CATHODIC PROTECTION/PARTIAL COATINGS

VERSUS

COMPLETE COATING in BALLAST TANKS-A PROJECT UPDATE

FEBRUARY 1985

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FOREWORD

This research 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 and Avondale Shipyards, Inc. The development work was accomplished by Associated Coatings Consultants under subcontract to Avondale Shipyards, Inc. The overall objective of the program is improved productivity and, therefore, reduced shipbuilding costs.

The studies have been undertaken with this goal in mind, and have followed closely the project outline approved by the Society of Naval Architects and Marine Engineers' (SNAME) Ship Production Committee.

Mr. Benjamin S. Fultz of Associated Coating Consultants served as principal investigator. Mr. John Peart of Avondale Shipyards was the R&D Program Manager responsible for technical direction and publication of the final report. Program definition and guidance was provided by the members of the 023-1 Surface Preparation and Coatings Committee of SNAME.

EXECUTIVE SUMMARY

Ship ballast tanks are one of the most costly items of new ship construction. In addition, ballast tanks are one of the most severe corrosion areas during ship operations. The 023-1 Panel of SNAME recognized these problems and selected a research and development project to investigate alternate, cost effective corrosion control solutions. Four approachs were originally selected for mock-up ballast tank testing and 20 year life cycle cost analysis.

- Completely coated tanks with high performance coating
- Partially coated tanks with cathodic protection
- Preconstruction primer with cathodic protection
- Soft coatings with cathodic protection

The initial report[1] published in 1982 demonstrated that, of the systems evaluated, the preconstruction primer with cathodic protection was the best performer, least expensive initially and least expensive over the 20 year economic life of the ship. After 3 years of testing, this system continues to be the best performer. Partial coating with cathodic protection have performed as well as complete coating and are more cost effective. Soft coatings with cathodic protection failed in the first 90 days and was discontinued.

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 conclusion, this project achieved all project goals. Identification was made of ballast tank corrosion protection approachs which are effective in mitigating corrosion and yet save both new construction and operating dollars.

[1]Benjamin S. Fultz, "Cathodic Protecon/Partial Coating verus Complete Coatings in Tanks," May 1982, A MarAd Sponsored Project.

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1. Conclusions

1.1 Project Results

The objective of this project was to evaluate the technical feasibility and economics of using a combination of cathodic protection and partial coatings in lieu of a complete coating of ballast tanks with high performance coatings. Based on the results of initial data collection concerning probable system performances, a test program was formulated and approved by SNAME Panel 023.1. The approved test program evaluated four corrosion control alternates. These were:

- 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 preconstruction primed plus cathodic protection

Both aluminum and zinc sacrificial anode systems were evaluated.

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

- Preconstruction primer with zinc anode is the best performer.
- Zinc anodes outperformed aluminum anodes.
- Partial coatings with cathodic protection provided adequate corrosion protection.
- All anodes exceeded calculated performance
- Soft coatings with cathodic protection failed after 90 days

Simultaneous with the original test program, a search was made to determine probable system performance based on historical data. Following the tank testing phase, cost data was also collected. The historical data, cost data and tank test results were then used to formulate a 20 year life cycle cost analysis.

The results of this analysis are as follows:

- Preconstruction primer with cathodic protection is the least costly alternate initially.
- Preconstruction primer and soft coatings (without cathodic protection) are the least expensive over twenty years
- Partial coatings with cathodic protection are less costly initially and at 20 years than the baseline, high performance approach.

In conclusion, both preconstruction. primer with cathodic protection and partial coatings with cathodic protection are viable, cost effective approaches to ballast tank corrosion protection.

1.2 Cost Savings

If the preconstruction primer with cathodic protection approach is selected over the high performance baseline system, approximately $150,000 can be saved in initial construction dollars and $270,000 in total life cycle cost. If partial coating with cathodic protection is selected in lieu of total coatings, at least $32,000 can be saved initially and $190,000 over twenty years.

1.3 Continued Research

The tank tests initiated as a part of this project should be continued for at least two additional years (5 year total) to verify the assumptions made in the economic analysis. Following an additional year of testing, a pilot test program should be initiated for ballast tanks on an actual ship.

2.   Project Plan of Action and Results

2.1   <u>Background Technical Information.</u>

The original study and test program published in May 1982 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 <u>High Performance Coating Systems</u>

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.   Tank 2, the tank which duplicates high performance coatings,generally supports this assumption.   This tank has 2 to 3% failure with no measurable metal loss.

2.1.2 <u>Partial Coating of Tanks Combined with Cathodic Protection</u>

Anode systems can 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 coatings have been 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 dry cycle, the coatings protect the high corrosion areas. Test Tanks numbers 1 and 3 duplicate partial coating of tanks.

The test program for partially coated tanks supports an anode life of at least eight years for aluminum anodes and ten years for zinc anodes.

2.1.3 <u>Preconstruction Primer Plus Cathodic Protection</u>

Many shipyards automatically abrasive blast and prime structural steel prior to fabrication. This primer is normally removed and replaced by a high performance tank coating system. If the tank coating could be eliminated and the preconstruction 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 preconstruction primer. Inorganic zinc primers provide the best shipbuilding handling and steel protection characteristics. One major limiting factor of cathodic protection can be tank geometry. In these cases, primers could actually compliment the cathodic protection system by protecting overheads, bottoms; and small pocket areas. This point has been substantiated by the test program.

2.2 <u>Tank Test Results</u>

To verify the relative performance of each proposed alternate and the compatibilities between the 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 2.1). Each tank was constructed to duplicate ship ballast tanks as concerns structure and configuration (See Figure 2.2). 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; i.e., surface preparation, coating system 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

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protection half cell potentials. A copper/copper sulfate half cell was used for all potential measurements (see Table III). Due to a delay in the test program, the tanks were dry for nine months after the first year; therefore, the actual ballast period is three years.
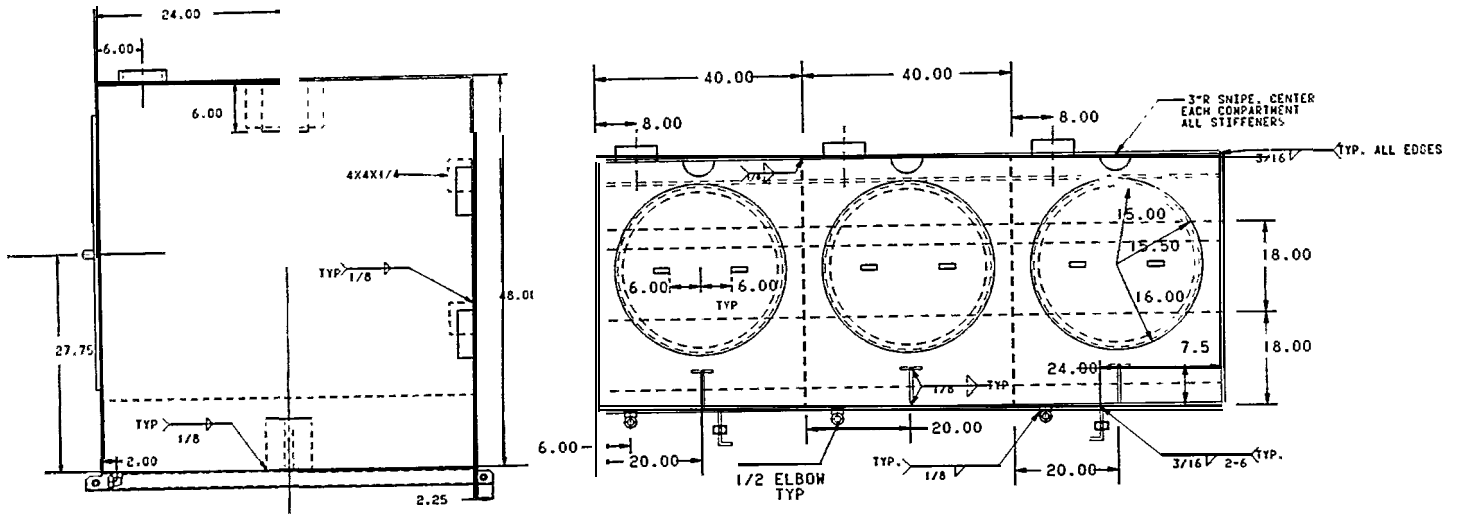

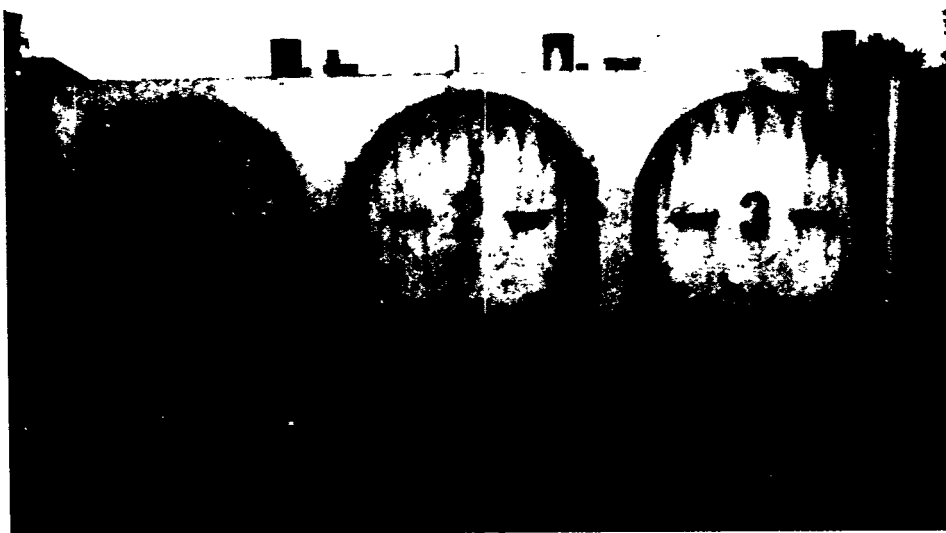Figure 2.2: Drawing Showing Details of Test Tank Assembly

Figure 2.1: Photograph of Test Tank Assembly

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2.2.1 Performance of Aluminum Anode with Partial Coatings

At the completion of the thirty-sixth ballast cycle, the entire uncoated area was rust colored. Removal of the calcareous deposit showed rust under the deposits. Where the deposit had delaminated, the area left exposed had rusted. See Figure 2.3. The aluminum anode was still providing sufficient potential to protect the steel. (-1.002v). 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. No significant amount of steel was lost in tank 1, even though there was some metal loss on the edges of structural members (See Table IV). No significant amount of rust scale was present. Most of the visible rust was moderate to light. The coating on the tank bottom seems to have lost resiliency and had number 6 dense blisters. The coating on the sides and top was still in good condition. This system continues to protect the tank steel.

2.2.2 Performance of Completely Coated Tank.

Figure 2.4 is a graphic representation of the performance of the paint system in Tank 2. The main failure points were in the weld areas and along the top o-f the roof flange. The overall breakdown of the coating was judged to be between 2 and 3% per-cent. There was no metal loss except for minor flange faces. The coating system continues to provide protection.

2.2.3 Performance of Zinc Anode with Partial Coatings

The color of the bare tank area was primarily the color of the calcareous deposit. See Figure 2.5. 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 Tank 3 was more dense and tenacious than that formed with the aluminum anode There was minimum coating failure amounting to no more than one percent. No metal loss was measured and the tank continues to be protected. No blisters in the tank bottom were detected. This system appears to be superior to the system in Tank 1 which uses an aluminum anode. The presence of blisters in the aluminum anode tank could be the result of excessive cathodic potential on the coating.

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2.2.4 <u>Aluminum Anode with Preconstruction Zinc Primer</u>

Early in the test cycle, the aluminum anode protected the zinc coating and even built up a calcareous deposit on bare welds and other damaged areas. At the end of the last cycle, the calcareous coating was gone. The low primer milage areas (damaged during fabrication) were rusting. The inorganic zinc coating was being depleted. See figure 2.6. The measured anode potential was still sufficient to protect the steel; however, the anode is almost depleted. Rust scale was visible on the overhead surfaces. No measurable metal loss. This system will probably not last for five years. The accelerated depletion of the anode could possibly be due to extra current requirements to protect the exposed zinc primer surface area.

Table I

<u>Corrosion Control Alternates Used In Tank Test</u>

Tank Number	Surface Preparation	Coating System	Film Thickness (MILS)	Anode Type
1	SP10	Two Coat Epoxy (MIL-P-23236) Partially coated - Top plus 6" down bulkheads and Bottom plus 6" up bulkhead.	6 - 10	Aluminum Alloy (Galvalum III)
	SP10	Two Coat Epoxy (MIL-P-23236) completely coated	6 .5-8.5	None
3	SP10	Same as Tank 1	6 - 9.5	Zinc (MIL-A-18001H)
4	SP10	Inorganic zinc preconstruction primer applied prior to fabrication	2.0	Aluminum (Galvalum III
5	SP10	Same as Tank 4	1.75-2.0	None
6	SP10	Same as Tank 4	1.8	Z i n c (MIL-A-18001H)

2.2.5 Performance of Preconstruction 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. See Figure 2.7.

2.2.6 Performance of Zinc Anodes with Preconstruction Primer

This continues to be the best performing system tested. A calcareous deposit formed on all the surfaces after the second cycle. These deposits were still present after thirty-six cycles. Figure 2.8 are photographs of this system. Note the deposits on the weld area. Minor corrosion is visible on the overhead area primarily due to air pockets.

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 (^{o}C)	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

Half Cell Potentials (Cu/CuSO$_4$)
(All Potentials Are Negative)

Tank Number	FIRST CYCLE 1HR	24HR	SECOND CYCLE	THIRD CYCLE	FIFTH-EIGHT CYCLE	TWELFTH CYCLE		Thirty-Sixth CYCLE
1	0.77	1.01	1.05	1.03	1.03	1.04	1.05	1.002
2	0.96	0.98	0.96	0.92	0.85	0.67	0.57	0.644
3	0.80	0.98	1.01	0.96	0.90	1.02	0.94	0.982
4	0.99	1.07	1.09	1.05	1.06	1.06	1.01	0.957
5	0.95	0.96	0.71	0.69	0.71	0.70	0.65	0.767
6	0.97	0.99	1.02	0.97	0.96	0.98	0.90	0.928

Table IV

Ultrasonic Steel Thickness Readings (Inches)

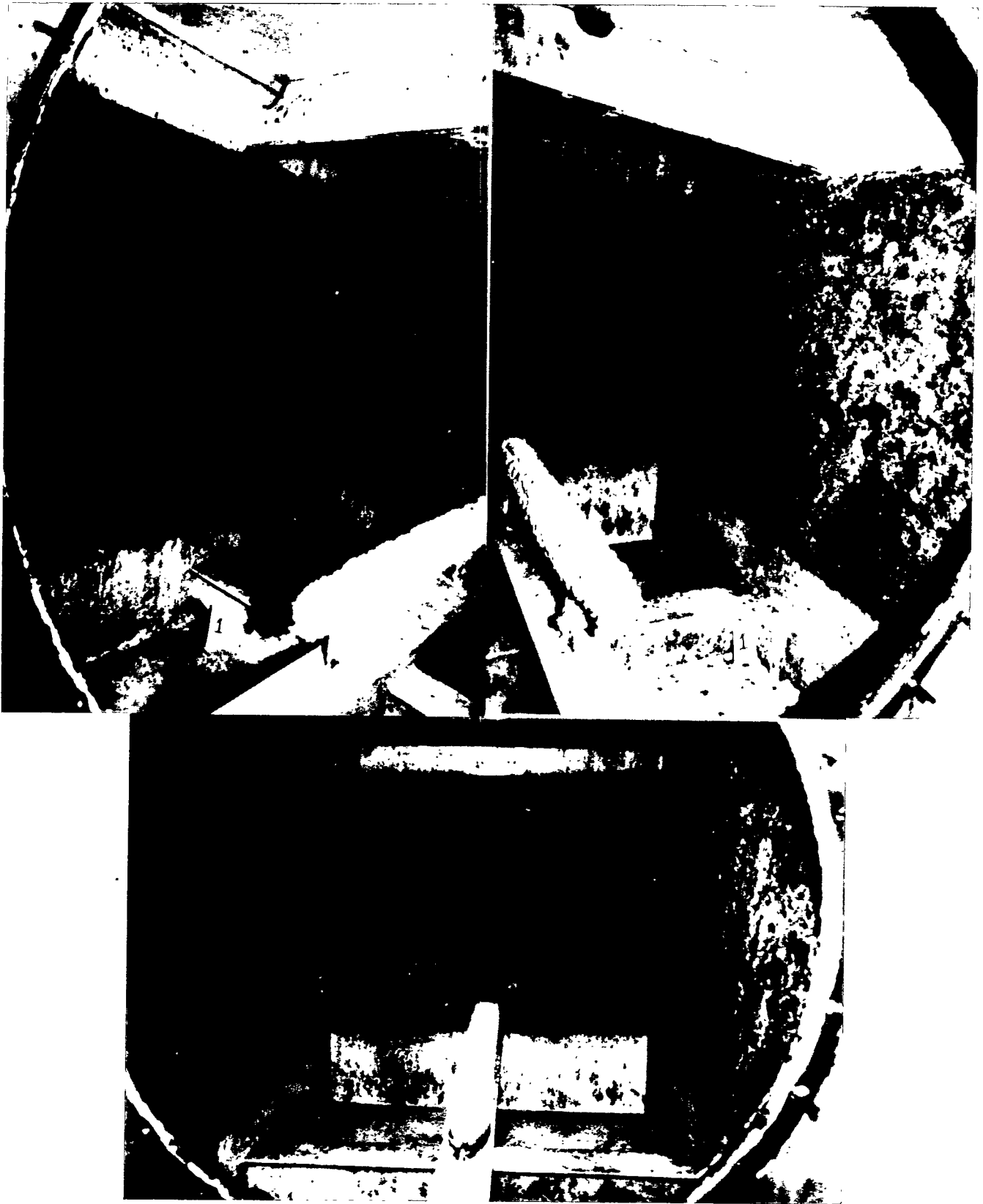| Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6
0.252	0.256	0.263	0.252	0.252	0.252
0.252	0.252	0.263	0.259	0.244	0.256
0.240	0.252	0.255	0.267	0.252	0.252
0.236	0.252	0.263	0.263	0.244	0.252
0.248	0.252	0.248	0.259	0.236	0.252
0.244	0.252	0.248	0.263	0.216	0.256
0.252	0.252	0.248	0.267	0.244	0.256
0.252	0.252	0.244	0.267	0.240	0.256
0.247	0.252	0.254	0.262	0.241	0.254 (Aver)

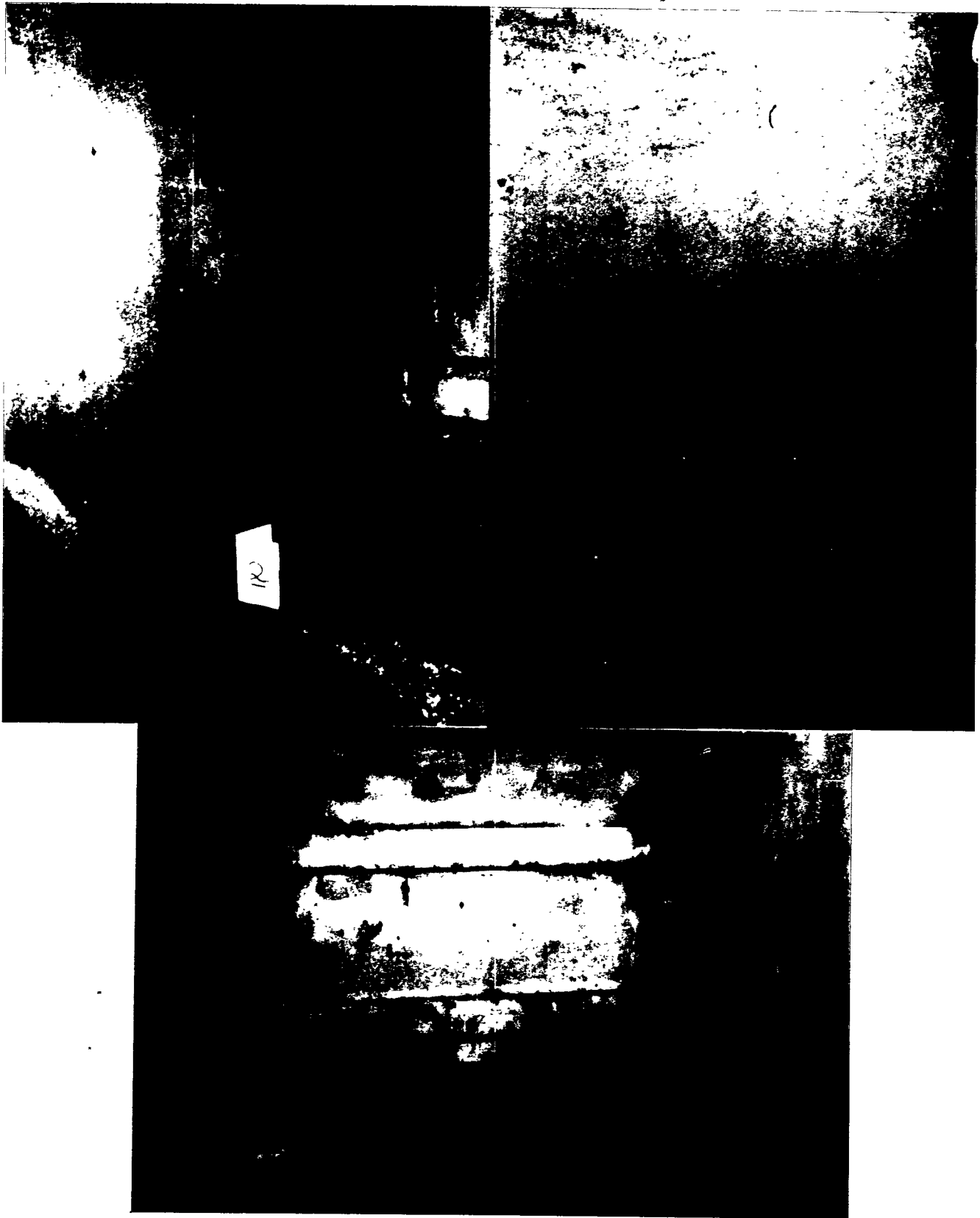Figure 2.3 Aluminum Anode/Partial Coating After Thirty-Six Cycles

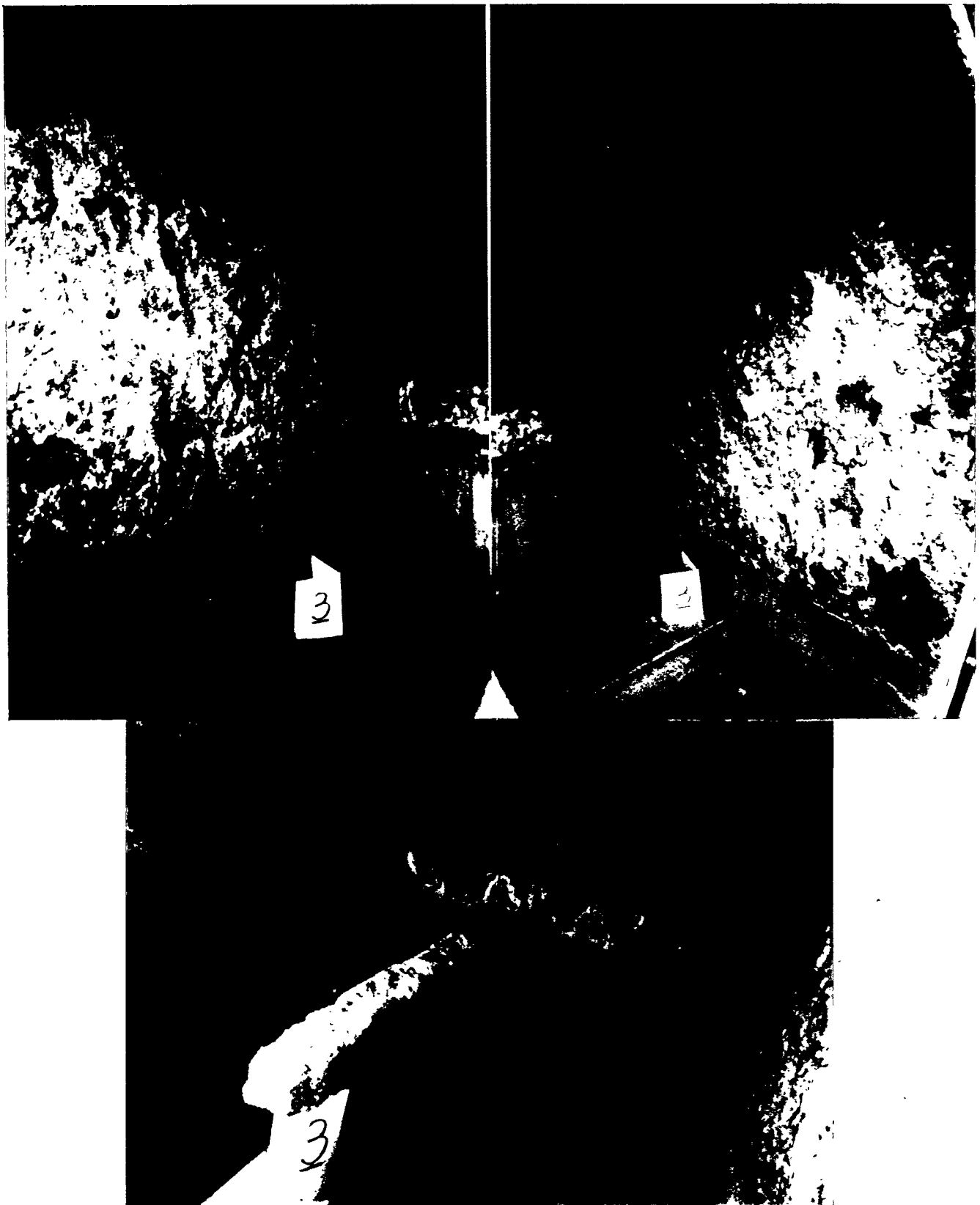Figure 2.4 High Performance Coating After Thirty-Six Cycles

Figure 2.5 Zinc Anode/Partial Coating After Thirty-Six Cycles

Figure 2.6 Zinc Primer/Aluminum Anode After Thirty-Six Cycles

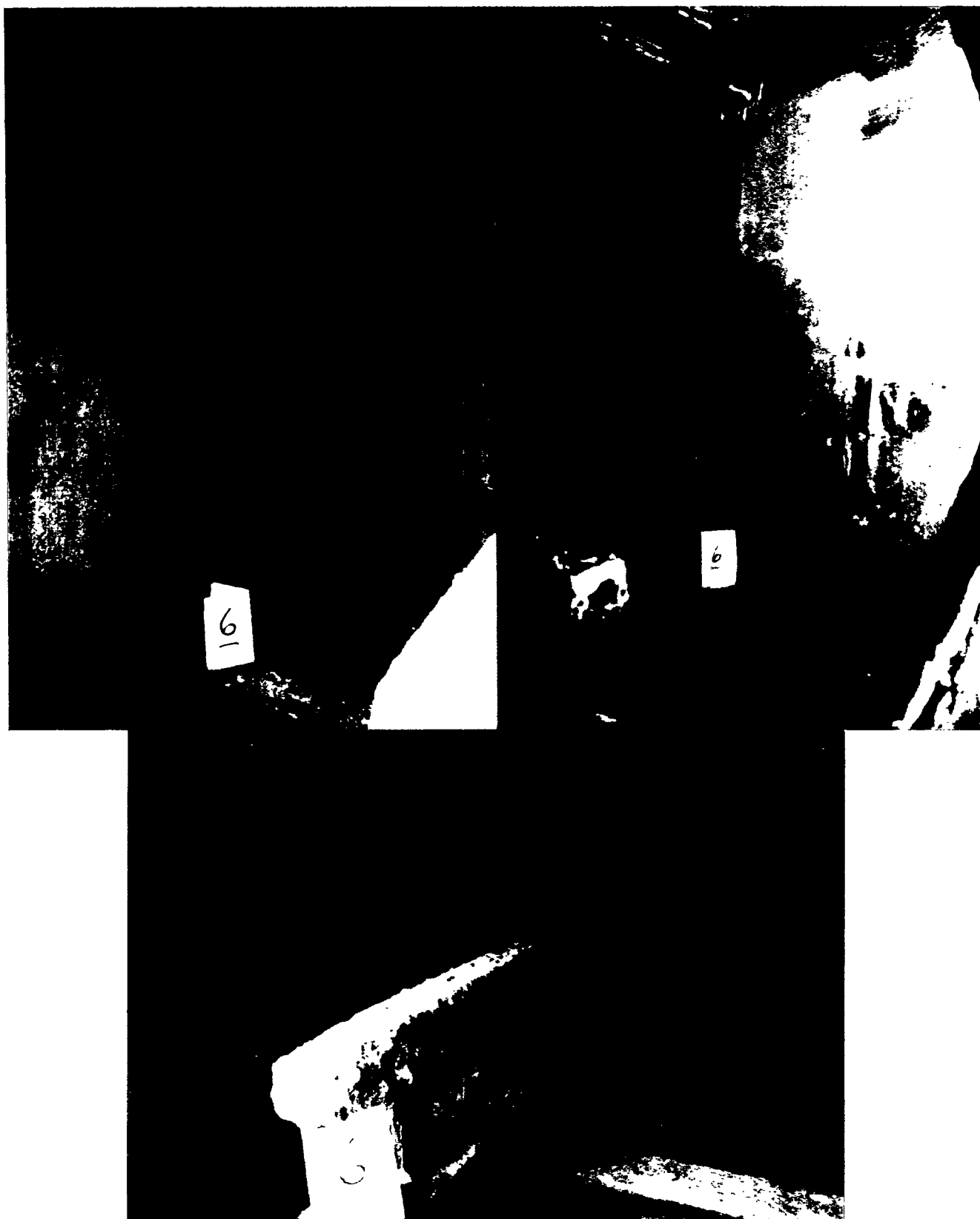Figure 2.7 Preconstruction Primer Only After Thirty-Six Cycles

Figure 2.8 Preconstruction Primer/Zinc Anode After Thirty-Six Cycles

2.3 Anode Performance

Prior to discussing actual anode performance, it is necessary to calculate anode requirements. Table V lists the basic design characteristics of the anodes used.

Table V
Basic Properties of Anodes in Sea Water

Anode Type	Current Capacity (Amp-Hr/Lb)	Consumption Rate (Lb/Amp-Yr)	Potential
Zinc (Mil-A-18001H)	372	23	-1.01
Aluminum (Galvalum III)	1150	7.6	-1.08

In addition, two other facts must be known. The first is the required current density to protect the steel in the intended service. For segregated ballast 14 milliamps for uncoated areas and 1 milliamp for coated areas are the generally accepted va- lues. The second is the sea water resistance which for the test was 26 to 29 ohms. The following equation can be used to calcu- late required anode weights:

$$W = \frac{A \times D \times F \times Y \times 8760}{I \times S \times 1000}$$

Where:
A = Surface area to be protected in ft^2
D = Required current density
F = Factor which represents percent immersion time as a decimal
Y = Design life in years (Usually 4)
I = Anode current capacity (Amp-Hr/Lb)
s = System efficiency (Normally 85%)
8760 represents the number of hours in a year

This equation gives the actual total weight of required anodes; however, a minimum number of anodes must also be calculated based on anode current output.

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The following examples will help to understand how the test anode requirements where calculated:

TANK 1- Aluminum Anode with Partial Coatings

Surface Area Coated = 63 ft^2
Surface Area Uncoated = 46 ft^2
Required Current Density
                              Coated Area = 1 milliamp/ft^2
                              Uncoated Area = 14 milliamps/ft^2
Immersion Factor = 0.6 (60% Ballast Time)
Design Life in Years = 4
System Efficiency = 0.85 (85% Efficient)
Anode Current Capacity = 1150 Amp-Hr/Lb (From Table V)

From the equation, the required anode weight can be calculated:

Where: $W_T = W_c + W_n$

W_c = Weight required for coated area

W_n = Weight required for uncoated area

$$W_c = \frac{63 \text{ ft}^2 \times 1 \text{ milliamp/ft}^2 \times 0.6 \times 4 \text{ Yr} \times 8760 \text{ Hr/Yr}}{1150 \text{ Amp-Hr/Lb} \times 1000 \text{ milliamps/amp} \times 0.85}$$

W_c = 1.35 Lbs

$$W_n = \frac{46 \text{ ft}^2 \times 14 \text{ milliamps/ft}^2 \times 0.6 \times 4 \text{ YR} \times .8760 \text{ Hrs/Yr}}{1150 \text{ Amp-Hr/Lb} \times 1000 \text{ milliamps/amp} \times 0.85}$$

W_n = 13.85

WT = 1.35 Lbs + 13.85 Lbs = 15.2 Lbs

Actual anode selected-for the test was a stock 20 Lb anode.

TANK 3- Zinc anode with partial coatings

$$w^t = W_c + W_n$$

$$W_c = \frac{63 \text{ ft}^2 \text{ x 1 milliamp/ft}^2 \, 0.6 \text{ x 4Yr x 8760 Hr/Yr}}{372 \text{ Amp-Hr/Lb x 1000 milliamps/Amp x 0.85}}$$

W_c = 4.19 Lbs

> NOTE: The only difference between this calculation and the one for aluminum is the anode current capacity (372 versus 1150).

$$W_n = \frac{46 \text{ ft}^2 \text{ x 14 milliamps/ft}^2 \, 0.6 \; 4 \text{ Yr x 8760 Hrs/Yr}}{372 \text{ Amp-Hr}\backslash\text{Lb x 1000 mil-liamp/Amp x 0.85}}$$

W_n = 42.82 Lbs

WT = 4.19 + 42.82 = 47.01 Lbs

One standard 50 Lb anode was selected.

Now that the anode requirements for each tank have been calculated, the same equation can be used to calculate projected annual anode consumption. This data can be compared to the actual measured weight loss of each anode used in the laboratory test place.
Table VI lists the calculated theoretical projected anode consumption rates for each tank plus the actual weight loss for each tank tested.

TABLE VI
Anode Performance Summary (12 months)

Tank Number	Anode Type	Theoretical Weight Loss at 100% Efficiency (lbs)*	Actual Weight Loss (lbs)
1	Aluminum (Galvalum III)	9.69	6.75
3	Zinc (MIL-A-18001H)	30.00	14.00
4	Aluminum (Galvalum III)	4.32	8.50
6	Zinc (MIL-A-18001H,)	13.41	9 . 5 0

*Assumes 15% damaged area.

Three conclusions can be drawn from the results contained in Table VI:

- All anodes performed better than projected

- Zinc anodes outperformed aluminum anodes

- Zinc anodes and inorganic zinc primer performed the best of all systems tested

- Aluminum anodes are suspect of causing blistering of epoxy coating in Tank 1

One probable explanation of the increased anode performance was the calcareous deposits formed on bare areas. Once formed, the anode demand decreased, therefore slowing consumption. Because the zinc anode created a calcareous deposit which was more dense and tenacious, less of the deposit was removed during ballasting. Again, reduced bare areas reduced anode consumption. Zinc anodes have also been reported in the literature as being more dependable and reliable than aluminum anodes. After two years of testing, the static test condition of the test tanks were questioned. The argument was presented that the calcareous deposit was not subjected to the erosion action of water movement in the tank due to ship roll during ocean movement. In an attempt to provide some duplication of the phenomenon, the tanks were opened at the end of each cycle and loose materials removed with a garden hose spray. No difference in performance was detected.

In the tank with inorganic zinc preconstruction primer with zinc anode, no detectable amount of zinc primer was depleted during the test with the exception of the area within an air pocket at the top of the tank. The weight loss of the zinc anode was such that the system would theoretically continue to protect for fifteen years with no anode replacement. The aluminum anode in the zinc primed tank probably exceeded the calculated theoretical consumption rate because the aluminum was actually depleting to protect the zinc which was at a lower potential. It is certainly within the realm of possibility that the zinc anode system would last for ten years as opposed to the normal four year life.

In summary, the zinc anodes outperformed the aluminum anodes

for the given test conditions. In all cases, the anodes performed better than the 85 percent projected efficiency.

2.4   Economic Analysis

2.4.1   Initial Construction Assumptions

The ship used as a model in this analysis was a 40,000 gross ton ship. The ballast tank surface area was assumed to be 150,000 total square feet. The detail manufacturing process varied with the corrosion control alternate; however, all steel shapes and plates were initially automatically abrasive blasted to remove mill scale. In the case of the preconstruction primer, this was applied by automatic means immediately following prefabrication blasting.

The first coat of the epoxy tank coating was applied in the sub-assembly configuration. The final coat of epoxy was applied after tank test. The soft coatings were applied after tank test. In all cases, the anodes were installed after all coatings applications were complete. These same procedures were followed for the tank coatings test program.

2.4.2   High Performance Coatings Assumptions

Complete coating of ballast tanks with high performance coatings is an industry standard and is therefore the baseline approach for the economic analysis. Two cases were assumed for the high performance coating system. These cases are based on actual corrosion control plans from two different ship owners.

The first plan consists of initially painting of the entire tank surface area with an epoxy tank coating system during the shipbuilding cycle. No maintenance is performed on the coating for ten years unless a major paint failure occurs. At the end of ten years, the entire coating system is removed and replaced. In the economic analysis, the primary case considered was renewal at 10 years; however, a sensitivity analysis was performed to show cost impact with renewal at eight years.

The second plan consists of initial coatings application as outlined in the first plan. The primary difference in this plan is that the shipowner maintains the coating at 5 year intervals with 2% replacement during the first five years, 5% replacement

during the second five years (l0-year total) and complete renewal
at 15 years.

2.4.3   Partial Coatings with Cathodic Protection

In this case, the uncoated area was assumed to be 50% of
the total surface area (75,000 sq. ft.). Using the proper equa-
tions, the calculated anode requirement was 1500 zinc anodes or
810 aluminum anodes. The ballast tanks were ballasted full 60%
of the time. The anode requirement was calculated based on
renewal at 4 year intervals. However, based on the test results
and case histories, the replacement cycle was extended to eight
years. The economic analysis considers both cases. No coatings
are renewed during the twenty year life cycle.

2.4.4   Preconstruction Primer with Zinc Anodes

As stated above, the preconstruction primer was applied
automatically prior to fabrication. No touch-up was performed
during construction. The primer was assumed to be inorganic
zinc. The amount of damaged area was assumed to be 15% of the
total surface area. Calculated anode requirements were based on
14 milliamps per square foot for damaged\bare areas and 1 mil-
liamp per square foot for primed areas. The total anode require-
ment was 1400 zinc anodes. Sixty percent ballast time was as-
sumed. No aluminum anodes were considered because of the results
of the tank test program. Four and eight year anode replacement
cycles were analyzed. The probable case was eight plus years
based on the test results. No coatings are to be replaced during
the life cycle.

2.4.5   General Assumptions

The following general assumptions were made:

- Twenty year economic ship life
- Escalation rate of 8 % per year
- Salvage value of ship not affected by protection system
- Anodes were priced at $35.00 each
- High performance coating was priced at $25.00 per gallon
  with a coverage of 100 ft^2 per gallon
- Preconstruction primer (inorganic zinc) was priced at
  $25.00 per gallon with a coverage of 300 .ft^2 per gallon
- Soft coating was priced at $10.00 per gallon with a

coverage of 65 ft^2 per gallon

- Blasting material was priced at $15-00 Per 200 ft^2 of surface area
- Initial installation of anodes was 1 manhour each
- At drydocking, installation of anodes was 1.5 manhours each
- Staging, ventilation and miscellaneous services were based on rate of 10% of blast, paint and anode installation manhours
- Rates for drydocking were approximately $0.50 per gross weight tons per day
- Rates for shore services was $500 per day
- Rate for lost revenue was $8000 per day
- Last rate revenues were only considered in those cases (4A, 4B and 4c) where work could not be completed in the normal 7 day out of service period.

2.4.6 Explanation of Economic Analysis Method

The cases were evaluated using Present Worth After Taxes (PWAT) as a measure of life cycle costs. Cases with lower PWAT are economically more desirable than cases with higher PWAT.

The analysis was developed using the Discounted Cash Flow (DCF) method. For each case, an estimate was made for the flow in each year for the 20 year life of the vessel. The values for each year were tabulated and added. Adjustments were made for tax savings due to depreciation and investment tax credit. A 46% Federal Income Tax rate was assumed and a 10% investment tax credit was used. Depreciation was based on the Accelerated Cost Recovery System (*ACRS) for 5 year property placed in service between 1981 and 1984. Net cash flows in each year were discounted to the first year using a 12% discount rate. (The first year was not discounted.) The discounted values were then algebraically summed to curve at the PWAT for each case.

2.4.7 Results of Analysis

The original study contains computer printouts of the results of each economic case. Sensitivity analysis were performed on some data to show impact. Tables VII and VIII contain summaries of the analysis.

Table VII

Summary of Economic Analysis

Alternate	Case No.	Coating Replacement (YRS)	Anode Replacement (YRS)	First Year	Twentieth Year (Total)
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	1D	NONE	8	321,597	349,539
Preconstruction* Primer-Zinc Anode	2A	NONE	8	258,441	377,944
Preconstruction Primer-Zinc Anode	2B	NONE	4	258,441	623,092

*Substantiated by historical and test data.

As can be seen from Table VII, the preconstruction primer with zinc anodes replaced at eight year intervals (Case 2A) is the least expensive initial cost system. This is also the best system performer in the tank tests. There is a substantial cost difference between the preconstruction primer system and the standard two coat epoxy systems. Taking a worst case, namely anode replacement at 4 year intervals, the preconstruction primer approach (Case 2B) is still less costly over twenty years than either complete coatings approach.

Partial coatings and cathodic protection with anode replacement at eight years (Cases 1C and 1D) are also less costly than complete coatings systems. Even if the anode replacement cycle is reduced to 4 years (Cases 1A and 1B), the cost is comparable to completely coated tanks. If complete coating systems are replaced at intervals shorter than 10 years, such as shown in Case 4A, the partial coatings cathodic protection approach is even more cost effective.

In conclusion, the preconstruction primer and partial coatings systems supplemented with cathodic protection are viable, cost effective corrosion control alternatives for ballast tanks.

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

Alternate	First Year (Initial)	Twentieth" Year (Total)
Preconstruction Zinc Primer with zinc anodes replaced at 8 year intervals	$258,441	$377,944
Partial Coatings with zinc anodes replaced at 8 year intervals	$376,443	$465,415
High Performance Coating No maintenance replaced at 10 years	$408,852	$654,000
High Performance Coating with maintenance replaced at 15 years	$408,852	$824,653