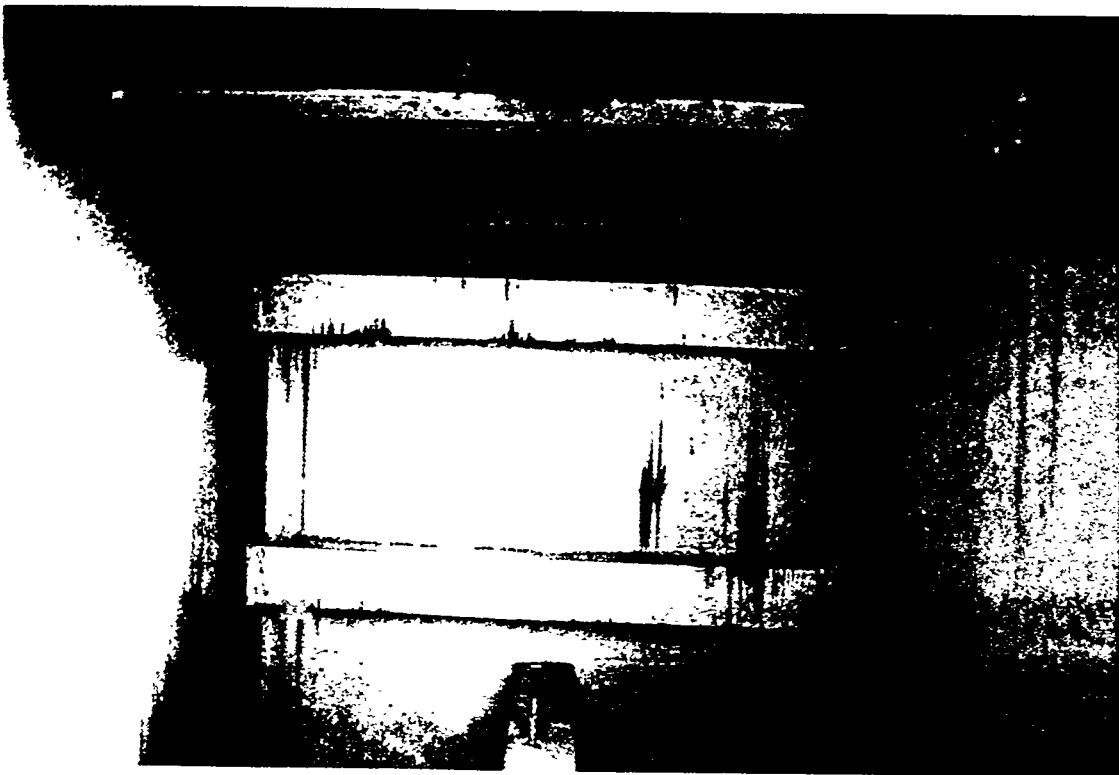
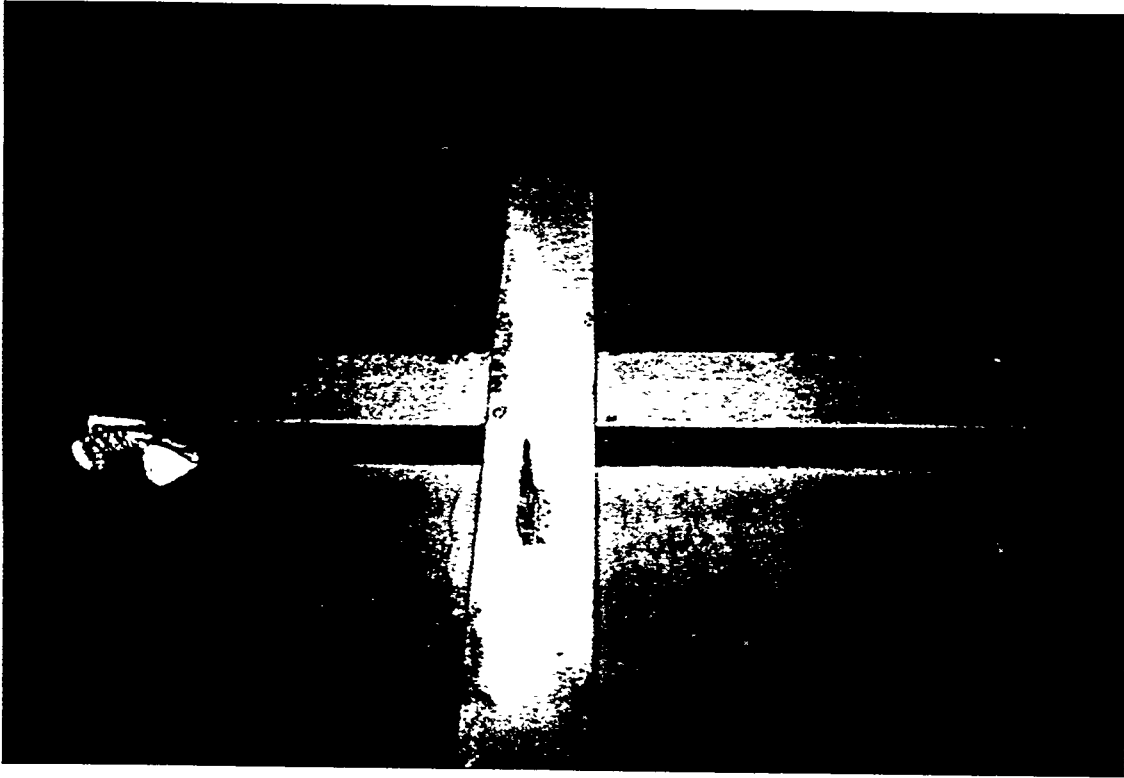
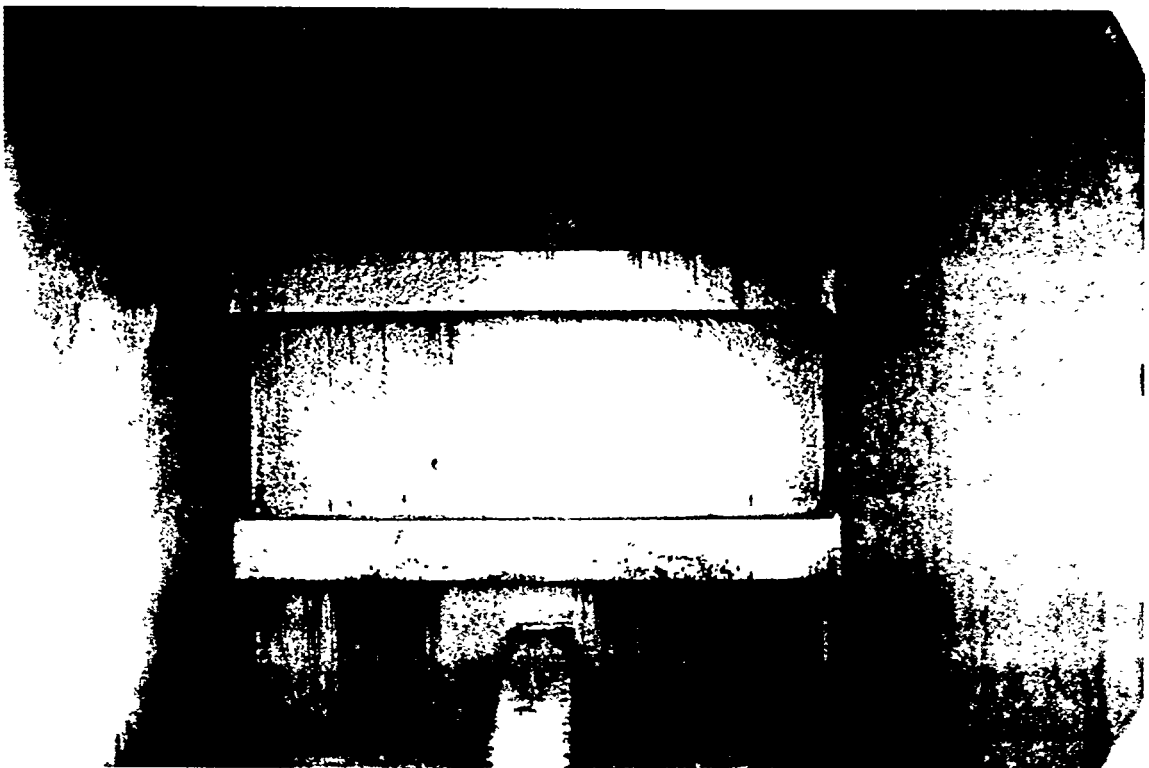
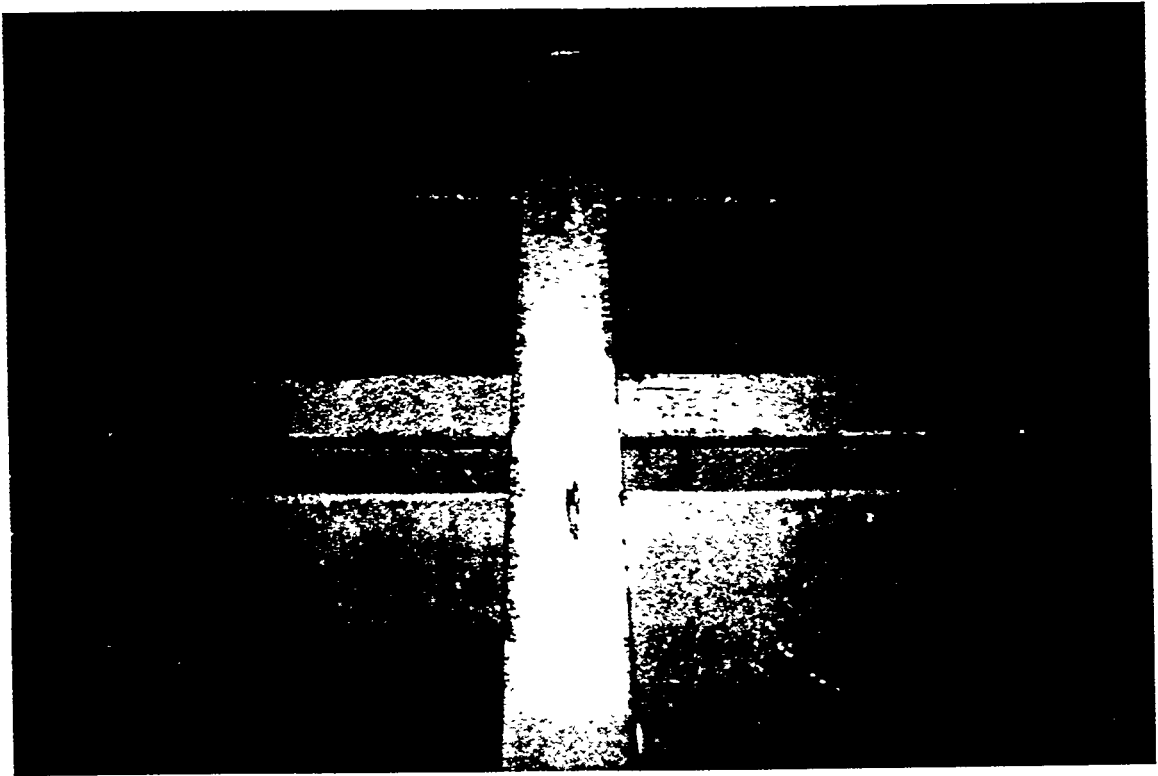


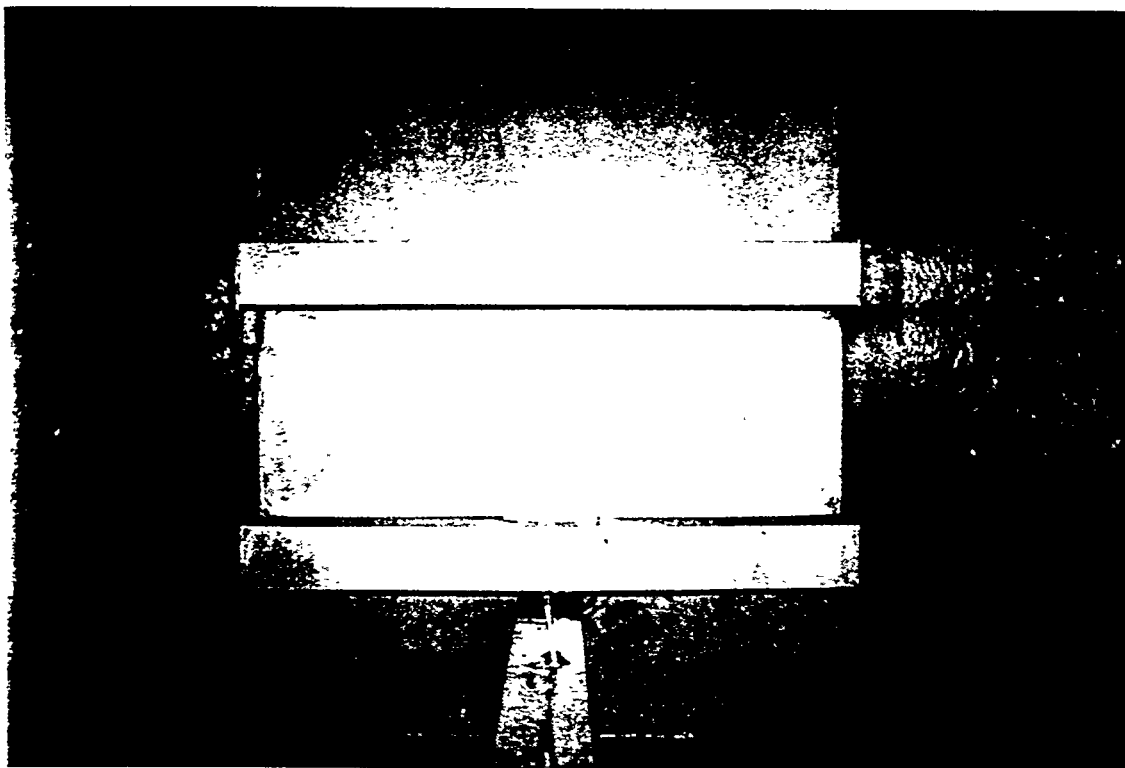
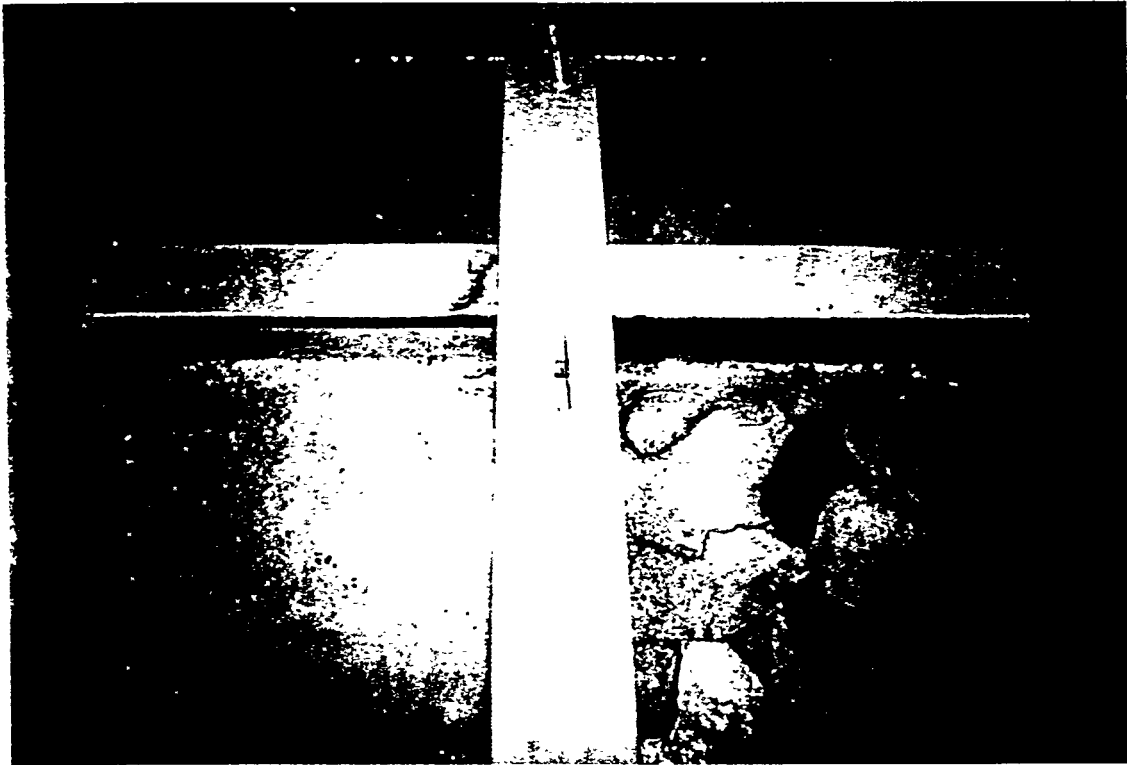
Figure 1.8: Hand Power Tool Cleaned Surface Prior to Coating



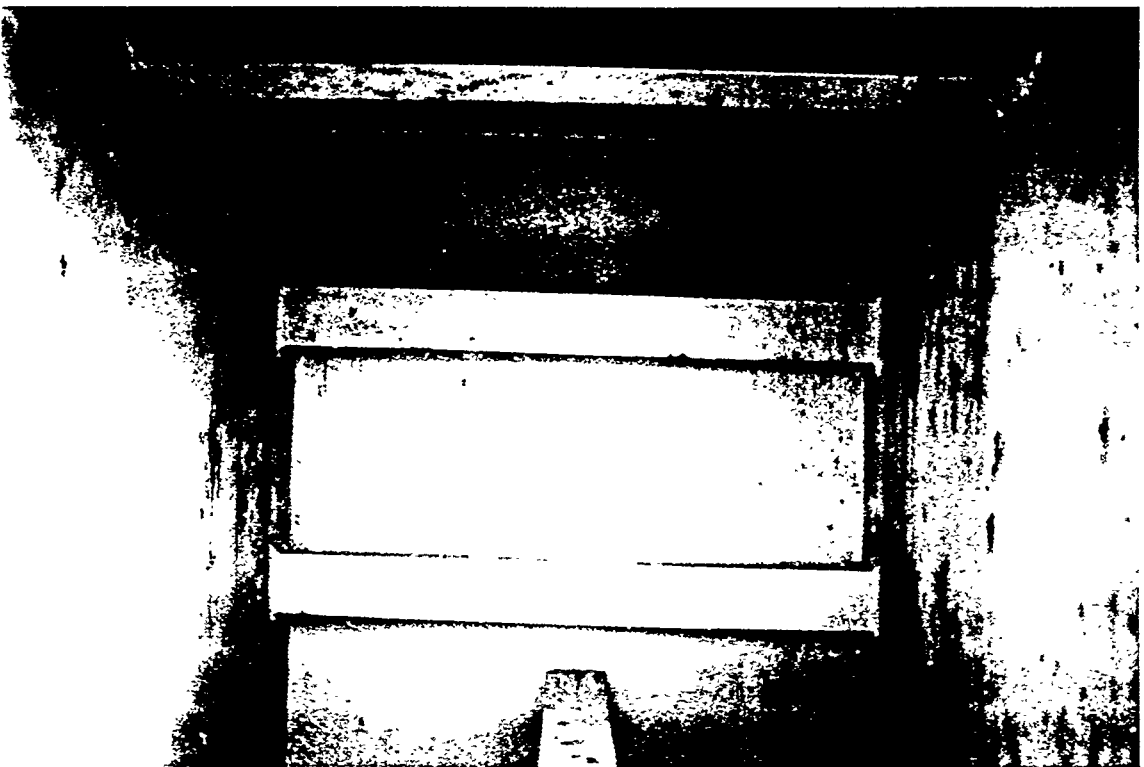
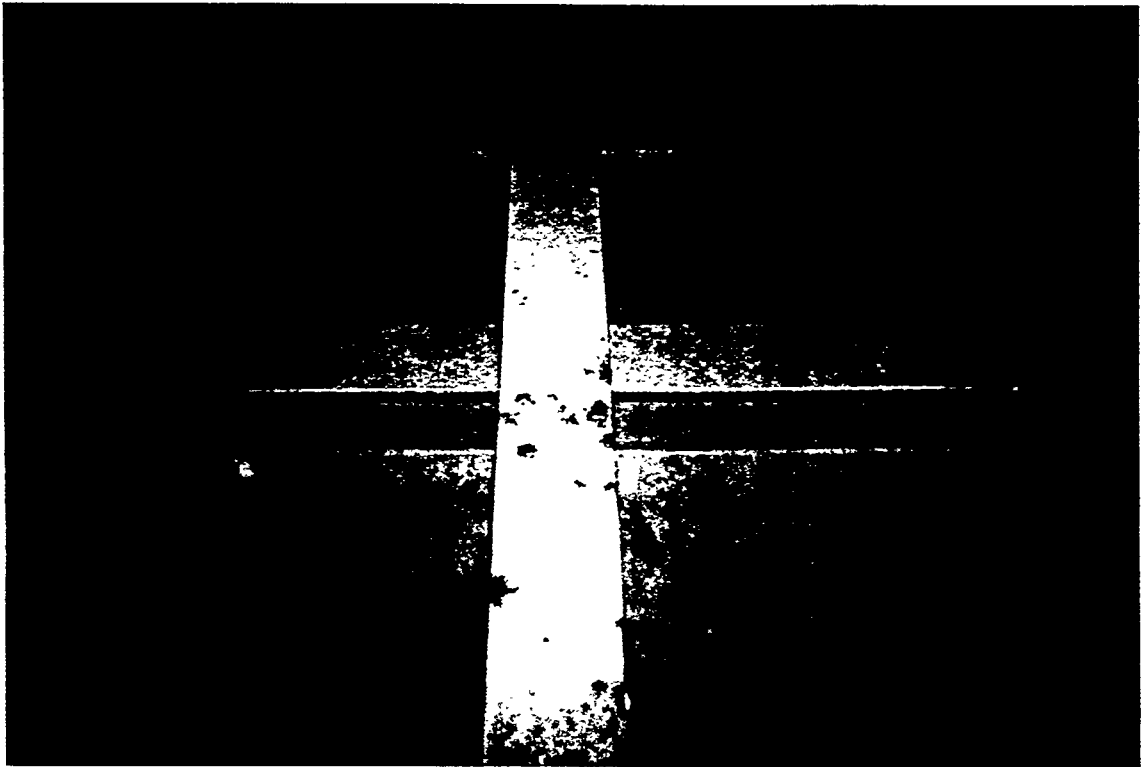
2.9: Epoxy "A" Over Hand/Power Tool Cleaned Steel After Two Years



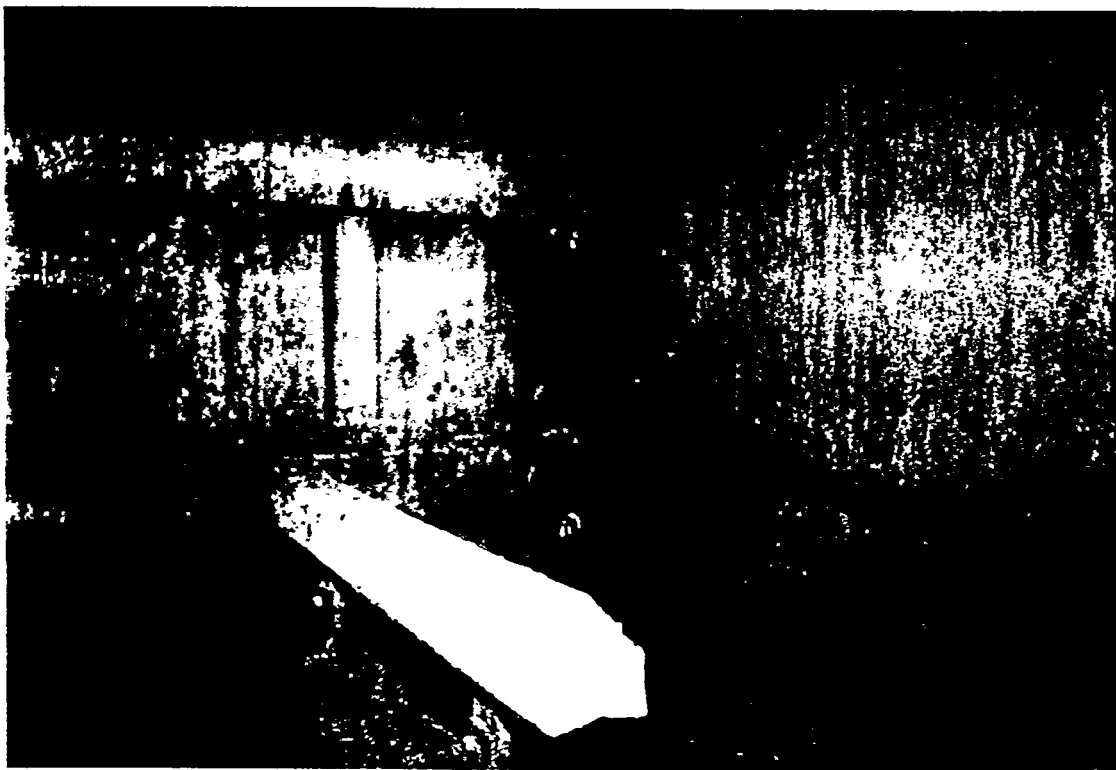
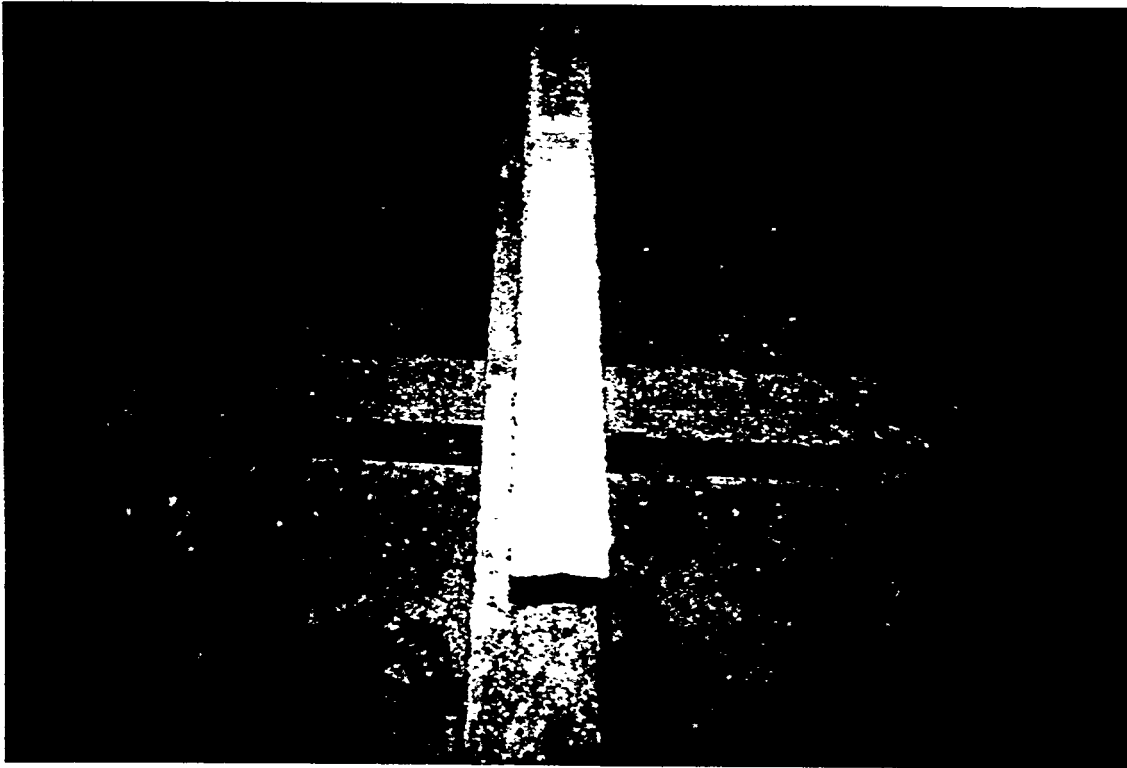
2.10: Epoxy "A" Over Abrasive Blasted Steel After Two Years



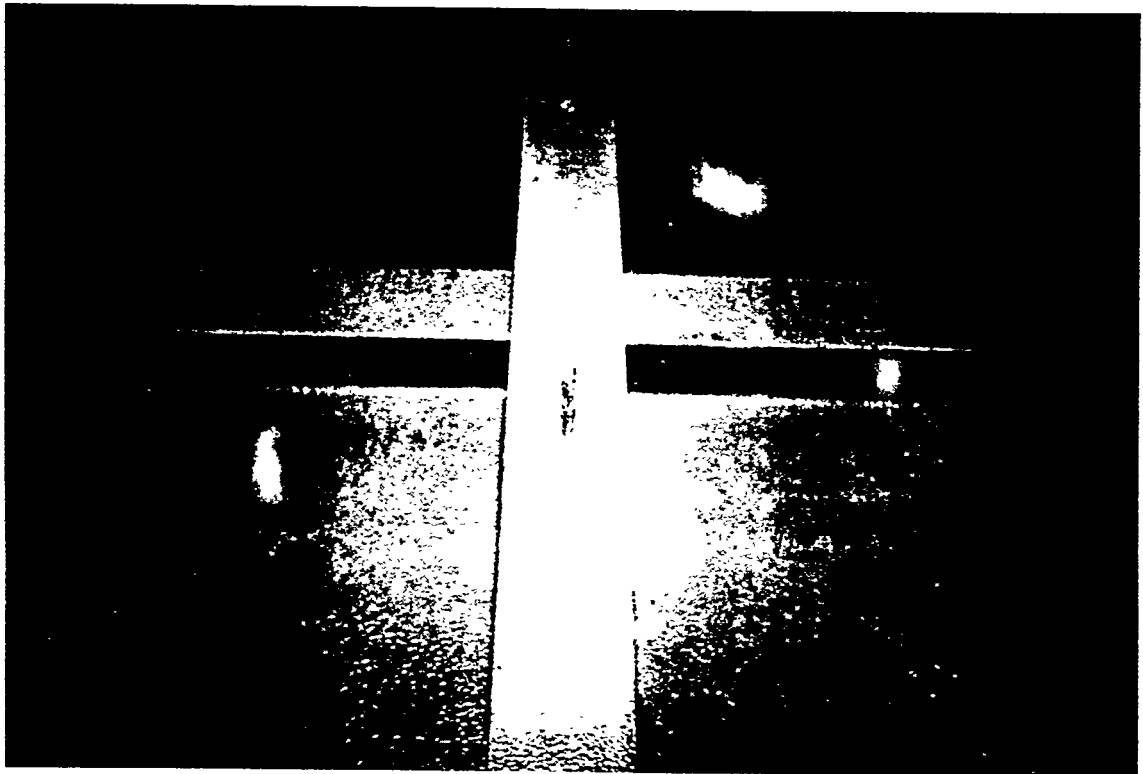
L.11: Epoxy"B"Over Hand Power Tool Cleaned Steel After Two Year



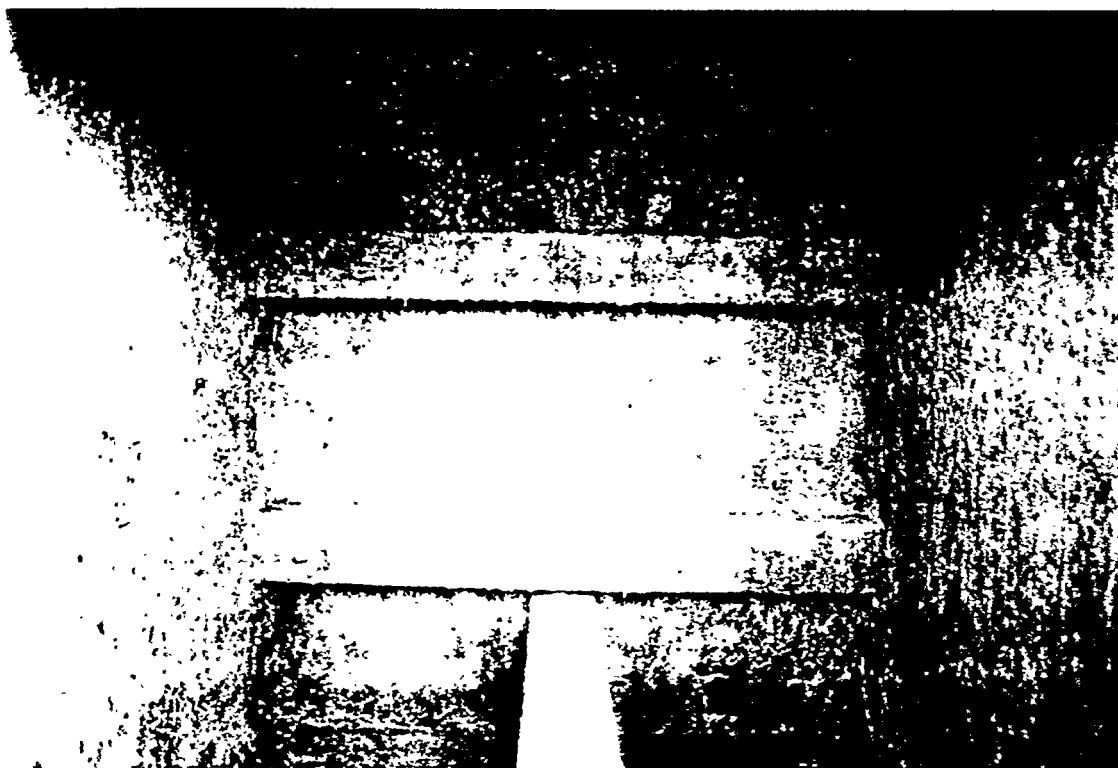
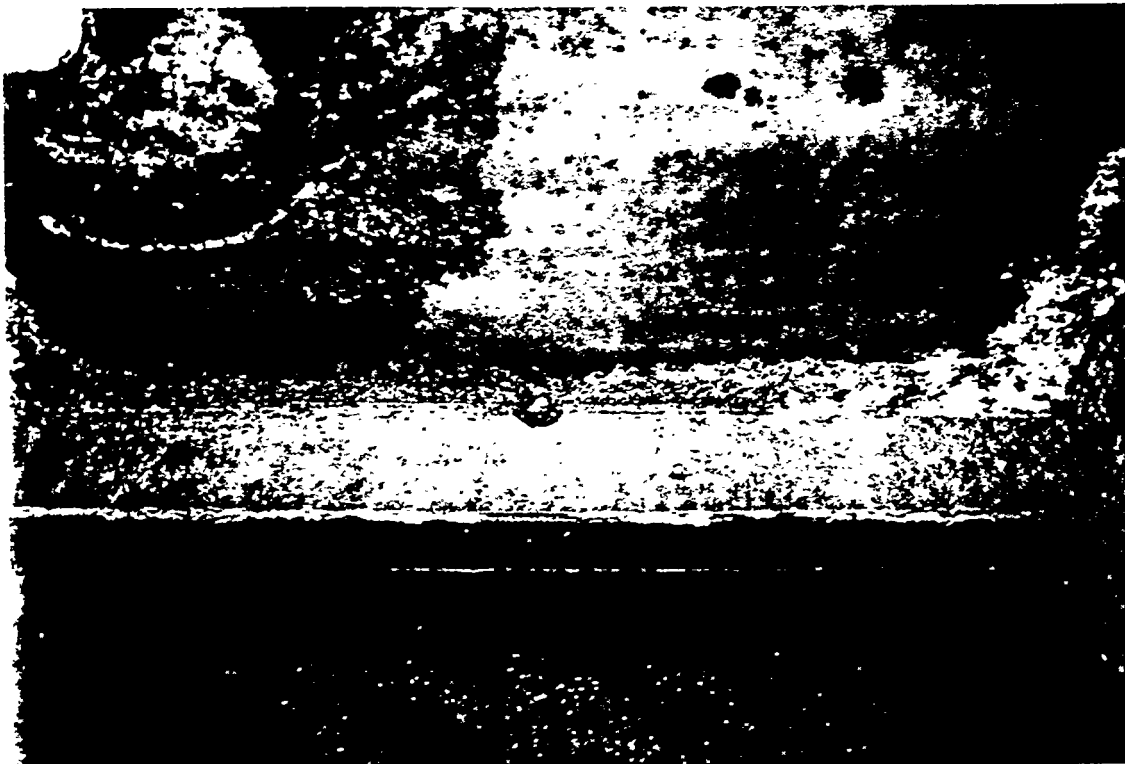
2.12: Epoxy "B" Over Abrasive Blast Cleaned Steel After Five Year:



2.13: Completely Coated Tank With Added Zinc Anode After Two Yea



2.14: WOC Compliant Version of MIL-P-24441 After Two Years



1.13: Biodegradable Soft Coating After One Year

Appendix A
Reprint From Original Report (Based on 1982 Cost Data)
Summary of Economic Analysis

<u>Alternate</u>	<u>Case No.</u>	<u>Coating Replacement (YRS)</u>	<u>Anode Replacement (YRS)</u>	<u>First Year</u>	<u>Twentieth Year (Tot)</u>
High Performance Coatings - No Maintenance	4A	8	NONE	408,852	1,319,974
High Performance Coatings - No Maintenance	4B	10	NONE	408,852	654,020
High Performance Coatings - With maintenance	4C	15	NONE	408,852	824,653
Partial Coatings Zinc Anodes	1A	NONE	4	376,443	724,142
Partial Coatings Aluminum Anode	1B	NONE	4	321,597	514,923
Partial Coatings Zinc Anodes	1C	NONE	8	376,443	465,415
Partial Coatings Aluminum Anode	1D	NONE	8	321,597	349,539
Pre-construction Primer-Zinc Anode	2A	NONE	8	258,441	377,944
Pre-construction Primer-Zinc Anode	2B	NONE	4	258,441	623,092

Listing of Proven Corrosion Control Alternatives in Ballast Tanks By Least Expensive Approach

<u>Alternate</u>	<u>First Year (Initial)</u>	<u>Twentieth Year (Total)</u>
1. Pre-construction Zinc Primer with zinc anodes replaced at 8 year intervals	\$258,441	\$377,944
2. Partial Coatings with zinc anodes replaced at 8 year intervals	\$376,443	\$465,415
3. High Performance Coating with no maintenance replaced at 10 years	\$408,852	\$654,000
4. High Performance Coating with maintenance replaced at 15 years	\$408,852	\$824,653