# Evaluation of New Surface Preparation and Coating Repair Techniques in Ballast Tanks
## Interim Report (Three Year Results)


U.S. DEPARTMENT OF TRANSPORTATION
Maritime Administration and the U.S. Navy

in cooperation with

National Steel and Shipbuilding Company
San Diego, California

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# EVALUATION OF NEW SURFACE PREPARATION

# AND

# COATING REPAIR TECHNIQUES IN BALLAST TANKS

INTERIM REPORT (THREE YEAR RESULTS)

MAY 1991

Prepared by
Associated Coating Consultants
in Cooperation with
National Steel and Shipbuilding Company
San Diego, California 92138

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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.

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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. 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

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

After three years of testing (nine years for some systems), all but one of the systems is providing protection. The biodegradable soft coating failed after one year. The use of this type of material would require replacement at one year intervals. 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” accept 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 totally delaminated at the end of three years. This coating and the same coating applied over abrasive blasted steel has been repaired using hand and power tool cleaning techniques. The soft coating has been replaced with a waterborne inorganic zinc, one coat system.

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.

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# l.Conclusions

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 three years of testing.

After concluding the initial test program, 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 Too1 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 over abrasive blasted surface
- Biodegradable soft coating
- VOC compliant surface tolerant epoxy "B" over Solvent (SSPC-SP l) and Hand Tooled cleaned SSPC-SP 2) surface

At the end of three 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" is essentially equal in performance over both the hand and abrasive blast cleaned surfaces.
- Except for areas of high film thickness in the hand cleaned tank, Epoxy "B" is performing equally well over both hand cleaned and abrasive blasted steel.
- Excessive thicknesses of surface tolerant epoxies can result in premature coating failures.
- Zinc anode addition to the six year old totally coated tank is providing extended protection without the necessity of coating repair/replacement. No new coating failure detected.
- The VOC compliant version of MIL-P-24441 is providing good corrosion protection after three years. No blistering was detected. Most failures can be attributed to poor application, i.e. difficult to reach areas not coated.

# 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, 1987 and 1990 contains a complete discussion of the pros and cons of each corrosion control technique and expected performance. Summarized below are some of the pertinent points of that discussion.

### 2.1.1 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.

### 2.1.2 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 overhead, bottoms, and small pocket areas. This point has been substantiated by the test program.

### 2.1.3 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 relatively short period of time, actual field service histories are not 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 also been actively involved in formulating new VOC compliant versions of MIL-P-24441.

### 2.1.4 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.

## 2.2 Test Tank Facilities

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. Each tank was constructed to duplicate ship ballast tanks as concerns structure and configuration . One side of each tank was of bolted construction to allow access for inspection.

Following tank fabrication and application/installation of each alternate. the tanks are ballasted and deballasted with fresh sea water. Each ballast cycle consisted of 20 days full and 10 days empty. 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 nine years.

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

Table I

Corrosion Control Alternates Used In Tank Test

| Tank Number | Surface Preparation | Coating System | Anode Type | System Age |
|---|---|---|---|---|
| One | SP2/SP3 | Surface tolerant VOC compliant epoxy “A” | None | 3 years |
| Two | SP10 | Two Coat Epoxy (MIL-P-23236) Completely coated | None initially Zinc (MIL-A-18001H) | 9 years Anode added @ 6 years |
| Three | SP10 | Two Coat Epoxy (MIL-P-23236) Partially coated | Zinc (MIL-A-18001H) | 9 years |
| Four | SP10 | Surface tolerant VOC compliant epoxy “A” | None | 3 years |
| Five | SP6 | Surface tolerant VOC compliant epoxy “B” | None | 6 years |
| Six | SP10 | Inorganic zinc pre-construction primer | Zinc (MIL-A-18001H) | 9 years |
| Seven | SP10 | VOC compliant MIL-P-24441 | None | 3 years |
| Eight | SP1/SP2 | Biodegradable soft coating | None | Failed 1 year |
| Nine | SP1/SP2 | Surface tolerant VOC compliant epoxy “B” | None | 3 years |

## 2.3 Summary of Test Results

### 2.3.1 Performance of Zinc Anode with Partial Coatings

After nine years, no new failures were detected. The color of the bare portion of the tank surface is still primarily the color of the calcareous deposit. Where the deposit had been removed, a new deposit had formed. The deposit was observed to b-e more porous than initially 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.

### 2.3.2 Performance of Zinc Anodes with Pre-construction Primer

Calcareous deposits are still present after nine years. The primary failure areas are scaling of the overhead due to air pockets and the coatings on the tank flat bottom subjected to erosion from ballast water filling operation. These areas are beginning to show significant corrosion. Some metal loss is evident. The anode seems to be losing effectiveness. More red rust is visible than previously reported. This system may be nearing useful life.

### 2.3.3 Performance Aged Coating System With Added Zinc Anode

There has been very little change since the last report. No new coatings failure was noted. Calcareous deposits continue to increase over the areas of failed coatings. Very little anode consumption can be detected.

### 2.3.4 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 five percent failure after three years.

The top two-thirds of the back has less than one percent failure. The bottom one-third of the back has forty percent failure. The top stiffener has fifty percent failure on the right side. The bottom stiffener has twenty percent failure. The tank sides have approximately three percent visible rust with most of the failure occurring on the lower sections.

The overhead has less than one percent failure; however, the edge of the top stiffener has failed.

The flat bottom has less than one percent failure. The bottom frame structure has localized areas of failure on edges with an overall rating judged to be less than ten percent.

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

After three 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.

As with the abrasive blast cleaned tank, the failure of the back of tank is primarily limited to the lower third and stiffener edges. Failure on the left side of the tank is also in the lower third, occurring over the old coating. The same is true on the right side. The tank overhead failure is on stiffener edges. The tank flat bottom and structure is essentially the same as the blast cleaned tank.

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

After six years, this system is beginning to show significant breakdown. The top of the tank has twenty-five to fifty percent breakdown. The right 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 five to ten percent failure, and the back has less than one percent failure. The flat bottom also has five to ten percent failure.

### 2.3.7 Performance of Surface Tolerant VOC Compliant Epoxy “B” Over Hand Tool Cleaned Steel

The bottom is divided into four quadrants because of the structural configuration. The coating in right front quadrant has cracked and totally failed. The left front has less than five percent failure. The right rear quadrants shows no sign of failure. The left rear quadrant has ten percent failure. All failures in this tank can be attributed to areas of excessive film thickness (30 plus mils). The coating on the left side of the bottom stiffener has cracked and blistered. The balance of the structure has less than one percent failure.

### 2.3.8 VOC Compliant Version of MIL-P-24441

After three years, the left side of the tank has less than one percent failure. The back also has one percent failure; however, the failure and rust bleed of an area located behind the bottom stiffener, in a difficult to reach area, gives the false impression of a greater degree of failure.

The left side has less than one percent coating breakdown. The right side has minimum failure except for the lower six inches, which is approximately twenty-five percent failed. Except for stiffener edges, the top and flat bottom have no failure. The bottom frame failures are primarily limited to edges, with less than five percent noted overall.

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 (Oc) | 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 |

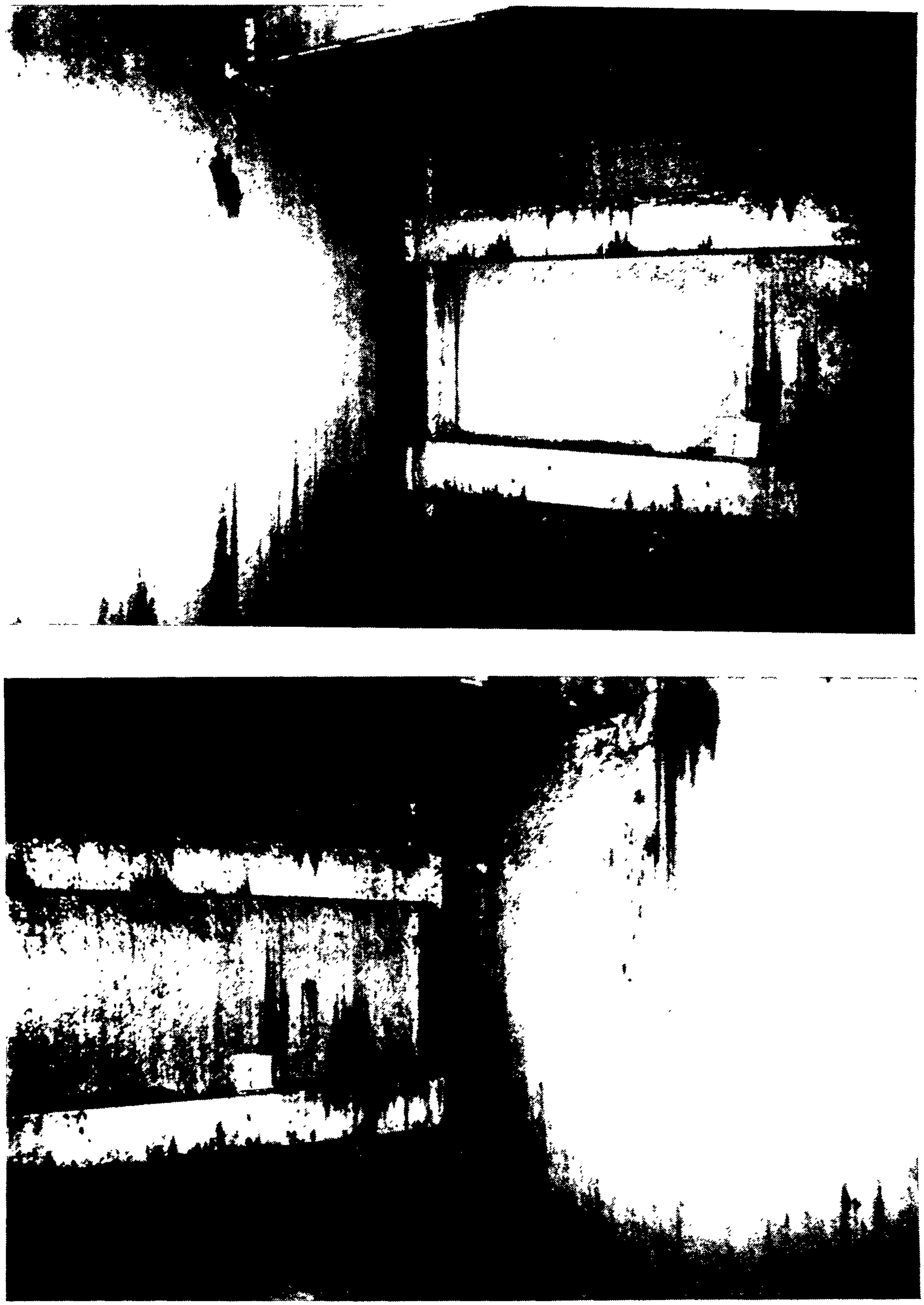


Figure 2.1: Epoxy "A" Over Hand/Power Tool Cleaned After Three Years

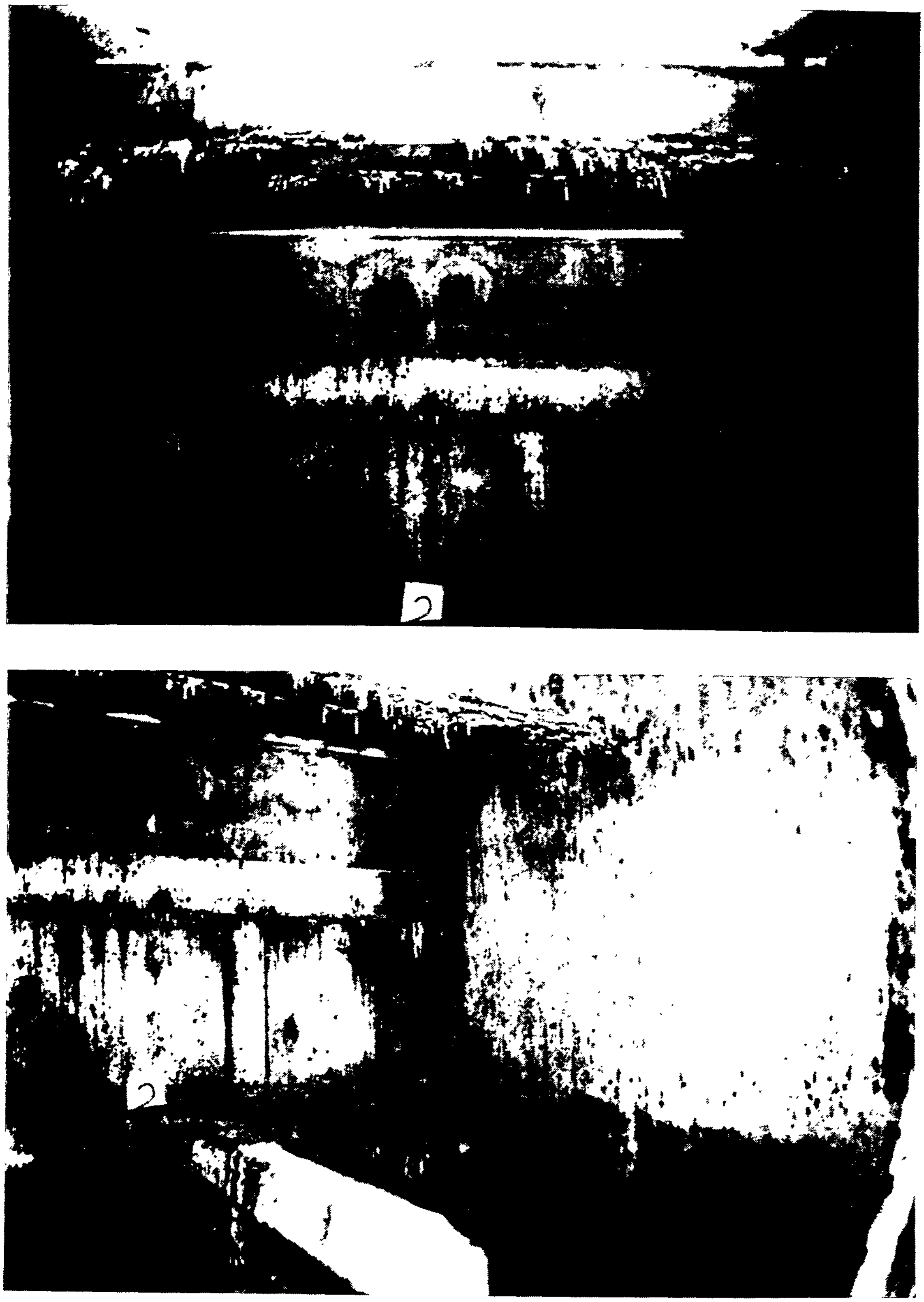
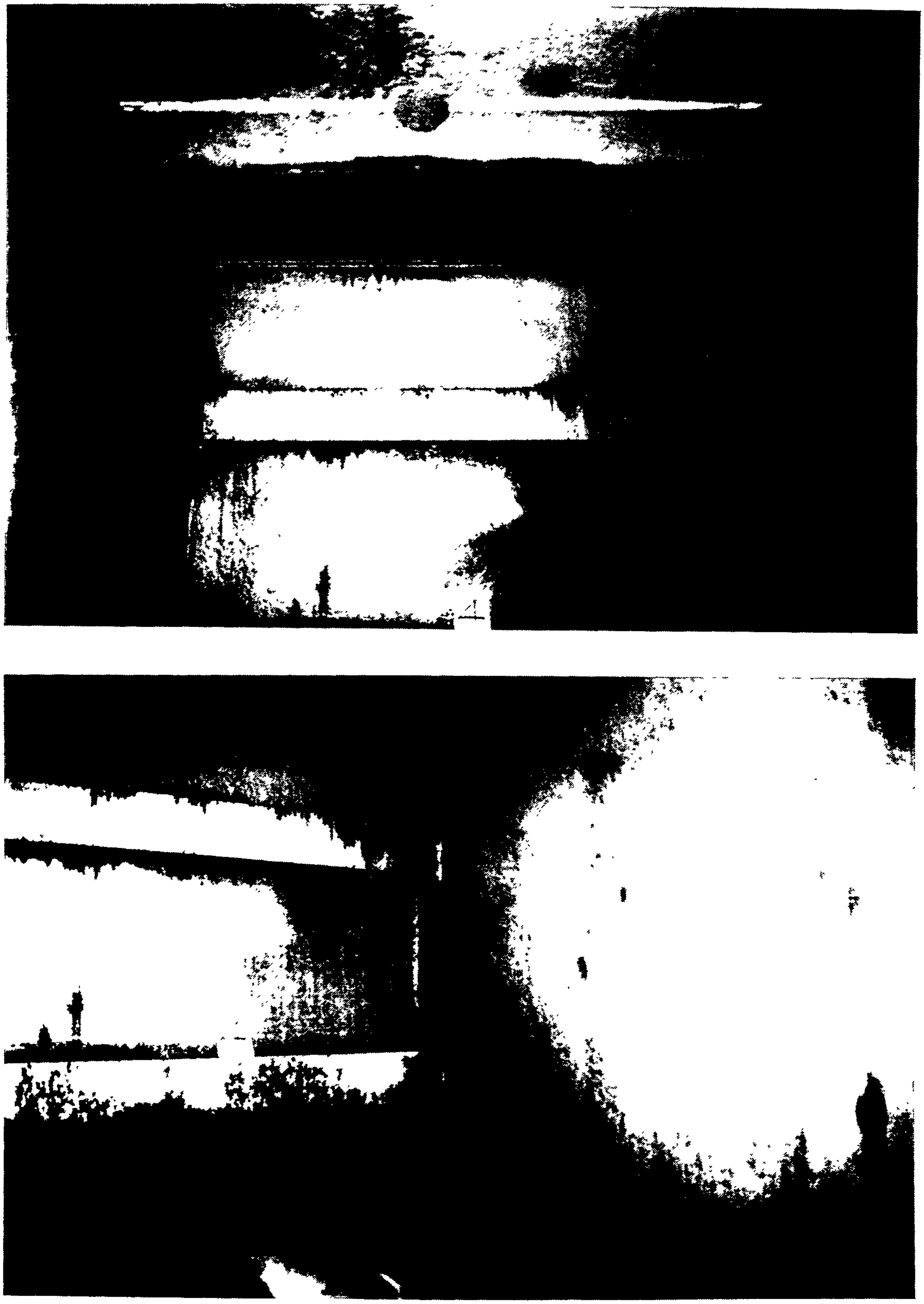
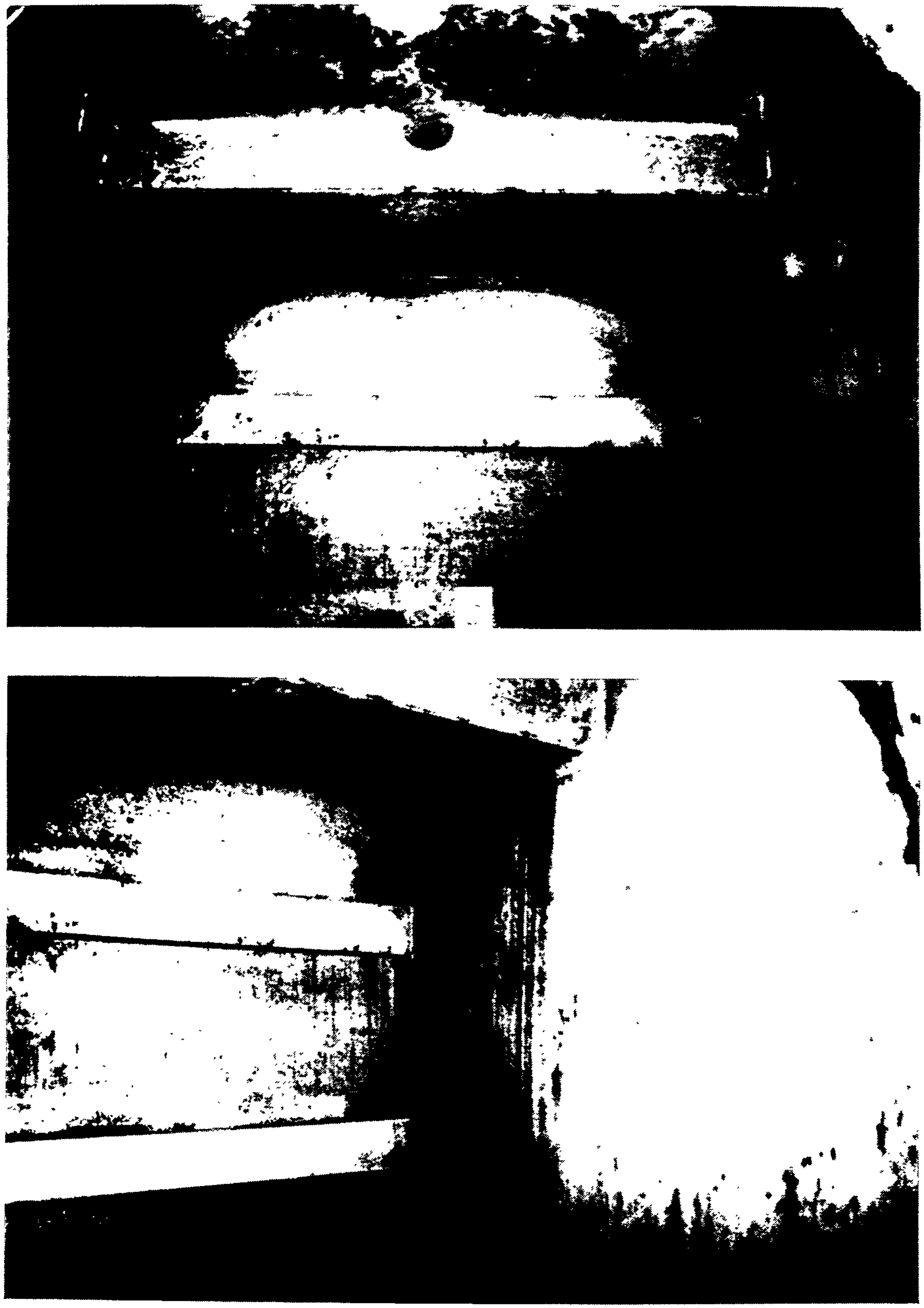



Figure 2.2: Completely Coated Tank W/Zinc Anode Added After Three Years

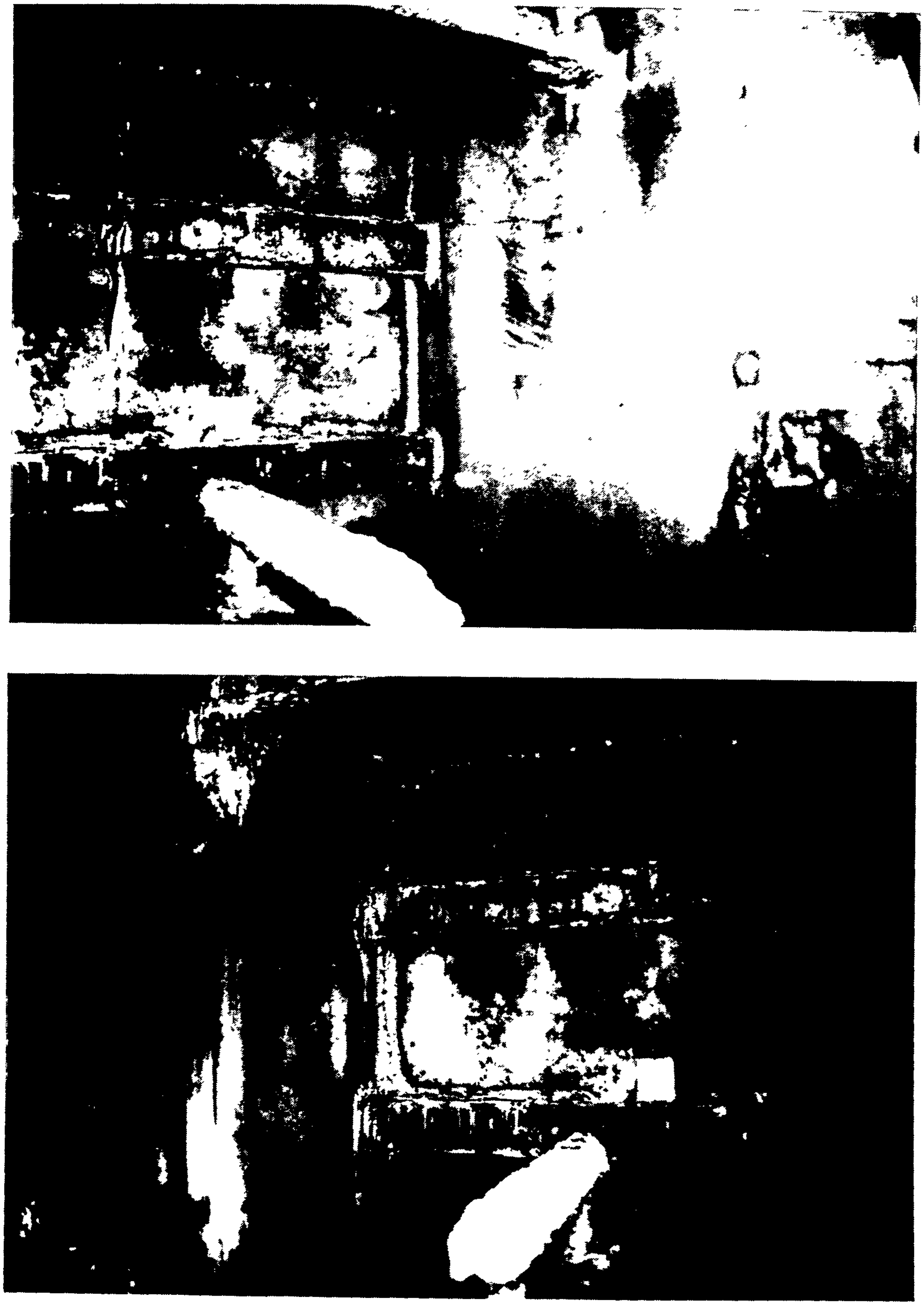

2.3: Zinc Anode/Partial Coatings After Nine Years



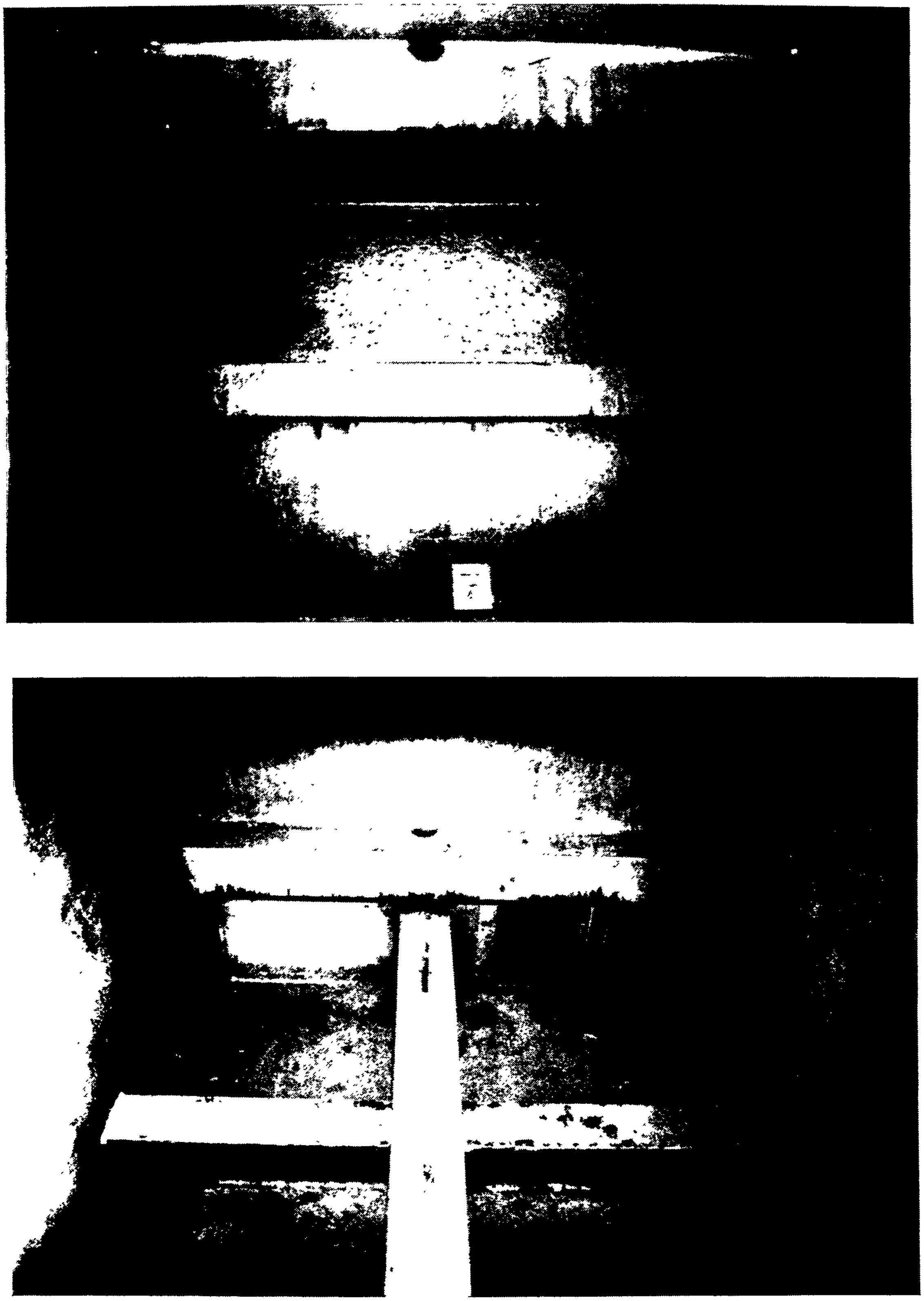
2.4: Epoxy "A" Over Abrasive Blasted Steel After Three Years



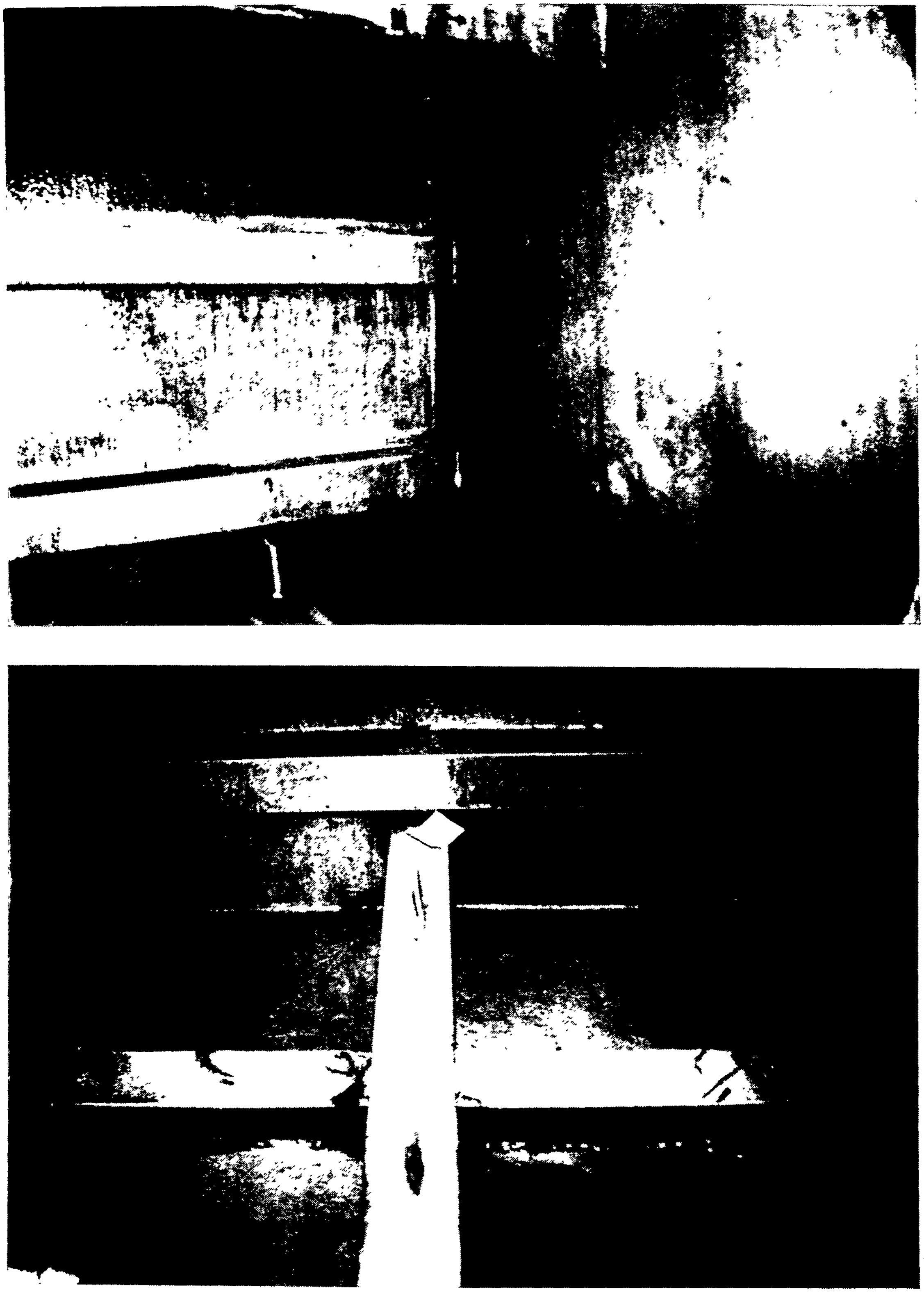
2.5: Epoxy "B" Over Abrasive Blast Cleaned Steel After Six Years



2.6: Preconstruction Primer/Zinc Anode After Nine Years



2.7: VOC Compliant Version of Mil-P-24441 After Three Years



2.8: Epoxy "B" Over Hand/Power Tool Cleaned Steel After Three Years

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