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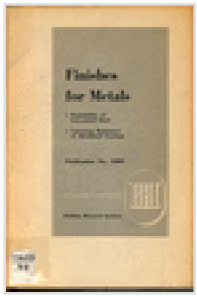

Finishes for Metals: Paintability of Galvanized Steel, Corrosion Resistance of Metallized Coatings (1963)

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Finishes for Metals

- Paintability of Galvanized Steel
- Corrosion Resistance of Metallized Coatings

Publication No. 1005

Report of a program
held as part of the
BRI 1962 Fall Conferences

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FINISHES FOR METALS

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The Building Research Institute gratefully acknowledges the contributions to building science made by the participants in this program.

MILTON C. COON, JR.
Executive Vice President

Contents

Report of the AISI Research Project on Paintability of Galvanized Steel

By Joseph Bigos, U. S. Steel Corporation; Harold H. Greene, Republic Steel Corporation; and George R. Hoover, Armco Steel Corporation

Abstract: This project was aimed at determining the best procedures for painting bright-spangled, galvanized sheet steel products using three classes of trade-sales paints: metallic zinc-dust, portland cement-in-oil, and proprietary products including water-base emulsion paints. Galvanized steel chemically treated to prevent wet-storage stain, as well as untreated galvanized steel, was tested. Test panels were exposed in three atmospheric environments. The results show that satisfactory paint adhesion can be obtained on both treated and untreated galvanized steel if suitable paints are used. The effect of chemical treatment of the steel was negligible.

THE USE OF VAST QUANTITIES of galvanized steel in the building industry has recently led to an increase in the number of painting failures encountered. The problems associated with the painting of galvanized steel have been long recognized (3, pp. 429-430) and sound recommendations for painting are available (1, p. 12; 4, p. 683). Most of this paint failure occurs as peeling of conventional paints on homes, small buildings, or bright-spangled, chemically treated galvanized steel products painted by the home owner, custodian, farmer, or local painter. This led to a joint research effort by the steel industry to determine proper painting procedures for galvanized steel products using locally available paints. The cooperative research work reported here was sponsored and directed by the Committee of Galvanized Sheet Producers of the American Iron and Steel Institute. The Steel Structures Painting Council, Mellon Institute, Pittsburgh, Pennsylvania, also participated in the test.

CHARACTERISTICS OF GALVANIZED STEEL

A review of the characteristics and behavior of galvanized steel will promote understanding of the research program. Galvanized

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BIGOS, JOSEPH. Head, Organic Coatings Section, Applied Research Laboratory, U. S. Steel Corporation; member, American Chemical Society, ASTM, National Association of Corrosion Engineers, BRI. GREENE, HAROLD H. Republic Steel Corporation. HOOVER, G. R. Supervising Research Metallurgist, Chemical Research Department, Research and Technology, Armco Steel Corporation; member, BRI.

sheets are made by passing specially cleaned steel through a bath of molten zinc. Zinc is used because it is an excellent and economical protective coating. It is the least expensive way of protecting the base steel against corrosion. The resulting galvanized sheet offers great strength and rigidity at low cost.

The coating of zinc results in a bright, spangled appearance, but as do other metals, it corrodes and stains when in contact with water for an extended period of time. If moisture is permitted to remain between the surfaces of a bundle of galvanized sheets, laps of coils, or nested fabricated objects during storage, a white discoloration known as wet-storage stain may develop. The white discoloration is a mixture of basic carbonates of zinc and zinc oxides or hydroxides, which probably results when electrochemical corrosion of the zinc takes place because of variations in humidity, water films, and oxygen concentration at different areas of the surface with the subsequent formation of anodic and cathodic areas and development of zinc hydroxides at the anodic areas.

These hydroxides react chemically with carbon dioxide in the air to form the white corrosion products referred to as wet- or humid-storage stain. The stain is usually superficial and does not impair the protective properties of the zinc coating, but the appearance may be unsatisfactory and the steel may require painting for this reason. Prolonged exposure to entrapped moisture may cause localized damage to the zinc coating, and painting may be required to prevent corrosion of the base steel. Galvanized sheets or products should be kept dry at a uniform temperature until bundles are opened and the steel is installed and exposed to the weather.

It is standard practice in the steel industry to chemically treat galvanized sheets during manufacture in order to minimize wet-storage staining during storage or shipment. Unfortunately, the chemical treatments that stabilize the surface have a detrimental effect on the adhesion of the trade-sales paints (paints that are manufactured for the retail trade) normally used on houses, other buildings, and farms. Zinc surfaces, if they are not chemically treated, are difficult to paint because new zinc reacts with ordinary paints and causes peeling and flaking. The exact reason for this failure is not known, but it has been surmised that there is a reaction between the zinc and the oil vehicle at the interface. This explanation, however, does not explain the failure of non-saponifiable vehicles.

When galvanized steel is exposed to the weather, the appearance of the bright, smooth zinc surface darkens and becomes dull. This change in appearance, which is accompanied by a roughening of the surface, is due to a reaction of the zinc with the atmosphere which creates a protective layer. This surface layer greatly slows further change in the character of the zinc and results in long life for the galvanized sheet. At the same time, any chemical treatment weathers away and better paintability results. If paint is applied over this weathered surface, the reactive zinc is insulated from the paint, the surface is roughened for better paint adhesion, and the paint adheres better to the metal. Weathering will make all types of paint perform better on galvanized steel, whether the galvanized steel is chemically treated to prevent staining or not.

Caution is necessary when special treatments, instead of weathering, are used to make the paint adhere. The "home cure" type of treatments such as washing the surface with vinegar, acetic acid, cider, copper sulfate solution, muriatic acid, or hydrochloric acid have been proved to be useless, or even harmful.

PAINT PRETREATMENTS

There are special pretreatments that may be used to improve the paintability of bright-spangled, galvanized steel. Special cold phosphate treatments are available as proprietary products from chemical suppliers. U. S. Military Specification MIL-C-10578A, "Compound, Metal Conditioner and Rust Remover," and Steel Structures Painting Council Pretreatment Specification SSPC PT2-53T, "Cold Phosphate Surface Treatment," may be obtained, but their effect is not outstanding, particularly if the surface is stabilized by chemical treatment to prevent staining.

Hot phosphate treatments of the "bonderizing" type, which convert the surface to zinc phosphate, are extremely good, and are widely used in production finishes. U. S. Military Specification MIL-C-490A, "Cleaning and Preparation of Ferrous and Zinc Coated Surfaces for Organic Protective Coatings," and Steel Structures Painting Council Pretreatment Specification SSPC-PT4-53T "Hot Phosphate Surface Treatment," are available. There is also an ASTM proposed specification, "Tentative Methods of Preparation of Zinc-Coated Steel Surfaces for Painting," covering the pretreatments available for galvanized steel. These treatments are ineffective if the surface has been chemically treated.

Another type of treatment is called a "wash primer." This material can be purchased from industrial paint suppliers, or directly from some paint manufacturers. It is mixed with phosphoric acid and applied like a very thin coat of paint, and if used freshly mixed it gives good results. This treatment is described in Steel Structures Painting Council Pretreatment Specification SSPC-PT3-53T, "Basic Zinc Chromate Vinyl - Vinyl Butyral Washcoat."

Because of the well-known difficulties involved in getting satisfactory paint adhesion on new galvanized steel, whether it is chemically treated to prevent staining or untreated, some producers make galvanized steel sheets that are mill-phosphatized and ready for immediate painting. These sheets combine all the good features of galvanized steel plus extremely good paint-holding qualities. They greatly improve the life of any paint applied on them. These sheets are supplied on special order only. They are recognizable by their dull surface, which is marked with a white streak when scratched by a fingernail. If these sheets become oily or greasy, the surface should be cleaned with mineral spirits, paint thinner, or naphtha. Fingerprints should be removed by using a 50% mixture of one of the above thinners in combination with alcohol.

Galvannealed sheets are produced by heating the zinc coating during production. This creates a dull gray alloy surface that is free of the typical spangles. These surfaces can be painted without any special treatment; oil, grease, or fingerprints can be removed by the methods mentioned above. These sheets, too, are supplied only on special order.

Unfortunately, the preceding special paint pretreatments or galvanized sheets with good paintability are used only on special or large installations, or for products that are finished by the manufacturer, such as prepainted galvanized steel windows, sheets or siding, or gutters and downspouts. The average builder, home owner, or farmer has the problem of painting bright-spangled galvanized steel that was selected because of its economy, and this material is normally chemically treated at the mill. The use of conventional house paints or metal paints applied under such circumstances occasionally results in considerable peeling of the paint unless proper paints are used.

THE AISI RESEARCH PROGRAM

When the AISI Committee of Galvanized Sheet Producers undertook the problem of painting with locally available, trade-sales paints, the technical painting experience of the various steel companies was utilized to outline the existing knowledge and the recognized problems. A research project was then designed to establish the best procedure for painting galvanized steel.

Committee members agreed that paints perform better on ordinary galvanized sheets, whether treated or not, if they are allowed to weather before being painted. Six months is generally adequate, and even less time may be necessary if the weather is very wet. In dry climates, or during prolonged periods of little rainfall, greater time is needed for adequate weathering.

Weathering may be continued for years without harm if there is no necessity to paint. When painting is postponed, greater economy is achieved, since the zinc is allowed to perform its normal function of protecting the steel base. Maximum life of the sheets at minimum coat is obtained if the sheets are painted just before red rusting of the steel begins to appear, or at the first sign of red rust on the face of the steel. Painting up to and at this stage utilizes the remaining zinc as part of the protective coating and greatly reduces paint requirements.

Since natural weathering is usually impractical for builders, other procedures are required for painting new galvanized steel. The effect of the chemical treatment on paint life immediately becomes of paramount interest.

Investigation has revealed that all successful chemical treatments which inhibit humid-storage stain of galvanized steel use hexavalent chromium in solution as chromic acid, chromate or dichromate, or other chromium salts. The effectiveness of chemical treatment in preventing humid-storage stain appears to be proportional to the amount of residual chromium on the surface. The Committee observed that only three generic types of chemical treatment are in commercial use on galvanized steel sheets produced in the United States, although minor variations within these three processes are used to some extent. These treatments may be classified as waterglass-dichromate, in which a solution of sodium silicate and sodium dichromate is used according to U. S. Patent No. 2,665,232; chromic acid, in which the sheets are treated with a solution of chromic acid according to U. S. Patent No. 2,784,122; and a proprietary chromate-containing solution, according to U. S. Patent No. 2,851,386. All these treatments result in a more stable surface that becomes increasingly hydrophobic upon aging. These treatment films are extremely difficult to remove, and mechanical abrasion or very strong cleaners must be used. Weathering will, however, remove the treatment films over a period of time.

The presence of treatment film may be detected by using a diphenyl carbazide spot test,[1] which shows a pink color in the presence of hexavalent chromium. Another method is to compare the immediate rate of plating out of copper from an acidified copper sulfate solution with the rate for untreated galvanized steel.

The preceding factors required that the research program establish the effect of chemical treatment on the paintability of galvanized steel. Since only three chemical treatments were in use, three steel suppliers, each using a different treatment, were selected. A corollary, but minor, objective that developed was to establish the effect of weathering on the removal of chemical treatment, and consequently on the paintability of the steel.

Previous experience had showed that zinc-dust paints can be used successfully on galvanized steel. Well-documented results of service tests of zinc-dust paints are available (2,5). These tests also authenticate the beneficial effect of prolonged weathering of galvanized steel on paint life. These zinc-dust paints generally contain about 80% zinc dust and 20% zinc oxide by weight in the pigment, but this ratio may be modified somewhat to change the color.

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[1] Dissolve 0.5 gram of 1-5 diphenyl carbohydrazide in solvent mixture consisting of 20 ml acetone and 20 ml of 95% ethanol by using a warm (120° F) water bath if necessary. Add diluted phosphoric acid consisting of 20 ml H_2O and 20 ml of phosphoric acid. Drop on surface to be tested; a pink to purple color developed indicates chromate anion. Test solution is heat- and light-sensitive and must be discarded when it discolors.

The vehicles are generally drying oils or alkyd varnishes, although phenolic varnish vehicles are used for water immersion or wet surroundings. Typical formulations are shown below:

Federal Specification TT-P-641b, Primer, Paint, Zinc Dust-Zinc Oxide

Type I Oil Base	Type II Alkyd	Type II Phenolic
Pigment, 80%	Pigment, 63.5%	Pigment, 65.5%
Zinc dust 80%	Zinc dust 80%	Zinc dust 80%
Zinc oxide 20%	Zinc oxide 20%	Zinc oxide 20%
Vehicle 20%	Vehicle 36.5%	Vehicle 34.5%
Raw linseed oil 90%	Alkyd resin solids 43%	Phenolic varnish solids 50%
Thinner and drier 10%	Thinner and drier 57%	Thinner and drier 50%

Recent commercial experience and research tests conducted by the steel companies showed that portland cement-in-oil paints provided good service on galvanized steel. These paints are unusual, since they incorporate portland cement as part of the pigment. These paints will be referred to as cement-base paints in this report, and it should be noted that these paints are completely different from cement-base water paints, which are not included. The composition of these paints varies considerably. The typical formulation ranges shown below do not indicate water additions, which are believed critical in obtaining optimum properties:

Pigment 60%	
Titanium dioxide, white lead or similar	15 to 20%
Zinc oxide	20 to 30%
Extenders	10 to 40%
Portland cement	5 to 40%
Vehicle 40%	
Drying oils, resins	60%
Volatile	40%

Some proprietary paints give good service on galvanized steel. These paints have been developed as specialty items by certain paint companies and usually their formulation or reason for good performance is not known. However, certain water-base proprietary paints have been developed recently that are based on latex emulsions, both polyvinyl acetate and acrylic.

PROJECT OBJECTIVES

On the basis of the foregoing studies, this research project included the evaluation of three classes of paint as a major objective of the test. These classes were zinc-dust paints, cement-base paints, and proprietary paints; under proprietary paints, a subclass of latex-base paints was included. A natural outgrowth of this objective was to compare various paints in each of the classes. To determine the effectiveness of the generic classification of paint, another major objective included the evaluation of as many paints in each of the different classes as practical. Each participating laboratory agreed to select 18 paints, six per class and include these in the test. The three steel companies, selected to participate in the program because their chemical treatments were representative, all participated in the paintability test; therefore, a total of 54 paints was proposed for evaluation.

Another major objective was to determine the variation in paintability of galvanized steels. Galvanized sheet steel meeting the requirements of ASTM Specification A93-59T, with 1.25 oz. of zinc per sq. ft., was selected as representative of almost all steel used in buildings. Untreated galvanized steel from each supplier was included in the program to determine the average performance of plain galvanized steel.

The major variations that might occur because of methods of application or differences in environmental exposure were determined by having three laboratories participate; each would use its own painting procedures, would include all the steel variations, and would expose the painted specimens at its laboratory test site. These sites, which included atmospheric exposures from suburban to industrial, were at Pittsburgh, Pennsylvania; Cleveland, Ohio; and Middletown, Ohio.

To minimize possible error due to variability in steel, chemical treatment, and application, the painted specimens were to be prepared in triplicate.

The design of the experiment is shown in Table 1 (p. 19). The major variables are indicated and the plan includes a total of 972 painted specimens. This amount does not include several hundred specimens used in corollary tests. Briefly, the main plan consists of an evaluation of three chemical treatments times two levels of treatment (treated and untreated) times three classes of paint times six paints per each class times three laboratories (exposure sites) times three replicates.

A setup for possible analysis of variance is also shown in Table 1 where the degrees of freedom for the main variances and first-order interactions are tabulated. Because of the small likelihood of complicated interactions, those beyond the first order are not listed, but the design of the experiment would show any such complicated interactions that would occur. There are 14 degrees of freedom between the main variances and 91 in the first-order interactions, which leaves 880 degrees of freedom for the determination of error. As a result, the accuracy of the findings should be very high, even though the design of the test was modified very slightly.

Minor objectives of the test, such as effectiveness of weathering, were included by one laboratory in both the treated and untreated condition. The effect of one coat versus two coats of paint was included, again by one laboratory. Another laboratory determined the repainting characteristics by applying one and two white-finish coats on panels that had been exposed for one year.

PREPARATION AND EXPOSURE OF PANELS

In conducting the test, the three steel companies selected (Armco, Republic, and U. S. Steel) each supplied 4 by 6 in. panels of untreated galvanized steel, as well as galvanized steel which was chemically treated by its own particular method. These panels were used in tests by the three respective research laboratories. These panels were 22, 24, 26, and 28 gage and were cut from galvanized steel sheets selected at random from representative routine production on commercial, continuous galvanizing lines. The panels in each group were randomized to minimize any normal variations in the steel samples. The three suppliers of steel were coded X, Y, and Z since one purpose of the study was to compare chemically treated galvanized steel with untreated; not to compare companies.

Each laboratory selected its own paints from trade-sales sources, but slight variations from the proposed plan occurred. Armco added two extra paints to the proprietary class for a total of 20 paints. Republic later learned that one of the proprietary paints they used was a cement-base paint, and therefore, put it into the cement-base group. Armco could not find two suitable latex paints and only used one in the proprietary class, but Republic found three proprietary latex paints and included them. As a result, 56 paints were used by the three laboratories; these paints are listed in Table 2 (p. 20). For obvious reasons, brand names and numbers have been withheld, but as much information as is available is given in the table so that comparable paints may be chosen on the basis of this test. Since nine of the paints were selected by two laboratories, 47 different paints were used in the evaluation. The nine duplications in the paints provided an excellent opportunity to check the agreement between the different laboratory applications and exposures.

The 4 by 6 in. panels of continuously galvanized steel, meeting ASTM Specification A93-T, with standard 1.25 oz. per sq. ft. coating weight of zinc, were prepared for painting at the research laboratories of the three steel companies in accordance with the proposed ASTM Standard Method of Preparation of Hot Dipped Nonpassivated Galvanized Steel Panels for Testing Paint, Varnish, Lacquer, and Related Products. Painting and exposure of panels

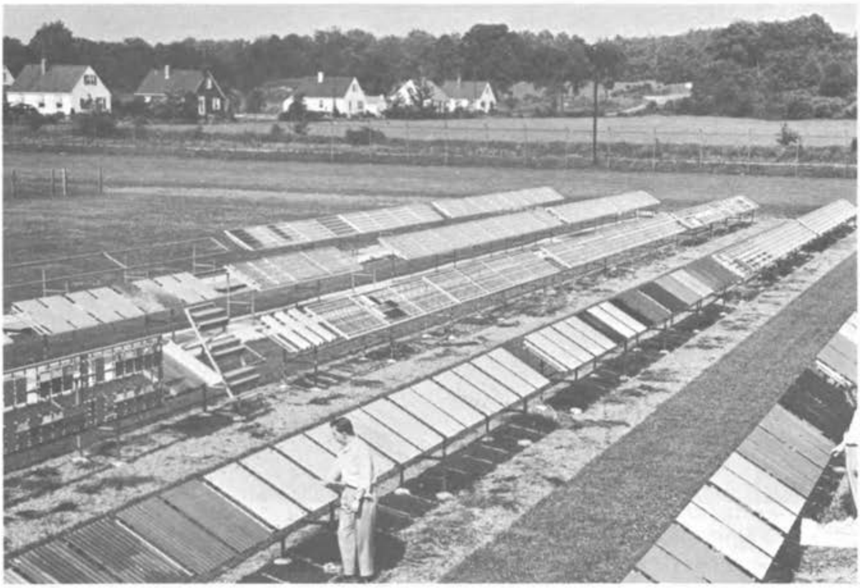

Figure 1 -- Armco Steel Corporation exposure site in Middletown, Ohio.

were conducted in general accordance with ASTM Specifications D1014-51 except as noted hereafter. The Armco Laboratory painted its series of panels by spraying the panels to a normal dry-film thickness and exposing the air-dried panels at 30° from the horizontal facing south at Middletown, Ohio, in an industrial exposure, as shown in Figure 1; at the end of one year, portions of the panels were painted by brush with one and with two coats of a white, oil-base house paint to determine repaintability. Dry film thickness of the primers is shown in Table 2. The Republic Laboratory painted its series of test panels by spraying the panels to a 1.5-mil dry-film thickness and exposing the air-dried panels at 30° from the horizontal facing south at its exposure site outside Cleveland, Ohio, in a surburban atmosphere. The panel size and mounting are shown in Figure 2.

Prior to painting, U. S. Steel exposed a series of chemically treated panels and untreated galvanized steel panels outdoors to determine the effect of weathering. The period of time required to completely remove the chemical treatment was found by checking the surface with the diphenylcarbazide spot test until all traces of chromate residues disappeared. U. S. Steel's Applied Research Laboratory painted its panels completely with one coat of paint

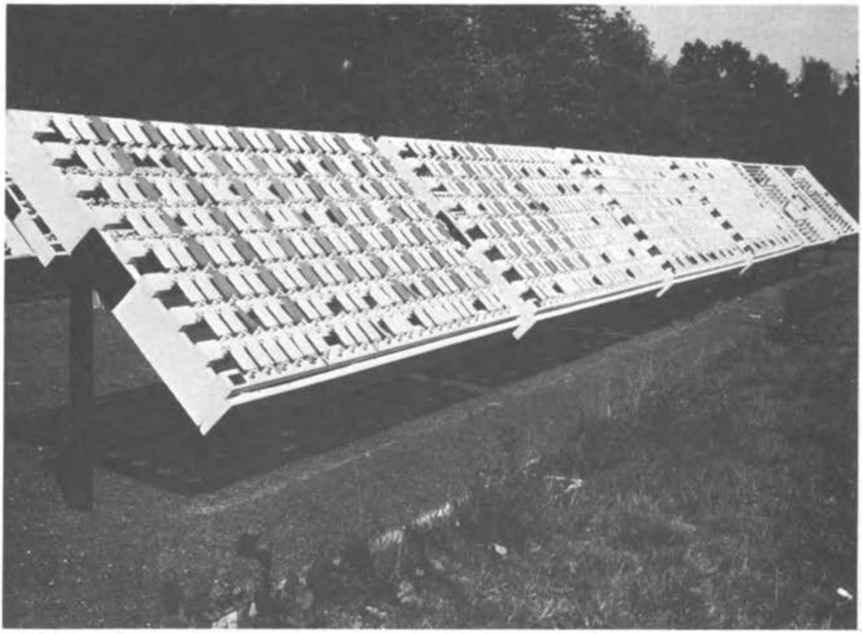

Figure 2 -- Panels on exposure at Republic Steel Corporation exposure site outside Cleveland, Ohio.

by brush to a normal film thickness for each paint; thicknesses are shown in Table 2. After air drying, the top half of each panel was painted with a second coat of the same paint to determine the effect of one coat versus two coats. After air drying, the panels were exposed at Monroeville, Pennsylvania (near Pittsburgh), at an angle of 30° from the horizontal, facing south, in a semi-industrial atmosphere.

All paints were applied in accordance with the manufacturers' directions. Some of the cement-base paints required the addition of a small amount of water prior to painting, while other cement-base paints had water added to the paint by the manufacturer. Some of the latex paints wetted the surfaces of the panels only with great difficulty and required repeated brushing out. The adhesion of some of the latex paints was extremely poor for a period of days or weeks after application, and some of these paints could, in fact, be peeled from the surface as an intact film. However, these paints, as a class, developed extremely good adhesion on prolonged exposure to the weather.

The painted panels were first exposed outdoors in the summer of 1960. Joint inspections and ratings of the panels were made about every six months until the panels had been exposed for two years.

The steel companies had planned to determine paintability by rating the panels for peeling of the paints, since this is the type of failure that occurs in service in six months to a year, or more, if

Figure 3 -- Knife adhesion testing of paint on panels exposed at the U. S. Steel Corporation site outside Pittsburgh, Pennsylvania.

such failure does occur. However, the rating procedures were modified because of the extremely good over-all performance of the paints, of which only a few peeled slightly. Judgments of paintability were therefore based upon the much more severe criteria of knife adhesion, and the resistance of the paint to physical removal by scraping and cutting with a sharp knife was rated on a scale of 0 to 10. The method of testing is shown in Figure 3. A rating of 10 represents excellent to almost perfect knife adhesion. In such a case the paint is extremely difficult to remove. A paint that has almost no resistance to removal by knife or that peels by itself is rated 0 and is a complete failure. Other steps on the scale are: 8, very good; 6, good; 4, fair; and 2, poor.

RESULTS OF PAINTABILITY TESTS

The average final ratings of each inspection for the replicated specimens, after two years outdoor exposure, are shown in Table 3 (p. 22). Ratings for individual panels are not shown because there was almost no difference between the replicates. Uniformity of results (replicability) is therefore considered excellent.

There was a high degree of agreement among the six inspectors, of whom five were from the three steel company laboratories and one from the Steel Structures Painting Council, except in the cases of several panels where the paint film itself had deteriorated. For paint U6 in the U. S. Steel laboratory exposure, the paint had deteriorated so badly on all specimens because of improper formulation or manufacture that it was difficult to grade adhesion. One inspector arbitrarily graded this paint 0 and this rating was eliminated from the averages because it was considered too erratic, and therefore obviously in error. In several other instances deterioration of the paint made it difficult to assess adhesion, but all ratings were used, and the average or mean grade is regarded as a fair assessment of the adhesion.

The average ratings of the inspection team for each group of replicates are tabulated in Table 4 to simplify analysis of the results. The effects of the main variables in the test are shown in Tables 5 through 7. (See pages 28 to 33 for Tables 4-7.)

The average grades for the different classes of paint are shown in Table 5. The zinc-dust paints performed best with the extremely high over-all average grade of 9.6 compared with a perfect rating of 10. All the one-coat zinc-dust paints performed well and no difficulty was encountered with them. The zinc-dust paints were primarily oil-base and alkyd-type paints that generally comply with Federal Specification TT-P-641b, Types I or II. One was a phenolic varnish vehicle paint, but none of the paints were of the zinc-rich type.

The cement-base paints also performed extremely well as a class, with an average over-all grade of 8.9 compared with 9.6 for the zinc-dust paints. The reduction in over-all average grade for this group was caused by two paints, the film properties of which deteriorated considerably during the 2-year exposure.

As a class, the proprietary paints rated very good, the over-all average grade being 7.5. Here again, two of the paints which failed to give satisfactory performance lowered the average of the group. The performance of the subgroup of latex-base paints, especially formulated for galvanized steel, was excellent, the average rating being 9.2.

A comparison of the differences between laboratories, from the over-all averages in Table 5, shows good agreement in the results obtained in the different laboratories despite the differences in application and exposure. The U. S. Steel laboratory average is slightly lower than that of the other two laboratories because it made an inadvertent selection of two extremely poor proprietary paints. Otherwise, agreement is extremely good. This indicates that the differences in the exposure environments did not affect paintability.

The greatest variations in the test occured among the various brands of paints. Table 6 presents a summary of the average ratings for the individual brands of paints. These range from 0.4 to 10, with an over-all mean rating of 8.67, an indication that, despite several poor performances, most of the paints rated very good or excellent. The individual zinc-dust paints performed excellently as previously stated; however, in an evaluation of two coats of paint in the U. S. Steel test, the second coat of zinc-dust paint U10 blistered slightly over the first coat.

The cement-base paints had somewhat poorer film properties than those of the zinc-dust paints. This was indicated by a tendency on the part of some of them to chalk or become brittle. Three cement-base paints -- A9, U4, and U5 -- showed paint-film deficiencies; one of these, U5, is the same paint as A15 in the Armco proprietary class and there it showed the same film deficiencies. The variation in performance of these paints indicates the importance of proper formulation and manufacture of the cement-base paints.

The proprietary paints showed the widest variation in performances. These paints had been selected because they were advertised for use on galvanized steel, or because the paint manufacturer recommended them for this use. Some of these were excellent. The latex-base paints were generally excellent, but must be used with caution for reasons to be explained later. Several of the proprietary paints probably contain portland cement. Paint U18 performed very poorly and is completely unsatisfactory for galvanized steel despite the claims of the manufacturer; the poor performance of this paint is shown in Figure 4. The purchased sample of U15 used in the U. S. Steel test performed poorly, even though the paint is advertised for galvanized steel. The same brand purchased by Armco performed better as a single coat, but showed early peeling when top-coated after one year of exposure.

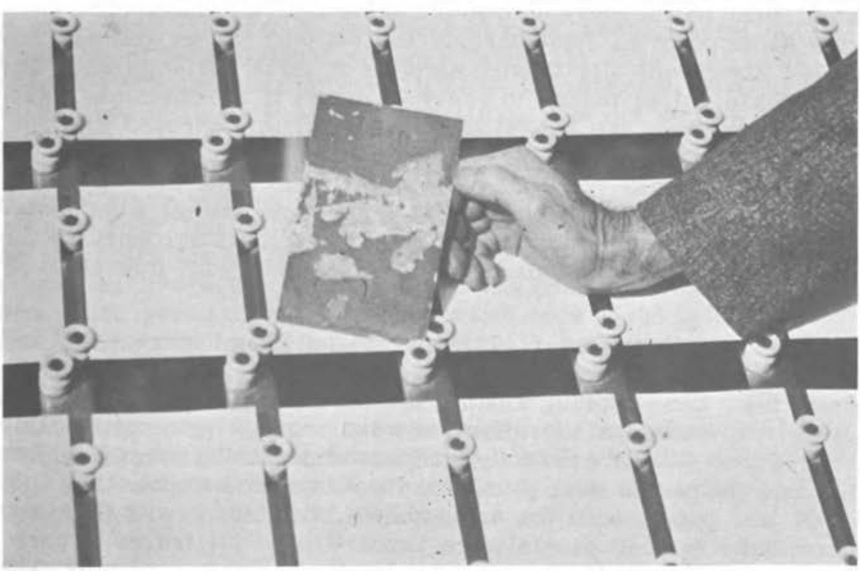

Figure 4 -- Characteristic peeling shown above occurred with only a few of the paints tested.

The over-all effect of chemical treatment on paintability of galvanized steel is shown in Table 7. On an over-all basis, the paintability of the untreated galvanized steel is slightly better than that of the chemically treated galvanized steel (8.85 vs. 8.48). This very slight difference would be extremely difficult to detect except by trained observers in a statistically designed experiment such as this one. The over-all averages for the untreated galvanized steels show no significant difference in paintability of the three suppliers' products. However, the chemically treated galvanized steels of three suppliers are slightly less paintable than the untreated. Only a very slight variation in paintability was found between the three chemical treatments (8.31, 8.51, and 8.61).

Several interactions between brands of paints and galvanized steels did develop. Table 4 shows that in the Armco test, cement-base paint A13 did not perform as well on Producer Y's chemically treated steel as on untreated steel (6.9 vs. 9.8). This is also true for zinc-dust paint A2 (7.7 vs. 9.4). Proprietary paint A3, which did not perform well in this test, performed more poorly on Producer Y's chemically treated galvanized steel. Proprietary latex-base (polyvinyl acetate) paint R2532 performed more poorly on the chemically treated galvanized steel of all suppliers than on their untreated panels in the Republic test. Proprietary latex-base (polyvinyl acetate) paint R2534 performed more poorly on Producer Z's treated galvanized steel in the Republic test than it did on untreated. In the U. S. Steel test, two zinc-dust alkyd paints, U9 and U11, performed more poorly on Producer Y's chemically treated galvanized steel than on the untreated. In the same test, U13 latex-base paint (the same paint as R2534) again did not perform as well on Producer Z's chemically treated steel as it did on the untreated. The latex-base paints tended to react adversely to the chemical treatments; however, the adhesion of these paints improved with age. Because of the hydrophobic nature of the chemical treatments, the somewhat erratic behavior of some of the latex-base paints is understandable. It is also easy to understand how the wide variation in pH and formulation of the latex-base paints accounts for the extremely good performance that is possible with this class of paints.

As a corollary test, U. S. Steel exposed chemically treated and untreated panels, from the same lots of steel as were used in the main test, to wet spring weather for two months before painting in order to determine the effect of weathering. The results of this test, Table 4-D, are directly comparable to all the preceding data because the panels were painted at the same time as the other U.S. Steel test panels with the same paints. Coincident with this test, chemically treated panels were exposed until all traces of chromate disappeared; this had occurred at the end of four months. The painted, weathered samples were slightly better than the unweathered. Their average rating was 8.4 compared to 8.1. The weathering completely eliminated the slight difference in paintability of the chemically treated galvanized steel and made it as good as the weathered, untreated galvanized steel (8.4 vs. 8.4). Weathering improved the paintability of chemically treated galvanized steel from an average grade of 7.9 to 8.4; it apparently improved the average paintability of untreated galvanized steel slightly from an average rating of 8.3 to 8.4.

In the U. S. Steel test, a second coat of each paint was applied on the top half of each panel to determine whether an extra coat of paint would affect the paint adhesion. Only slight differences were observed with a few of the paints. Paints U1, U4, U9, U10, U12, and U15 showed slightly better adhesion with two coats of paint. Paint U13 showed slightly better adhesion with two coats on Producer Y's untreated sample but poorer adhesion with two coats on Producer Z's treated specimen. The worst paint in the test, U18, showed much worse peeling with two coats than with one coat. These results are derived from the records of inspectors' comments from the last inspection. In general, two coats of paint were better than one or else there was no difference in adhesion.

In the Armco test, one set of the exposed panels painted with one coat of paint, was repainted with one and with two coats of white alkyd house paint at the end of one year. The average ratings for adhesion of the paint systems to the galvanized steel are shown in Table 8 (p. 34), with the ratings for one coat taken from Table 4. The over-all average ratings show that a slight improvement in adhesion occurs when two coats are used, and there is a further slight improvement when three coats are used (one and two coats of white finish paint used over the test paint, respectively). An examination of the individual ratings or averages shows that 13 of the 20 paint systems were improved by the additional costs. Five showed no improvement because they had almost perfect scores for one coat alone; one was indeterminate; and one -- proprietary paint A3 (same as U15) -- developed bad peeling when the extra coats of paint were applied. For this paint, the adhesion was probably initially poor, but did not become apparent until the shrinkage of the top coats peeled the base paint from the metal. This test paint showed an interaction with Producer Z's chemically treated samples which greatly improved the performance of the paint. In general, the application of a second or third coat improved performance. Some paints that deteriorated when exposed to the weather performed better when repainted.

An interesting aging effect was observed. The paints developed better adhesion as they aged and differences in adhesion which were observed early in the test were reduced. Adhesion leveled off so that at the end of two years little change was occurring.

CONCLUSIONS

The following conclusions are based upon the AISI research project on paintability of galvanized steel in which painted panels were exposed to the weather for two years.

1. New galvanized steel may be satisfactorily painted with trade-sales paints available through retail outlets, provided zinc-dust paints, portland cement-in-oil paints, or latex or other proprietary paints intended for galvanized steel are used.
2. The greatest variation in results occurs because of differences in the paints used. Therefore, paints from trade-sales manufacturers should be chosen from reputable producers, and outdoor experience with the paint is highly desirable.
3. The zinc-dust paints perform best, but if white or light colors are desired a suitable top coat must be used.
4. Cement-in-oil paints perform almost as well as the zinc-dust paints, are lower in cost, easier to apply, and may be used as whites or colors in one-coat systems.
5. Certain latex-base proprietary paints, both polyvinyl acetate and acrylic, are excellent for galvanized steel. Some of them, however, do not wet galvanized steel which has been chemically treated to prevent humid storage stain, or develop adequate adhesion on such surfaces. Until experience is developed with proprietary paints for galvanized steel, they should be used with caution because several proved to be unsatisfactory.
6. Although the chemical treatments used on galvanized steel to prevent humid storage stain have a slightly detrimental effect on paint adhesion, the effect is so slight, except in the case of some latex-base paints, that when the above types of paint are used it is virtually negligible.
7. Weathering before painting improved the performance of chemically treated and untreated galvanized steels only slightly, although weathering does remove the chemical treatment.
8. Better performance is generally achieved when two coats of paint are used, or when the primer is recoated before deterioration of the paint film begins.

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4. Evans, U. R. Metallic Corrosion Passivity and Protection. London: Edward Arnold & Co., 1937.
5. Muehling, A. J., & Curtis, J. O. 10-Year Paint Tests on Weathered Galvanized Roofing. University of Illinois Agricultural Experiment Station Bulletin 676, Urbana: the University, 1961.

OPEN FORUM DISCUSSION

Moderator - Arnold L. Windman, Syska & Hennessy, Inc.*

H. Nussbaum, Western Products, Ltd.: Are there any test results on baked-on paints which might be used for roll coating applications?

Mr. Bigos: Excellent results are available with baked coatings, production finishes and the like. This is so much under the control of the finishers, the paint companies, and the steel producers that it's only a matter of calling the steel producer and getting complete information. In addition, BRI publication 993, Prefinishing of Exterior Building Components, contains information on this subject. Adhesion of the paints to galvanized steel has to be better than the adhesion of the zinc or it's considered a complete failure. We have no more trouble in obtaining adhesion of paints to the galvanized surface than we do in getting adhesion of the galvanizing itself.

George Azrak, Port of New York Authority: Can the cost of painting galvanized surfaces be justified? That is, would it be more economical to leave the metal unpainted until the galvanizing has been weathered, or actually worn off?

Mr. Bigos: I'm glad somebody asked that. I'd like to say just a word on my philosophy of galvanizing. I think of galvanizing as the cheapest coat of paint that you can possibly buy. Mr. Plummer mentions a cost of 10¢ or 15¢ per sq. ft. for blast cleaning. This is a very conservative blast cleaning cost; you might have to spend 25¢ per sq. ft. for it. If you buy galvanized steel, the cost of galvanizing above plain steel is roughly 2¢ per sq. ft., including surface preparation. It includes one mil of zinc. If you put that same mil of zinc on as metallizing, it costs you about 25 times the cost you would have if you buy directly from a steel producer.

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*BRI member.

If you put it on as a zinc-rich paint, it will cost you from 10 to 15 times as much. Then you have to decide whether you are going to use one coat of paint, or whether you are going to protect this coat of paint by additional coats. In this connection, one should consider that it's not necessary to use priming paints on galvanized steel providing you paint in such a manner that you get good adhesion. If you get adhesion by phosphatizing, or in some other way, you can go directly to finish coats.

As far as I am concerned, the most economical way to use galvanized steel is to let it weather. Ideally, you should wait until the first rust begins and then go back and paint it two weeks before that. As long as there is any galvanized steel left, it doesn't matter when you paint. In some environments, it is not uncommon to have it go for as much as 15 years. When the first yellow rust begins in the alloy layer then it is time to paint, but you have gotten your money's worth out of the galvanizing, because you can still use that as your primer and build up with the customary finish paints. If you wait too long, though, you have to use rust inhibitor such as zinc paint or red lead paint to stop the red rust which begins.

Francis Scofield, National Paint Assn.: Cement-base paints may be difficult to recoat with other paints. Is work on this being done?

Mr. Bigos: I didn't go into any details, but part of the test involved the recoating of the cement-base paints at the end of one year. The first test is terminated, but all of the panels are being retained and recoated and we will have further information. There can be no question that cement-base paints are not as good as we would like to have in comparison to other paints that are available. But they do a good job and, most important of all, they do it at a reasonable price. The price is the basis of all this. Otherwise, there wouldn't be any painting problems, because all you would have to do is to have the builders spend $3.00 per ton more, less than a tenth of a cent per sq. ft., to buy material already phosphatized.

Mr. Scofield: How much weathering is required where the galvanized steel is used for gutter applications on houses?

Mr. Bigos: I can't give you an answer to cover every possible application, because I am sure that there are some areas where it would take years to weather the chemical treatment. We find that two months were completely adequate to eliminate the differences. In four months we find that every vestige of the chemical treatment has disappeared, but you still have the basic problem of painting a galvanized steel surface whether it's treated or untreated. I can't tell you how long it would take an untreated surface to weather where it's in a sheltered location.

TABLE 1 -- DESIGN OF MAIN AISI RESEARCH PROJECT ON PAINTABILITY OF GALVANIZED STEEL

Main Test

Major Variables		Degrees of Freedom
Classes of Paints	3	2
Brands of Paints	6	5
Chemical Treatments	3	2
Treated Versus Untreated (Levels)	2	1
Laboratories	3	2
Replicates	3	2
Total Panels	972	14

First-Order Interactions

Classes of Paints x Brands	10
Classes of Paints x Treatments	4
Classes of Paints x Level of Treatment	2
Classes of Paints x Laboratories	4
Classes of Paints x Replicates	4
Brands x Treatments	10
Brands x Levels	5
Brands x Laboratories	10
Brands x Replicates	10
Treatments x Levels	2
Treatments x Laboratories	4
Treatments x Replicates	4
Levels x Laboratories	2
Levels x Replicates	4
Laboratories x Replicates	4
Total	77
Total Interactions	91
Determination of Error	880
Total	971

TABLE 2 -- PAINTS USED IN AISI RESEARCH TEST

A. ARMCO LABORATORY TEST

Paint Class and Code	Mils	Color	Description
Cement-Base			
A9	2.2	White	Portland cement-in-oil
A10	2.0	Pearl Gray	Portland cement-in-oil
A13	3.5	Gray	Portland cement-in-oil
A14	3.5	White	Portland cement-in-oil
A16	2.2	White	Portland cement-in-oil; same as R2531
A18	2.6	White	Portland cement-in-oil; same as U3
Zinc-Dust			
A1	2.2	Gray	Linseed-oil vehicle; same as R2524
A2	1.2	Gray	Alkyd vehicle
A7	1.6	Gray	Alkyd vehicle; same as U7
A11	3.0	Gray	Linseed-oil vehicle
A12	2.2	Gray	Alkyd vehicle; same as U8
A17	2.6	Gray	------
Proprietary			
A3	1.6	Gray	Contains metallic lead pigment; same as U15
A4	2.2	Red	Iron oxide - linseed oil, alkyd
A5*	1.3	Red	Red oxide, acrylic emulsion
A6	2.3	White	Linseed, tung, and phenolic vehicle
A8	1.8	Red lead	Red lead, zinc chromate, drying oil
A15	2.3	White	Cement base; same as U5
A19	3.5	Green	Zinc chromate epoxy
A20	2.2	Gray	Lacquer, acrylic

B. U. S. STEEL LABORATORY TEST

Paint Class and Code	Mils	Color	Description
Cement-Base			
U1	2.5	Buff	Portland cement-in-oil
U2	1.5	White	Portland cement-in-oil
U3	2.5	White	Portland cement-in-oil; same as A18
U4	2.0	White	Portland cement-in-oil; same as R2529
U5	1.5	White	Portland cement-in-oil; same as A15
U6	3.9	White	Portland cement-in-oil
Zinc-Dust			
U7	1.9	Gray	Alkyd; same as A7
U8	3.1	Gray	Oil base; same as A12
U9	1.0	Gray	Alkyd
U10	1.9	Gray	TT-P-641b, Type I, oil
U11	1.9	Gray	TT-P-641b, Type II, alkyd
U12	2.1	Gray	MIL-D-15145A, phenolic
Proprietary			
U13*	1.3	White	Polyvinyl acetate emulsion; same as R2534
U14*	3.1	Red	Polyvinyl acetate emulsion
U15	1.7	Gray	Contains metallic lead; same as A3
U16	2.7	Red	Contains cement
U17	1.2	Red	Zinc chromate, zinc oxide, iron oxide-soya alkyd
U18	1.1	Green	Chrome green, modified alkyd

*Denotes latex-base paint.

TABLE 2 -- CONCLUDED

C. REPUBLIC LABORATORY TEST

Paint Class and Code	Mils	Color	Description
Cement-Base			
R2523	1.0 to 1.5	White	Portland cement-in-oil, water
R2526	1.0 to 1.5	White	Portland cement-in-oil
R2527	1.0 to 1.5	White	Pqrtland cement-in-oil
R2528	1.0 to 1.5	White	Portland cement-in-oil
R2529	1.0 to 1.5	White	Portland cement-in-oil; same as U4
R2530	1.0 to 1.5	White	Portland cement-in-oil
R2531	1.0 to 1.5	White	Portland cement-in-oil, water; same as A16
Zinc-Dust			
R2519	1.0 to 1.5	Gray	——
R2520	1.0 to 1.5	Gray	——
R2521	1.0 to 1.5	Gray	——
R2522	1.0 to 1.5	Gray	TT-P-641b
R2524	1.0 to 1.5	Gray	Linseed-oil vehicle; same as A1
R2525	1.0 to 1.5	Gray-green	Chromated zinc dust
Proprietary			
R2523*	1.0 to 1.5	White	Masonry paint, PVA-emulsion base
R2533	1.0 to 1.5	White	Chlorinated rubber
R2534*	1.0 to 1.5	White	Polyvinyl acetate emulsion; same as U13
R2535*	1.0 to 1.5	White	Polyvinyl acetate emulsion
R2536	1.0 to 1.5	Gray-green	Polyamide-cured epoxy

*Denotes latex-base paint.

TABLE 3 -- INDIVIDUAL AISI RATINGS OF PAINTS FOR GALVANIZED STEEL AFTER TWO-YEAR EXPOSURE (Average for Three Panels)

A. ARMCO LABORATORY TEST

Paint Class and Code	Producer Z												Avg. Treated	Avg. Untreated
	Treated						Untreated							
Grader	1	2	3	4	5	6	1	2	3	4	5	6		
Cement-Base														
A9	8	9	9	6	7	7	8	10	9	6	7	7	8.0	7.8
A10	10	9	8	8	8	9	10	10	8	7	8	9.5	8.7	8.8
A13	10	10	10	10	10	10	10	9	10	10	10	10	10.0	9.8
A14	10	10	10	9	8	9.5	9	9	9	6	6	9	9.4	8.0
A16	9	9	9	8	10	9.5	9	9	9	8	10	9	9.1	9.0
A18	10	10	10	8	10	10	10	10	10	8	10	10	9.7	9.7
										Class Averages			9.1	8.9
Zinc-Dust														
A1	10	10	10	9	9	10	10	10	10	10	10	10	9.7	10.0
A2	10	10	9	9	9	8.5	10	10	9	9	9	8.5	9.3	9.3
A7	10	9	10	10	10	9.5	10	10	10	10	10	9.5	9.8	9.9
A11	10	10	10	10	10	10	10	10	10	9	10	10	10.0	9.8
A12	10	10	10	10	10	10	10	10	10	10	10	10	10.0	10.0
A17	10	10	10	10	10	10	10	10	10	10	10	10	10.0	10.0
										Class Averages			9.8	9.8
Proprietary														
A3	8	8	10	6	7	9.5	8	8	10	7	7	8.5	8.1	8.1
A4	9	10	9	9	7	9.5	7	7	8	8	6	8.5	8.9	7.4
A5	10	10	9	9	8	10	10	10	9	10	8	10	9.3	9.5
A6	10	9	9	8	8	9	10	10	10	8	8	9.5	8.8	9.3
A8	9	8	7	5	9	9.5	9	8	7	5	9	9.5	7.9	7.9
A15	5	9	9	6	6	5	5	9	9	6	6	5	6.7	6.7
A19	10	10	10	10	10	10	10	9	7	10	8	9.5	10.0	8.9
A20	8	9	7	5	5	8.5	8	8	7	6	5	8.5	7.1	7.1
										Class Averages			8.4	8.1
										Average for all Paints			9.02	8.85
										Over-all Average			8.93	

Paint Class and Code	Producer X												Avg. Treated	Avg. Untreated
	Treated						Untreated							
Grader	1	2	3	4	5	6	1	2	3	4	5	6		
Cement-Base														
A9	8	9	9	5	7	7	8	10	9	6	7	7	7.5	7.8
A10	10	9	8	7	6	9.5	10	10	8	8	8	9.5	8.3	8.9
A13	9	9	8	9	8	9	10	9	10	7	10	10	8.7	9.3
A14	10	10	9	8	8	9.5	10	10	9	9	8	9.5	9.1	8.2
A16	9	9	9	8	9	9.5	9	9	9	8	10	9.5	8.9	9.1
A18	10	10	10	8	10	10	10	10	10	8	10	10	9.7	9.7
										Class Averages			8.7	8.8
Zinc-Dust														
A1	10	10	10	7	10	10	10	10	10	10	10	10	9.5	10.0
A2	10	10	10	9	9	7	10	10	10	9	9	8.5	9.2	9.4
A7	10	9	10	10	10	9.5	10	10	10	10	10	9.5	9.8	9.9
A11	10	10	10	10	10	10	10	10	10	10	10	10	10.0	10.0
A12	10	10	10	10	10	10	10	10	10	9	10	10	10.0	9.8
A17	10	10	10	10	9	10	10	10	10	10	10	10	9.8	10.0
										Class Averages			9.7	9.9
Proprietary														
A3	8	8	7	5	7	8.5	8	8	8	6	7	8.5	7.3	7.6
A4	9	10	7	9	6	8	7	7	6	8	6	8.5	8.2	7.1
A5	10	10	9	9	8	10	10	10	10	10	8	10	9.3	9.7
A6	10	9	9	9	8	9	10	10	10	8	8	9.5	9.0	9.3
A8	9	10	8	4	9	9.5	9	10	9	5	9	9.5	8.3	8.6
A15	5	9	8	5	6	5	5	9	9	5	6	5	6.3	6.5
A19	10	10	10	10	10	10	10	10	10	10	10	10	10.0	10.0
A20	8	9	7	6	6	8.5	8	9	7	5	5	8.5	7.4	7.1
										Class Averages			8.2	8.2
										Average for all Paints			8.80	8.90
										Over-all Average			8.86	

TABLE 3 -- CONTINUED

Paint Class and Code	Producer Y												Avg. Treated	Avg. Untreated	Over-all Avg. for Paints
	Treated						Untreated								
Grader	1	2	3	4	5	6	1	2	3	4	5	6			
Cement-Base															
A9	8	10	9	6	7	7	8	9	9	6	7	7	7.8	7.7	7.77
A10	10	8	8	7	6	9	10	9	7	7	6	9.5	8.0	8.1	8.44
A13	6	7	6	7	7	8.5	10	9	10	10	10	10	6.9	9.8	9.10
A14	9	8	8	8	7	9	10	9	9	6	7	9.5	8.2	8.4	8.54
A16	9	9	9	8	9	9.5	9	9	9	8	10	9.5	8.9	9.1	9.01
A18	10	10	10	9	10	10	10	10	9	8	10	10	9.8	9.5	9.67
												Class Averages	8.3	8.8	8.76
Zinc-Dust															
A1	10	9	10	10	10	10	10	10	10	10	10	10	9.8	10.0	9.83
A2	8	7	8	8.5	6	8.5	10	10	10	9	9	8.5	7.7	9.4	9.01
A7	9	8	9	10	10	9	10	10	10	10	10	10	9.2	10.0	9.75
A11	10	10	10	10	10	10	10	10	10	10	10	10	10.0	10.0	9.97
A12	10	10	9	9	10	10	10	10	10	10	10	10	9.7	10.0	9.92
A17	10	9	9	10	10	10	10	10	10	10	10	10	9.7	10.0	9.92
												Class Averages	9.3	9.9	9.73
Proprietary															
A3	5	5	7	2	2	4	8	8	10	7	7	7	4.2	7.8	7.17
A4	7	7	6	8	6	8	7	8	7	8	6	8	7.0	7.3	7.65
A5	9	9	8	9	7	10	10	10	10	10	8	10	8.7	9.7	9.36
A6	10	10	9	9	9	9	10	10	10	8	9	10	9.3	9.5	9.19
A8	9	9	7	4	8	9	9	10	7	4	9	9.5	7.7	8.1	8.07
A15	5	9	8	6	6	5	5	9	9	4	6	5	6.5	6.3	6.50
A19	No Sample						10	9	8	9	8	9.5		8.9	9.57
A20	7	8	6	4	5	8.5	8	9	6	5	5	8.5	6.4	6.9	7.00
												Class Averages	7.1	8.1	8.03
												Average for all Paints	8.18	8.83	
												Over-all Average	8.51		8.84
	Average for all Treated 8.53						Average for all Untreated 8.86								

(Continued on next page)

TABLE 3 -- CONTINUED

B. REPUBLIC LABORATORY TEST

Paint Class and Code	Producer Z												Avg. Treated	Avg. Untreated
	Treated						Untreated							
Grader	1	2	3	4	5	6	1	2	3	4	5	6		
Cement-Base														
2523	10	9.7	10	8	9	9.1	10	9.3	9.3	8	9	9.3	9.3	9.2
2526	10	9	8.7	7	8	9.7	10	9.7	8	8	8	9	8.7	8.8
2527	10	9	9	9	8	8.5	10	9.3	9	9	9	9.7	8.9	9.3
2528	9.5	9.3	9	9	10	9	9.5	9.3	9	10	9.1	9.1	9.3	9.3
2529	9	9	9	6	10	8.8	9	9	10	6	10	9.5	8.6	8.9
2530	10	9.3	7.3	8	8	9.1	10	9.7	8.3	8	10	9.1	8.6	9.2
2531	10	9	8	6	8	8.7	10	9	9	7	8	9	8.3	8.7
										Class Averages			8.8	9.1
Zinc-Dust														
2519	10	9	9.3	8	8	9.5	10	9.3	10	9	10	9.5	9.0	9.6
2520	10	10	10	10	10	10	10	10	10	10	10	9.8	10.0	10.0
2521	10	9	9	8.7	10	9.1	10	9	9	9	10	9.3	9.3	9.4
2522	10	9	9	9	10	9.5	10	9	10	9	10	9.5	9.4	9.6
2524	10	9	10	10	10	9.7	10	10	10	10	10	10	9.8	10.0
2525	10	9	9	10	10	9.5	10	9	9.3	10	10	9.5	9.6	9.6
										Class Averages			9.5	9.7
Proprietary														
2532	6	7	5	4	3	7	10	10	10	10	10	9.3	5.3	9.9
2533	8.5	8	4	4	5	6	8.5	8	5	4	5	7	5.9	6.3
2534	8	8	7	3	10	8.5	10	10	10	10	10	10	7.4	10.0
2535	9	9.3	7.9	6	8.3	8.7	10	10	10	10	10	10	8.2	10.0
2536	8.7	8	6	5	7	9	8.7	8	6	5	8	9	7.3	7.5
										Class Averages			6.8	8.7
										Average for all Paints			8.50	9.17
										Over-all Average			8.84	

Paint Class and Code	Producer X												Avg. Treated	Avg. Untreated
	Treated						Untreated							
Grader	1	2	3	4	5	6	1	2	3	4	5	6		
Cement-Base														
2523	10	9	10	8	9	9.5	10	9	9.7	9	9	9.3	9.3	9.3
2526	10	9.3	8	7	8	8.8	10	9.7	9	8	8	9.5	8.5	9.0
2527	10	9.7	9.7	9	9	9.5	10	9.7	9.7	9	9	9.5	9.5	9.5
2528	9.5	9.3	9	8	10	8.7	9.5	9	9	8	10	9	9.1	9.1
2529	9	10	10	6	10	9.1	9	9.3	10	6	10	9.3	9.0	8.9
2530	10	9.7	8	9	10	9	10	10	9	9	10	9.5	9.3	9.6
2531	10	9	8	6	8	9	10	9.7	9	6	8	9	8.3	8.6
										Class Averages			9.0	9.2
Zinc-Dust														
2519	10	9	9.7	9	10	9.5	10	9	9.7	8.7	10	9.5	9.5	9.5
2520	10	10	10	10	10	9.5	10	10	10	10	10	9.5	9.9	9.9
2521	10	9.7	9	10	10	9	10	9.3	9	10	10	9.5	9.6	9.6
2522	10	9	10	9	10	9.7	10	9	10	9	10	9.8	9.6	9.6
2524	10	10	10	10	10	9.8	10	10	10	10	10	9.7	10.0	10.0
2525	10	10	10	10	10	9.8	10	9.3	9.3	10	10	9.5	9.8	9.7
										Class Averages			9.7	9.7
Proprietary														
2532	7	7	5	5	5	7.3	10	10	10	10	10	10	6.1	10.0
2533	8.5	8	4	4	5	5.6	8.5	8.7	5	6	6	7.3	5.9	6.9
2534	10	10	9	7	10	9.3	10	10	10	10	10	10	9.2	10.0
2535	10	10	10	8	10	9.5	10	10	10	10	10	10	9.6	10.0
2536	8.7	8.3	6	6	7	9	8.7	8.7	6.3	5	8	9.1	7.5	7.6
										Class Averages			7.6	8.9
										Average for all Paints			8.87	9.27
										Over-all Average			9.07	

TABLE 3 -- CONTINUED

Paint Class and Code	Producer Y												Avg. Treated	Avg. Untreated	Over-all Avg. for Paints
	Treated						Untreated								
Grader	1	2	3	4	5	6	1	2	3	4	5	6			
Cement-Base															
2523	10	10	10	9	9	9.5	10	9.3	10	9	9	9.5	9.6	9.5	9.35
2526	10	9	7	7	8	8	9	9	8	8	8	9.7	8.2	8.6	8.64
2527	10	9	7	7	8	9	9	9.3	9.3	9	9	9.7	8.3	9.2	9.13
2528	9.5	10	9	8	10	9	9.5	9.7	9	9	10	9	9.3	9.4	9.23
2529	9	9.7	9.7	6	10	9	9	9	10	6	10	9.1	8.9	8.9	8.87
2530	10	9	6.7	8	9	8.5	10	10	10	9	10	9.1	8.5	9.7	9.15
2531	10	9	8.7	6	8	9	10	9	8.7	6	8	9	8.5	8.5	8.47
											Class Averages		8.8	9.1	8.98
Zinc-Dust															
2519	10	9.3	10	10	10	9.5	10	9	10	9.7	10	9.5	9.8	9.7	9.52
2520	10	9	9.3	9	10	9.3	10	10	10	10	10	9.7	9.4	10.0	9.86
2521	10	9	8.7	9.7	10	9.5	10	9	9	8.7	10	9.5	9.5	9.4	9.46
2522	10	9	10	9	10	9.5	10	9.7	10	9	10	9.7	9.6	9.7	9.59
2524	10	9.7	10	10	10	9.7	10	10	10	10	10	9.8	9.9	10.0	9.93
2525	10	10	10	10	10	9.5	10	9	9.3	10	10	9.5	9.9	9.6	9.71
											Class Averages		9.7	9.7	9.68
Proprietary															
2532	8	8.3	5.3	5	6	8	10	10	10	10	9.3	9.5	6.8	9.8	7.42
2533	8.5	7.7	5	6	6	7	8.5	8	5	6	6	7	6.7	6.8	6.40
2534	10	10	9	10	10	9.5	10	10	10	10	10	10	9.8	10.0	9.40
2535	10	10	10	9	8	9	10	10	10	10	10	10	9.3	10.0	9.51
2536	7.7	8	5	5	8	9	8.7	9	7.7	6	9	9	7.1	8.2	7.54
											Class Averages		7.9	9.0	8.15
											Average for all Paints		8.83	9.26	
											Over-all Average		9.05		8.96
	Average for all Treated 8.73						Average for all Untreated 9.24								

(Continued on next page)

TABLE 3 -- CONTINUED

C. U. S. STEEL LABORATORY TEST (NOT PREWEATHERED)

Paint Class and Code	Producer Z												Avg.	Avg.
	Treated						Untreated						Treated	Untreated
Grader	1	2	3	4	5	6	1	2	3	4	5	6		
Cement-Base														
1	9.5	10	10	8	10	9	9.3	10	10	8	10	9.7	9.4	9.5
2	10	10	10	9	10	9.5	10	10	10	9	10	9.7	9.8	9.8
3	9.5	10	10	9	9.7	9	9.5	10	10	9	10	9	9.5	9.6
4	8.5	9	10	7	8	9	8.5	9.3	10	7	8	9	8.6	8.6
5	4.5	8	6	-	7	4.7	4.5	8	6	-	7	3.3	6.0	5.8
6	10	9	9.3	9	9	9	10	9	10	9	9	9	9.2	9.3
										Class Averages			8.8	8.6
Zinc-Dust														
7	10	10	10	10	10	10	10	10	10	10	10	10	10.0	10.0
8	10	10	10	10	10	10	10	10	10	10	10	10	10.0	10.0
9	10	9.3	9	9	10	9.5	10	9.7	10	9	10	9.5	9.5	9.7
10	10	10	10	10	10	9.5	10	9.3	10	10	10	10	9.9	9.9
11	10	9.7	10	10	10	10	10	10	10	10	10	10	10.0	10.0
12	9	9	9.3	7	10	9	9	8.7	10	6	10	9	8.9	8.8
										Class Averages			9.7	9.7
Proprietary														
13	3	3	5	3	5	8	10	10	10	10	10	10	4.5	10.0
14	9	9.3	9	9	9	10	10	10	10	10	10	10	9.2	10.0
15	2	2	5	2	2	5	2	2	4.3	3	2	7	3.0	3.4
16	8	10	6	8	7	8.7	8	10	6	8	7	9.3	8.0	8.1
17	6	10	9.3	9	10	9.5	8	10	8	8	8	9.5	9.3	8.6
18	0	0	1	0	0	0	0	0	0.3	0	0	0	0.2	0.1
										Class Averages			5.7	6.7
										Average for all Paints			8.06	8.41
										Over-all Average			8.24	

Paint Class and Code	Producer X												Avg.	Avg.
	Treated						Untreated						Treated	Untreated
Grader	1	2	3	4	5	6	1	2	3	4	5	6		
Cement-Base														
1	9.5	10	9.3	9	10	9.5	9.5	10	10	8	10	9.5	9.6	9.5
2	10	10	10	9	10	9.5	10	10	10	9	9.7	9.5	9.8	9.7
3	9.5	10	10	9	10	9	9.5	10	10	9	10	9.3	9.6	9.6
4	8.5	9.3	9.7	5	8	9	8.5	8.7	9.7	7	9.3	9	8.3	8.7
5	4.5	8	6	-	7	4.3	4.5	8	6	-	7	4.7	6.0	6.0
6	10	9	10	9	10	9	10	9	10	9	10	9	9.5	9.5
										Class Averages			8.9	
Zinc-Dust														
7	10	10	10	10	10	10	10	10	10	10	10	10	10.0	10.0
8	10	10	10	10	10	9.8	10	10	10	10	10	10	10.0	10.0
9	10	9.3	10	9	10	9.5	10	9	9	9	10	9.5	9.6	9.4
10	10	9.7	10	10	10	9.8	10	9.3	10	10	10	10	9.9	9.9
11	10	9.7	9.3	10	10	10	10	10	9	10	10	10	9.8	9.8
12	9	9	10	6	10	9	9	9	10	7	10	9	8.8	9.0
										Class Averages			9.7	9.7
Proprietary														
13	7.3	9	9.3	8	8.3	9.7	10	10	10	10	10	10	8.6	10.0
14	9.5	9	10	8	9	10	10	10	10	10	10	10	9.3	10.0
15	2	0	1.3	1	2	6	2	0	2.3	2	2	6	2.1	2.4
16	8	10	7	8	7	8.5	8	10	8	8	7	8.8	8.1	8.3
17	8	9.3	6.7	8	8	8.7	9	9.7	10	8	9	9	8.1	9.1
18	0	0	1	0	0	0	0	0	3	0	0	0	0.2	0.5
										Class Averages			6.0	6.7
										Average for all Paints			8.18	8.44
										Over-all Average			8.31	

TABLE 3 -- CONCLUDED

Paint Class and Code	Producer Y												Avg. Treated	Avg. Untreated	Over-all Avg. for Paints
	Treated						Untreated								
Grader	1	2	3	4	5	6	1	2	3	4	5	6			
Cement-Base															
1	9.5	10	9.3	8	9.7	9.1	9.5	10	10	8	10	9.5	9.3	9.5	9.46
2	10	10	8	9	9.3	9.5	10	10	10	9	10	9.5	9.3	9.8	9.67
3	9.5	10	10	8	10	9.3	9.5	10	10	9	10	9.7	9.5	9.7	9.58
4	8.5	8	10	5	9	9	8.5	9.3	10	7	9.7	9	8.3	8.9	8.56
5	4.5	8	6	-	7	4.7	4.5	8.3	6	-	7	4.3	6.0	6.0	5.97
6	10	8.3	10	9	10	9	10	8.7	10	9	10	8.8	9.4	9.4	9.39
												Class Averages	8.7	9.0	8.85
Zinc-Dust															
7	10	10	10	10	10	10	10	10	10	10	10	10	10.0	10.0	10.00
8	10	10	10	10	10	9.8	10	10	10	10	10	10	10.0	10.0	9.99
9	8	8	7	3	10	7	10	9	9	7	10	9	7.2	9.0	9.07
10	10	10	10	10	10	9.5	10	10	10	10	10	9.5	9.9	9.9	9.91
11	7	8	7.3	3	8.3	8.5	10	9	10	10	10	10	7.0	9.8	9.41
12	9	9	8	6	10	8.5	9	9	9	5	8.3	9	8.4	8.2	8.69
												Class Averages	8.8	9.5	9.51
Proprietary															
13	10	10	9.7	9	10	9.8	10	10	10	10	10	10	9.8	10.0	8.81
14	9	9.7	9.7	10	10	10	10	10	10	10	10	10	9.7	10.0	9.70
15	2	0	2	2	2	6	2	0	3	2	2	5	2.3	2.3	2.58
16	8	8	6	8	7	8.5	8.5	10	8	8	7	9.1	7.6	8.4	8.07
17	6	7	6	8	7	8.5	8	8	7	8	8	9	7.1	8.0	8.37
18	0	0	2	0	0	2	0	0	2	0	0	2	0.7	0.7	0.37
												Class Averages	6.2	6.6	6.32
												Average for all Paints	7.87	8.34	
												Over-all Average	8.10		
	Average for all Treated 8.04						Average for all Untreated 8.40								

D. U. S. STEEL LABORATORY TEST (PREWEATHERED)

Paint Class and Code	Producer Y												Avg. Treated	Avg. Untreated	Over-all Avg. for Paints
	Treated						Untreated								
Grader	1	2	3	4	5	6	1	2	3	4	5	6			
Cement-Base															
1	9.5	10	10	9	10	9.5	9.5	10	10	8	10	9.7	9.7	9.5	9.59
2	10	10	10	9	10	9.8	10	10	10	9	10	9.5	9.8	9.8	9.78
3	10	10	10	9	10	9	10	10	10	9	10	9.7	9.7	9.8	9.73
4	8.5	8.7	10	5	9.7	9	8.5	8	10	7	10	9	8.5	8.8	8.62
5	4.5	8	4.7	-	7	4	4.5	8	5.7	-	7	4	5.6	5.8	5.74
6	10	8.3	10	9	10	9	10	8	10	9	10	9	9.4	9.3	9.36
												Class Averages	8.9	8.9	8.89
Zinc-Dust															
7	10	10	9.3	10	10	10	10	10	10	9	10	10	9.9	9.8	9.86
8	10	10	10	10	10	10	10	10	10	10	10	10	10.0	10.0	10.00
9	10	9	9	7	10	9	10	9	9	8	10	9	9.0	9.2	9.01
10	10	10	10	10	10	9.5	10	10	10	10	10	9.5	9.9	9.9	9.92
11	10	10	9.7	10	10	10	10	9	10	9	10	9.8	10.0	9.6	9.79
12	9	9	9	5	10	9.3	9	9	10	5	10	9.1	8.6	9.7	8.62
												Class Averages	9.6	9.5	9.55
Proprietary															
13	10	10	10	10	10	10	10	10	10	10	10	10	10.0	10.0	10.00
14	10	10	9.7	10	10	10	10	10	9.3	10	10	10	10.0	9.9	9.92
15	2	0	2	3	2	5	2	3	3	3	2	5	2.3	3.0	2.67
16	9	10	8	8	7	9	9	10	8	8	7	9	8.5	8.5	8.50
17	9.5	10	10	8	9	9	9.5	10	10	9	9	9	9.3	9.4	9.33
18	0	0	3	0	0	0	0	0	3	0	0	0	0.5	0.5	0.50
												Class Averages	6.8	6.9	6.82
												Average for all Paints	8.39	8.44	
												Over-all Average	8.41		

TABLE 4 -- AVERAGE AISI RATINGS OF PAINTS FOR GALVANIZED STEEL AFTER TWO-YEAR EXPOSURE

A. ARMCO LABORATORY TEST

Paint Class and Code	Producer Z		Producer X		Producer Y		Average
	Treated	Untreated	Treated	Untreated	Treated	Untreated	
Cement-Base							
A9	8.0	7.8	7.5	7.8	7.8	7.7	7.8
A10	8.7	8.8	8.3	8.9	8.0	8.1	8.4
A13	10.0	9.8	8.7	9.4	6.9	9.8	9.1
A14	9.4	8.0	9.1	8.2	8.2	8.4	8.5
A16	9.1	9.0	8.9	9.1	8.9	9.1	9.0
A18	9.7	9.7	9.7	9.7	9.8	9.5	9.7
Average	9.1	8.9	8.7	8.8	8.3	8.8	8.8
Zinc-Dust							
A1	9.7	10.0	9.5	10.0	9.8	10.0	9.8
A2	9.3	9.3	9.2	9.4	7.7	9.4	9.0
A7	9.8	9.9	9.8	9.9	9.2	10.0	9.8
A11	10.0	9.8	10.0	10.0	10.0	10.0	10.0
A12	10.0	10.0	10.0	9.8	9.7	10.0	9.9
A17	10.0	10.0	9.8	10.0	9.7	10.0	9.9
Average	9.8	9.8	9.7	9.9	9.3	9.9	9.7
Proprietary							
A3	8.1	8.1	7.3	7.6	4.2	7.8	7.2
A4	8.9	7.4	8.2	7.1	7.0	7.3	7.7
A5	9.3	9.5	9.3	9.7	8.7	9.7	9.4
A6	8.8	9.3	9.0	9.3	9.3	9.5	9.2
A8	7.9	7.9	8.3	8.6	7.7	8.1	8.1
A15	6.7	6.7	6.3	6.5	6.5	6.3	6.5
A19	10.0	8.9	10.0	10.0	—	8.9	9.6
A20	7.1	7.1	7.4	7.1	6.4	6.9	7.0
Average	8.4	8.1	8.2	8.2	7.1	8.1	8.0
Average for Treatment	9.0	8.9	8.8	8.9	8.2	8.8	
Average for Supplier	8.9		8.9		8.5		

Average for Over-all Test 8.8

Average for all Treated 8.7 — Average for all Untreated 8.9

TABLE 4 -- CONTINUED

B. REPUBLIC LABORATORY TEST

Paint Class and Code	Producer Z		Producer X		Producer Y		Average
	Treated	Untreated	Treated	Untreated	Treated	Untreated	
Cement-Base							
R2523	9.3	9.2	9.3	9.3	9.6	9.5	9.4
R2526	8.7	8.8	8.5	9.0	8.2	8.6	8.6
R2527	8.9	9.3	9.5	9.5	8.3	9.2	9.1
R2528	9.3	9.3	9.1	9.1	9.3	9.4	9.3
R2529	8.6	8.9	9.0	8.9	8.9	8.9	8.9
R2530	8.6	9.2	9.3	9.6	8.5	9.7	9.2
R2531	8.3	8.7	8.3	8.6	8.5	8.5	8.5
Average	8.8	9.1	9.0	9.2	8.8	9.1	9.0
Zinc-Dust							
R2519	9.0	9.6	9.5	9.5	9.8	9.7	9.5
R2520	10.0	10.0	9.9	9.9	9.4	10.0	9.9
R2521	9.3	9.4	9.6	9.6	9.5	9.4	9.5
R2522	9.4	9.6	9.6	9.6	9.6	9.7	9.6
R2524	9.8	10.0	10.0	10.0	9.9	10.0	10.0
R2525	9.6	9.6	9.8	9.7	9.9	9.6	9.7
Average	9.5	9.7	9.7	9.7	9.7	9.7	9.7
Proprietary							
R2532	5.3	9.9	6.1	10.0	6.8	9.8	8.0
R2533	5.9	6.3	5.9	6.9	6.7	6.8	6.4
R2534	7.4	10.0	9.2	10.0	9.8	10.0	9.4
R2535	8.2	10.0	9.6	10.0	9.3	10.0	9.5
R2536	7.3	7.5	7.5	7.6	7.1	8.2	7.5
Average	6.8	8.7	7.6	8.9	7.9	9.0	8.2
Average for Treatment	8.5	9.2	8.9	9.3	8.8	9.3	
Average for Supplier	8.8		9.1		9.1		

Average for Over-all Test 9.0

Average for all Treated 8.7 — Average for all Untreated 9.2

(Continued on next page)

TABLE 4 -- CONTINUED

C. U. S. STEEL LABORATORY TEST (NOT PREWEATHERED)

Paint Class and Code	Producer Z		Producer X		Producer Y		Average
	Treated	Untreated	Treated	Untreated	Treated	Untreated	
Cement-Base							
U1	9.4	9.5	9.6	9.5	9.3	9.5	9.5
U2	9.8	9.8	9.8	9.7	9.3	9.8	9.7
U3	9.5	9.6	9.6	9.6	9.5	9.7	9.6
U4	8.6	8.6	8.3	8.7	8.3	8.9	8.7
U5	6.0	5.8	6.0	6.0	6.0	6.0	6.0
U6	9.2	9.3	9.5	9.5	9.4	9.4	9.4
Average	8.8	8.6	8.9	8.9	8.7	9.0	8.9
Zinc-Dust							
U7	10.0	10.0	10.0	10.0	10.0	10.0	10.0
U8	10.0	10.0	10.0	10.0	10.0	10.0	10.0
U9	9.5	9.7	9.6	9.4	7.2	9.0	9.1
U10	9.9	9.9	9.9	9.9	9.9	9.9	9.9
U11	10.0	10.0	9.8	9.8	7.0	9.8	9.4
U12	8.9	8.8	8.8	9.0	8.4	8.2	8.7
Average	9.7	9.7	9.7	9.7	8.8	9.5	9.5
Proprietary							
U13	4.5	10.0	8.6	10.0	9.8	10.0	8.8
U14	9.2	10.0	9.3	10.0	9.7	10.0	9.7
U15	3.0	3.4	2.1	2.4	2.3	2.3	2.6
U16	8.0	8.1	8.1	8.3	7.6	8.4	8.1
U17	9.3	8.6	8.1	9.1	7.1	8.0	8.4
U18	0.2	0.1	0.2	0.5	0.7	0.7	0.4
Average	5.7	6.7	6.0	6.7	6.2	6.6	6.3
Average for Treatment	8.1	8.4	8.2	8.4	7.9	8.3	
Average for Supplier	8.2		8.3		8.1		

Average for Over-all Test 8.2

Average for all Treated 8.0 — Average for all Untreated 8.4

TABLE 4 -- CONCLUDED

D. U. S. STEEL LABORATORY TEST (PREWEATHERED)

Paint Class and Code	Producer Y Treated	Producer Y Untreated	Average
Cement-Base			
U1	9.7	9.5	9.6
U2	9.8	9.8	9.8
U3	9.7	9.8	9.7
U4	8.5	8.8	8.6
U5	5.6	5.8	5.7
U6	9.4	9.3	9.4
Average	8.9	8.9	8.9
Zinc-Dust			
U7	9.9	9.8	9.9
U8	10.0	10.0	10.0
U9	9.0	9.2	9.0
U10	9.9	9.9	9.9
U11	10.0	9.6	9.8
U12	8.6	9.7	8.6
Average	9.6	9.5	9.6
Proprietary			
U13	10.0	10.0	10.0
U14	10.0	9.9	9.9
U15	2.3	3.0	2.7
U16	8.5	8.5	8.5
U17	9.3	9.4	9.3
U18	0.5	0.5	0.5
Average	6.8	6.9	6.8
Average for Treatment	8.4	8.4	
Average for Supplier	8.4		

Average for Over-all Test 8.4

TABLE 5 -- PERFORMANCE OF PAINTS BY CLASS AFTER TWO-YEAR EXPOSURE

Paint Class	Armco Test	Republic Test	U. S. Steel Test	Average
Cement-Base	8.8	9.0	8.9	8.9
Zinc-Dust	9.7	9.7	9.5	9.6
Proprietary	8.0	8.2	6.3	7.5
(Latex Base)	(9.4)	(9.0)	(9.3)	(9.2)
Over-all Average for Laboratories	8.83	8.97	8.23	8.67

TABLE 6 -- PERFORMANCE OF PAINTS IN VARIOUS CLASSES AFTER TWO-YEAR EXPOSURE

Armco Test			Republic Test			U. S. Steel Test		
Paint Code	Avg. Grade	Comments	Paint Code	Avg. Grade	Comments	Paint Code	Avg. Grade	Comments
Cement Base Paints								
A9	7.8	Paint deteriorating	R2523	9.4		U1	9.5	
A10	8.4		R2526	8.6		U2	9.7	
A13	9.1		R2527	9.1		U3	9.6	
A14	8.5		R2528	9.3		U4	8.7	Second coat slight flaking from first.
A16	9.0		R2529	8.9		U5	6.0	Bad checkering and alligatoring.
A18	9.7		R2530	9.2		U6	9.4	
			R2531	8.5				
	8.8			9.0			8.9	
Zinc-Dust Paints								
A1	9.8		R2519	9.5		U7	10.0	
A2	9.0		R2520	9.9		U8	10.0	
A7	9.8		R2521	9.5		U9	9.1	
A11	10.0		R2522	9.6		U10	9.9	Second coat blistered.
A12	9.9		R2524	10.0		U11	9.4	
A17	9.9		R2525	9.7		U12	8.7	
	9.7			9.7			9.5	
Proprietary Paints								
A3	7.2	Some peeling.	R2532*	8.0		U13*	8.8	Early peeling on Armco treated.
A4	7.7		R2533	6.4	Brittle	U14*	9.7	
A5*	9.4		R2534*	9.4		U15	2.6	Peeling and flaking.
A6	9.2		R2535*	9.5		U16	8.1	
A8	8.1		R2536	7.5	Brittle	U17	8.4	
A15	6.5	Paint disintegrating.				U18	0.4	Failed by peeling.
A19	9.6							
A20	7.0							
	8.0			8.2			6.3	

*Latex-base paint.

TABLE 7 -- PERFORMANCE OF TREATED GALVANIZED STEEL
VS. UNTREATED GALVANIZED STEEL
AFTER TWO-YEAR EXPOSURE

Paint Class	Test	Producer Z		Producer X		Producer Y		Average
		Treated	Untreated	Treated	Untreated	Treated	Untreated	
Cement-Base	Armco	9.1	8.9	8.7	8.8	8.3	8.8	8.8
	Republic	8.8	9.1	9.0	9.2	8.8	9.1	9.0
	U. S. Steel	8.8	8.6	8.9	8.9	8.7	9.0	8.9
		8.90	8.87	8.87	8.96	8.60	8.97	8.90
Zinc-Dust	Armco	9.8	9.8	9.7	9.9	9.3	9.9	9.7
	Republic	9.5	9.7	9.7	9.7	9.7	9.7	9.7
	U. S. Steel	9.7	9.7	9.7	9.7	8.8	9.5	9.5
		9.67	9.73	9.70	9.77	9.27	9.70	9.63
Proprietary	Armco	8.4	8.1	8.2	8.2	7.1	8.1	8.0
	Republic	6.8	8.7	7.6	8.9	7.9	9.0	8.2
	U. S. Steel	5.7	6.7	6.0	6.7	6.2	6.6	6.3
		6.97	7.83	7.27	7.93	7.07	7.90	7.50
	Steel Averages	8.51	8.81	8.61	8.88	8.31	8.86	8.68

Over-all average, treated 8.48 — Over-all average, untreated 8.85

TABLE 8 -- COMPARISON OF A SINGLE COAT OF PAINT WITH A SINGLE COAT REPAINTED WITH ONE AND TWO COATS AFTER ONE-YEAR

ARMCO LABORATORY TEST

Paint Class and Code	No. of Coats	Producer Z		Producer X		Producer Y		Average
		Treated	Untreated	Treated	Untreated	Treated	Untreated	
Cement-Base								
A9	1	8.0	7.8	7.5	7.8	7.8	7.7	7.8
	2	8.2	8.5	9.0	8.8	8.7	8.8	8.7
	3	9.2	9.2	9.5	9.3	9.8	9.7	9.5
A10	1	8.7	8.8	8.3	8.9	8.0	8.1	8.4
	2	9.3	8.8	9.7	9.7	9.2	9.5	9.4
	3	9.5	9.2	9.8	9.8	9.5	9.8	9.6
A13	1	10.0	9.8	8.7	9.4	6.9	9.8	9.1
	2	9.5	9.5	8.3	9.3	8.2	9.8	9.1
	3	9.3	9.3	8.5	10.0	9.5	10.0	9.4
A14	1	9.4	8.0	9.1	8.2	8.2	8.4	8.5
	2	10.0	10.0	10.0	10.0	10.0	9.7	9.9
	3	10.0	10.0	10.0	10.0	10.0	10.0	10.0
A16	1	9.1	9.0	8.9	9.1	8.9	9.1	9.0
	2	9.7	9.8	9.7	9.7	9.5	9.7	9.7
	3	10.0	10.0	9.8	9.8	9.8	9.8	9.8
A18	1	9.7	9.7	9.7	9.7	9.8	9.5	9.7
	2	9.8	9.8	9.8	9.8	9.7	10.0	9.8
	3	10.0	9.8	10.0	10.0	10.0	9.8	9.9
Zinc-Dust								
A1	1	9.7	10.0	9.5	10.0	9.8	10.0	9.8
	2	9.8	9.8	10.0	10.0	10.0	10.0	9.9
	3	10.0	10.0	10.0	10.0	10.0	10.0	10.0
A2	1	9.3	9.3	9.2	9.4	7.7	9.4	9.0
	2	9.7	9.5	9.8	9.8	9.5	9.8	9.7
	3	10.0	9.5	10.0	10.0	9.5	10.0	9.9
A7	1	9.8	9.9	9.8	9.9	9.2	10.0	9.8
	2	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	3	10.0	10.0	10.0	10.0	10.0	10.0	10.0
A11	1	10.0	9.8	10.0	10.0	10.0	10.0	10.0
	2	9.8	10.0	9.8	9.8	9.8	9.8	9.8
	3	10.0	10.0	10.0	10.0	10.0	10.0	10.0
A12	1	10.0	10.0	10.0	9.8	9.7	10.0	9.9
	2	9.7	9.7	9.8	10.0	10.0	10.0	9.8
	3	10.0	10.0	10.0	10.0	10.0	10.0	10.0
A17	1	10.0	10.0	9.8	10.0	9.7	10.0	9.9
	2	9.8	10.0	10.0	10.0	10.0	9.8	9.9
	3	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Proprietary								
A3	1	8.1	8.1	7.3	7.6	4.2	7.8	7.2
	2	5.5	3.0	3.2	4.0	1.2	3.8	3.5
	3	6.8	0.5	0.8	1.2	0.2	1.0	1.8
A4	1	8.9	7.4	8.2	7.1	7.0	7.3	7.7
	2	7.8	5.7	5.8	6.2	6.2	6.0	6.3
	3	8.2	6.3	7.0	7.0	7.0	7.0	7.1
A5	1	9.3	9.5	9.3	9.7	8.7	9.7	9.4
	2	9.3	9.3	9.3	9.7	9.3	9.8	9.4
	3	9.5	9.5	9.8	10.0	9.7	10.0	9.7
A6	1	8.8	9.3	9.0	9.3	9.3	9.5	9.2
	2	9.8	9.8	10.0	10.0	9.7	10.0	9.8
	3	9.8	10.0	10.0	10.0	9.7	10.0	9.8
A8	1	7.9	7.9	8.3	8.6	7.7	8.1	8.1
	2	7.7	8.8	8.5	8.5	8.5	8.7	8.4
	3	8.2	9.2	9.7	9.7	9.7	9.7	9.4
A15	1	6.7	6.7	6.3	6.5	6.5	6.3	6.5
	2	9.3	9.5	9.3	9.3	9.0	9.2	9.3
	3	9.7	10.0	9.8	10.0	9.8	9.8	9.8
A19	1	10.0	8.9	10.0	10.0	Lost	8.9	9.6
	2	10.0	10.0	10.0	10.0	9.7	9.8	9.9
	3	10.0	10.0	10.0	10.0	9.8	9.8	9.9
A20	1	7.1	7.1	7.4	7.1	6.4	6.9	7.0
	2	7.5	7.3	8.3	7.7	7.7	7.7	7.7
	3	8.3	8.0	9.2	8.3	8.7	8.5	8.5

Over-all average rating for 1 coat = 8.76
Over-all average rating for 2 coats = 9.00
Over-all average rating for 3 coats = 9.20

Corrosion Resistance of Metallized Coatings

By Fred L. Plummer, American Welding Society

Abstract: Metallizing is the deposition of an adherent coating of finely divided particles of metal, intermetallics, or metallic oxides upon a base metal. The corrosion protection of aluminum and zinc coating applied to low-carbon steel is considered in this paper. Panels coated with these metals were exposed to urban, industrial and marine environments over a nine-year period. Studied were thicknesses of coating, effect of methods of steel preparation, and effect of seal coats. Adequate corrosion protection was afforded in nearly all cases, aluminum providing slightly better protection than zinc.

NO ENGINEER OR ARCHITECT can give his clients effective, responsible service unless he keeps himself informed concerning new materials, new methods of fabrication, and new design procedures.

Innovations in building science and technology are being made every day by organizations such as the American Welding Society, the Welding Research Council, and the International Institute of Welding. These groups are actively collecting, coordinating, and disseminating authoritative information about metals; the materials, equipment and processes used in the joining of metals; and the design, fabrication, erection, testing and inspection of welded metal structures. Research programs costing about $1,000,000 annually are conducted by these organizations, and they help to coordinate and report the results of projects costing more than $3,000,000 per year. This paper will describe in detail one project sponsored by the American Welding Society.

METALLIZED COATED STEEL

Metallizing, shown in Figure 1, is the process of depositing finely divided particles of metal, intermetallics or metallic oxides in a heated, semi-molten condition in order to form an adherent coating. Metal in the form of wire or powder is fed to a "gun",

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PLUMMER, FRED L. Past President and Executive Director, American Welding Society; Vice President, International Institute of Welding; member, American Welding Society, American Society of Civil Engineers, American Society of Mechanical Engineers, American Society for Metals, American Society of Electrical Engineers, Welding Research Council.

Figure 1 -- Metallizing operation shows tank being aluminumized to prevent corrosion.

heated by an oxy-fuel gas or plasma arc, and delivered to the work by high velocity air. The coating adheres to the base metal by a combination of mechanical interlocking and metallurgical bonding. Figures 2A and 2B show the effect of a metallized application.

The use of metallized, coated steel offers outstanding design opportunities for many classes of commercial and industrial building. During 1950, the Committee on Metallizing of the American Welding Society initiated an 18-year study of the corrosion protection afforded by metallized aluminum and zinc coatings applied to low-carbon steel. The three major objectives of this program are:

1. To determine the life of any given thickness of coating in any specific environment.

2. To determine the effect of various methods of steel preparation on the properties of the metallized coating which determine corrosion protection.

3. To determine the increase in the life of the aluminum and zinc metallized coatings with the addition of seal coats.

Results to date indicate that all coating systems, with the exception of metallized, zinc coated panels with thin zinc coatings, are still providing adequate corrosion protection to the steel. The

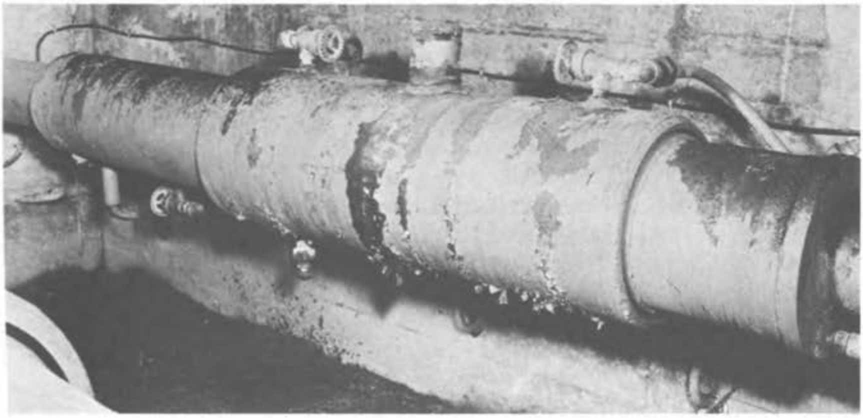

Figure 2A -- Painted, underground high voltage junction box peeling after one and a half years of service.

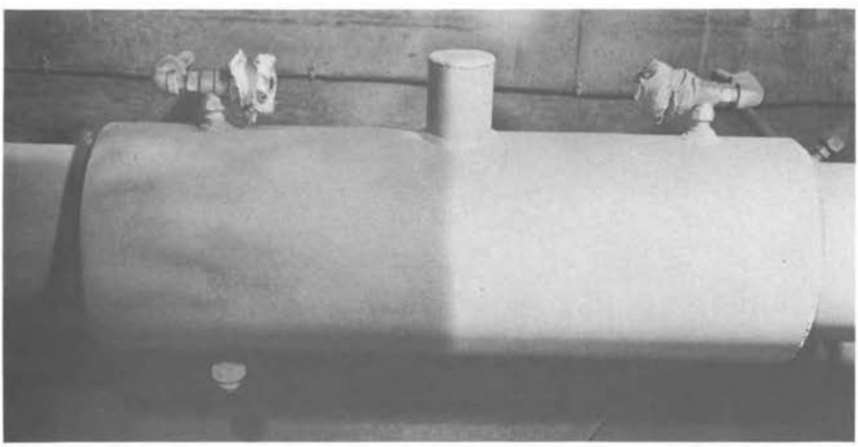

Figure 2B -- The same box has been blast-cleaned and partially metallized with zinc. Such treatment has lasted for 11 years without deterioration.

method of preparation of the steel does not have any apparent effect on the corrosion protection properties of the metallized coatings. Thus, the most economical procedure seems to be justified as adequate. The addition of seal coats, with the exception of chlorinated rubber, increases the life of the metallized coatings.

Test Sites

Eight widely dispersed test sites were selected so that the panels might be exposed in many different environments. Test panels for exposure in urban, industrial and marine environments, are shown in Figure 3. Test panels for sea water immersion, exposed at the mean-tide and below-low-tide levels, and totally immersed, are mounted on racks in a vertical position. Test sites and types of environment were as follows:

Atmospheric Exposure	Sea Water Exposure
Brazos River, Texas (salt air)	Freeport, Texas
Columbus, Ohio (urban)	Wrightsville Beach, N. C. (mean-tide)
East Chicago, Ind. (industrial)	Wrightsville Beach, N. C. (below-low-tide)
Kure Beach, N. C. (severe marine)	
Kure Beach, N. C. (salt air)	
New York, N. Y. (industrial)	
Point Reyes, Calif. (salt air)	

Figure 3 -- Typical exposure racks for test panels.

Test Panels

The test panels, made of low carbon steel, are 4 x 6 x 1/8 in. with aluminum and zinc metallized coatings of .003, .006, .009, .012 and .015 in. thickness for the atmospheric exposure tests. For the sea water exposure tests, the test panels of the same steel are 4 x 12 x 1/8 in. with the same coating thickness and, in addition, .018 in.

Panel Preparation

The steel panels were carefully prepared. After pickling in clean acid, panels were given identification marks by using a system of edge notches. The panels were next thoroughly blast cleaned, using a forced-feed blast generator with minimum pressure of 90 psi at the generator, and three types of controlled abrasives: coarse silica sand, fine silica sand and steel grit.

The metallizing operations were done on a special, automatic machine on which 36 panels were metallized at one time. The speeds of rotation and traverse of both panels and metallizing gun across the surface were automatically controlled in order to obtain uniformity of coating thickness. The panels were first metallized on one surface with the desired coating thickness and then on the remaining surface.

Coating thickness on all panels was checked by magnetic thickness gage and by weight increase. The edges of the panels were then coated separately. Three types of metallizing wire were used.

1. 1/8 in. aluminum, 99.0% minimum purity.
2. 1/8 in. zinc, 99.9% minimum purity.
3. 1/8 in. steel, SAE 1010 grade.

Steel wire was used for a flash bonding coat on some specimens, and was applied automatically to a thickness of .001 in. This bonding coat is not considered as part of the metallizing coating thickness. In order to determine the effects of seal coats on the metallized coatings, a number of the panels had a seal coat applied with a paint sprayer. In cases where two seal coats were applied, the first was allowed to dry before the second was applied. As in the metallizing operation, first the surfaces and then the edges were coated. Four types of seal coats were used:

1. An air drying, two-part, acid-zinc chromate wash coat primer.
2. A vinyl copolymer-aluminum flakes, air drying type.
3. A clear, vinyl copolymer-air drying type.
4. A clear, chlorinated rubber-air drying type.

There were 112 different panel types included to test various combinations of surface preparation, thicknesses of the two metallizing materials, and use of the various seal coats. The total number of panels tested was 4248.

Inspection

Standard practice in evaluating hot-dipped aluminum, zinc or other metallic coatings on steel has been to report the percentage of rusted base metal area. For this test program, it was felt that the appearance and condition of the coating itself should be fully described in order to accurately assess the progress of the deterioration of the coating. Inspectors are required to make separate reports on the conditions of the seal coats, the metallized coatings, and the base metal. Since the panels are inspected visually, the results depend on the interpretations of the individual inspectors. Major variations in reporting the inspection results have been minimized by the utilization of standard inspection forms with specific instructions for reporting the various conditions of the panels. In most cases where unusual conditions affected the panels, these have also been noted.

Results of Atmospheric Exposure Tests

Following initial pilot tests, panels have now been exposed about nine years. After six years and seemingly until the present time under atmospheric exposure, all coatings of aluminum and zinc, both sealed and unsealed, are providing adequate corrosion protection to the steel base metal, with one exception. In one industrial environment the sealed and unsealed zinc coated panels with a coating thickness of .003 in. exhibit evidence of base metal corrosion over a small percentage of their surface areas. In industrial environments the aluminum coatings which were sealed with two coats of aluminum vinyl show evidence of less dirt retention than the other coating systems.

Results of Total Immersion Sea Water Exposure Tests

Similarly, under total immersion sea water exposure, all the sealed aluminum coated panels are providing adequate corrosion protection for the base metal. The unsealed aluminum coated panels have some base metal corrosion present, but show no evidence of base metal pitting.

The base metal of all the panels with zinc coating thicknesses of .006 in. and greater is adequately being protected from corrosion. As was anticipated at the inception of this program, all .003 in. zinc coatings gave protection for only a limited time. Severe corrosion of the steel base metal began to occur between the second and third years of exposure.

Results of Mean-Tide Sea Water Exposure Tests

Under mean-tide sea water exposure, all the sealed aluminum coatings are adequately protecting the base metal from corrosion. The unsealed aluminum coatings show some blistering of the aluminum coating with some base metal discoloration; however, there is no evidence of base metal pitting.

The .015 and .018 in. unsealed zinc coatings are providing the base metal with adequate corrosion protection. As was anticipated, the sealed and unsealed .006 in. zinc coated panels have some evidence of base metal corrosion. On the panels with .003 in. zinc coatings, the coatings have been completely dissipated and severe base metal corrosion has occurred.

Test Results

Based on the results of the sixth annual inspection of the panels in this 18-year test program, the following conclusions seem to be justified:

1. The life of the unsealed aluminum coatings is definitely longer than a comparable zinc coating in the case of the thinnest coating thicknesses. However, no estimate can be made on the actual longevity of aluminum coatings.

2. The life of unsealed zinc coatings appears to be directly related to the coating thickness and the environment. In alternate exposure to the atmosphere and to sea water, unsealed zinc .003 in. thick provides less than six years of protection. In some heavy industrial atmospheres, unsealed zinc .003 in. thick may also provide little more than six years of protection. The life of the thicker unsealed coatings cannot, as yet, be predicted.

3. The type of base metal preparation, prior to the metallizing operation, within the range of abrasives used in this program, does not appear to have any effect on the corrosion protection properties of the metallized coatings.

4. In all environments the sealed, aluminum coated panels are the least affected with respect to coating dissipation and apparent marring. Those sealed with two seal coats are in slightly better condition than those with one seal coat.

5. The aluminum vinyl seal coat on the zinc coated panels has lengthened the life of the zinc coatings when compared to the unsealed zinc coatings. Chlorinated rubber sealed coatings have no advantage over the unsealed coatings and in some cases the chlorinated rubber seal coat has detrimental effects.

6. For sea water exposure applications, metallized aluminum sealed with clear vinyl is the best coating system tested in this program for the corrosion protection of steel.

In estimating long-term maintenance costs, it is difficult to evaluate such items as equipment transport, set-up time, scaffolding, and similar variables. Solely on the basis of coating costs, blast cleaning, metallizing with aluminum, and adding two seal coats might cost approximately twice as much as for blast cleaning, a prime coat, and two cover coats of paint. Field experience indicates the metallizing system would have a life of at least 20 years.

OPEN FORUM DISCUSSION

Moderator - Arnold L. Windman, Syska & Hennessy, Inc.*

Axel Kaufmann, Campbell and Aldrich, Architects: What building trades would perform the metallizing operation in the field?

Mr. Plummer: It could be performed by the trades much as is welding. Iron workers, plate fabricators, and pipe fitters do welding operations, and metallizing could be done by any of these. It would presumably be done by one of the metal workers' unions rather than by the painters' union.

Mr. Kaufmann: Is there any color control to the metallizing, or is the finished product always a shiny zinc or aluminum?

Mr. Plummer: A metal color has always been used in the past.

W. W. Ranson, E. I. du Pont de Nemours & Co.: To what extent and by what industries in what applications is the system of corrosion protection which you described being used commercially? Is there an increasing commercial use of metallized coatings?

Mr. Plummer: I think I should preface any answer by stating that I have no close personal ties to the companies which produce the equipment for doing this kind of work, or to those producing the metal used in the work. Therefore, I don't think that I am competent to answer the question. In the past it has been used more for marine work, where very serious corrosion problems exist, than for any other. Its use is increasing, however.

George Azrak, Port of New York Authority: What is the possibility of metallizing in-place steel piles in a salt water tidal zone? What service life could be expected in such an application?

Mr. Plummer: This has been done. The effective service life should be a matter of perhaps 20 years. The tests we're running have been going on for only eight years, but our experience to date would indicate that for thicknesses on the order of .012" to .015" at least 20 years of protection can be expected.

Irwin Kolk, Port of New York Authority: Can a pickling method of surface preparation be used in lieu of blast cleaning? In regard

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*BRI member.

to the coating of interior surfaces of water tanks, has any data been collected on the effect of the metallized coatings on drinking water?

Mr. Plummer: A pickling method could be used. With respect to drinking water, I know of no specific studies. I know that metallized coatings have been used on the interior of tanks used for water storage, and so there has been some experience accumulated. I have no specific information concerning actual tests of any kind.

Loren E. Lynn, Hercules Powder Co.: What was the composition of the chlorinated rubber seal coat? Was it clear or pigmented? Was a single seal of chlorinated rubber coating applied, or did it have a base coat?

Mr. Plummer: The solids were chlorinated rubber plus two types of chlorinated parafins plus a stabilizer (34%). The solvents were aromatic petroleum (66%). It was a clear, air-drying, chlorinated rubber type coating material. There was no base coat; the seal coat was applied to the metallizing itself. I might add that a report giving complete test data, as well as all the controls that were involved, will be made available in the very near future. An earlier report is available and has been for some time, but the one coming out will be a nine-year report.

H. A. Segalas, Procter & Gamble Co.: Do you have any performance comparison data between metallized coatings and the newer, cold galvanizing systems consisting of high zinc content epoxy coatings, and any cost comparison between these two?

Mr. Plummer: We have neither. This was a specific project, studying only the life of these metallized coatings, and there were no comparative studies with paints or any other type of coating.

W. R. Tyler, Aluminum Co. of America, Inc.: Was the effect of raw edges investigated with respect to performance of the two coatings?

Mr. Plummer: There was no raw metal. The panels were coated, both on the surface and on the edges.

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BRI Publications

The Building Research Institute publishes and distributes to its members the proceedings of its conferences and other reports on research in the field of the building sciences. Each member receives the Building Science Directory, a comprehensive guide to sources of information about research and technical developments in the building industry, and the Building Science News, the Institute's monthly newsletter. Non-members may purchase the Directory and the technical reports, titles of which appear below. Orders should be addressed to the Building Research Institute, 1725 De Sales Street, N.W., Washington 6, D. C. A complete list of BRI publications, with annotations, is available upon request.

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Adhesives in Building, No. 979, Selection and Field Application, Pressure Sensitive Tapes, 1962, 95 p., $6.00
Sealants for Curtain Walls, No. 715, 1959, 82 p., $3.00
Requirements for Weatherproofing Thin Shell Concrete Roofs, No. 972, 1962, 47 p., $5.00

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Cleaning and Purification of Air in Buildings, No. 797, 1960, 62 p., $4.00

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Building Research, International, 1960, 41 p., $1.50
College and University Research Reports, 1961, 18 p., mimeo., $1.50
Documentation of Building Science Literature, No. 791, 1960, 46 p., $2.00
New Building Research, Fall 1960, No. 910, 1961, 86 p., $6.00
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Modern Masonry: Natural Stone and Clay Products, No. 466, 1956, 163 p., $4.50
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Current Status of Modular Coordination, No. 782, 1960, 30 p., $2.50

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Noise Control in Buildings, No. 706, 1959, 136 p., $5.00

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Design for the Nuclear Age, No. 992, 1962, 162 p., $10.00

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Performance of Buildings, No. 879 1961, 90 p., $5.00
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Intersociety Reports on Plastics in Building Activities, No. 978, 1962, 66 p., $5.00

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