U. S. DEPARTMENT OF COMMERCE

BUILDING MATERIALS AND STRUCTURES

REPORT BMS102

Painting Steel

by

WILBUR C. PORTER

NATIONAL
BUREAU OF STANDARDS

BUILDING MATERIALS AND STRUCTURES REPORTS

On request, the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., will place your name on a special mailing list to receive notices of new reports in this series as soon as they are issued. There will be no charge for receiving such notices.

An alternative method is to deposit with the Superintendent of Documents the sum of $5, with the request that the reports be sent to you as soon as issued, and that the cost thereof be charged against your deposit. This will provide for the mailing of the publications without delay. You will be notified when the amount of your deposit has become exhausted.

If 100 copies or more of any report are ordered at one time, a discount of 25 percent is allowed. Send all orders and remittances to the *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.*

The following publications in this series are available by purchase from the Superintendent of Documents at the prices indicated:

BMS1 Research on Building Materials and Structures for Use in Low-Cost Housing ---------- 10¢
BMS2 Methods of Determining the Structural Properties of Low-Cost House Constructions --- 10¢
BMS3 Suitability of Fiber Insulating Lath as a Plaster Base ---------- 10¢
BMS4 Accelerated Aging of Fiber Building Boards ---------- 10¢
BMS5 Structural Properties of Six Masonry Wall Constructions ---------- 15¢
BMS6 Survey of Roofing Materials in the Southeastern States ---------- 15¢
BMS7 Water Permeability of Masonry Walls ---------- 10¢
BMS8 Methods of Investigation of Surface Treatment for Corrosion Protection of Steel ------ 10¢
BMS9 Structural Properties of the Insulated Steel Construction Co.'s "Frameless-Steel" Constructions for Walls, Partitions, Floors, and Roofs ---------- 10¢
BMS10 Structural Properties of One of the "Keystone Beam Steel Floor" Constructions Sponsored by the H. H. Robertson Co ---------- 10¢
BMS11 Structural Properties of the Curren Fabrihome Corporation's "Fabrihome" Constructions for Walls and Partitions ---------- 10¢
BMS12 Structural Properties of "Steelox" Constructions for Walls, Partitions, Floors, and Roofs Sponsored by Steel Buildings, Inc ---------- 15¢
BMS13 Properties of Some Fiber Building Boards of Current Manufacture ---------- 10¢
BMS14 Identation and Recovery of Low-Cost Floor Coverings ---------- 10¢
BMS15 Structural Properties of "Wheeling Long-Span Steel Floor" Construction Sponsored by the Wheeling Corrugating Co ---------- 10¢
BMS16 Structural Properties of a "Tilecrete" Floor Construction Sponsored by Tilecrete Floors, Inc ---------- 10¢
BMS17 Sound Insulation of Wall and Floor Constructions ---------- 10¢
Supplement to BMS 17, Sound Insulation of Wall and Floor Constructions ---------- 5¢
BMS18 Structural Properties of "Pre-fab" Constructions for Walls, Partitions, and Floors Sponsored by the Harnischfeger Corporation ---------- 10¢
BMS19 Preparation and Revision of Building Codes ---------- 15¢
BMS20 Structural Properties of "Twachtman" Constructions for Walls and Floors, Sponsored by Connecticut Pre-Cast Buildings Corporation ---------- 10¢
BMS21 Structural Properties of a Concrete-Block Cavity-Wall Construction Sponsored by the National Concrete Masonry Association ---------- 10¢
BMS22 Structural Properties of "Dun-Ti-Stone" Wall Construction Sponsored by the W. E. Dunn Manufacturing Co ---------- 10¢
BMS23 Structural Properties of a Brick Cavity-Wall Construction Sponsored by the Brick Manufacturers Association of New York, Inc ---------- 10¢
BMS24 Structural Properties of a Reinforced-Brick Wall Construction and a Brick-Tile Cavity-Wall Construction Sponsored by the Structural Clay Products Institute ---------- 10¢
BMS25 Structural Properties of Conventional Wood-Frame Constructions for Walls, Partitions, Floors, and Roofs ---------- 15¢
BMS26 Structural Properties of "Nelson Pre-Cast Concrete Foundation" Wall Construction Sponsored by the Nelson Cement Stone Co., Inc ---------- 10¢
BMS27 Structural Properties of "Bender Steel Home" Wall Construction Sponsored by the Bender Body Co ---------- 10¢
BMS28 Backflow Prevention in Over-Rim Water Supplies ---------- 10¢
BMS29 Survey of Roofing Materials in the Northeastern States ---------- 10¢
BMS30 Structural Properties of a Wood-Frame Wall Construction Sponsored by the Douglas Fir Plywood Association ---------- 10¢
BMS31 Structural Properties of "Insulite" Wall and "Insulite" Partition Constructions Sponsored by The Insulite Co ---------- 15¢

[List continued on cover page III]

UNITED STATES DEPARTMENT OF COMMERCE · Jesse H. Jones, Secretary

NATIONAL BUREAU OF STANDARDS · Lyman J. Briggs, Director

BUILDING MATERIALS *and* STRUCTURES

REPORT BMS102

Painting Steel

by

WILBUR C. PORTER

ISSUED OCTOBER 16, 1944

The National Bureau of Standards is a fact-finding organization; it does not "approve" any particular material or method of construction. The technical findings in this series of reports are to be construed accordingly

UNITED STATES GOVERNMENT PRINTING OFFICE · WASHINGTON · 1944

FOR SALE BY THE SUPERINTENDENT OF DOCUMENTS, U. S. GOVERNMENT PRINTING OFFICE
WASHINGTON 25 D. C. • PRICE 10 CENTS

Foreword

This is the third and final report issued by the National Bureau of Standards covering the investigation of pretreatments and paints for protecting plain and galvanized steel surfaces against corrosion.

A description of the tests and an explanation of their limitations were published in a previous report, Methods of Investigation of Surface Treatment for Corrosion Protection of Steel, BMS8. The results of the tests made on pretreatment processes have been published as report BMS44, Surface Treatment of Steel Prior to Painting.

The present paper describes the relative durability of priming-coat and topcoat paints for plain and galvanized steel surfaces when subjected to accelerated laboratory and outdoor exposure tests.

Lyman J. Briggs, *Director.*

Painting Steel

by WILBUR C. PORTER

CONTENTS

ABSTRACT

More than 60 priming paints for plain and galvanized steel surfaces were tested. Because some of these primings were duplicates or near duplicates and others were considered unsuitable, only 41 have been selected for this report. Accelerated laboratory and outdoor exposure tests were employed to determine the relative protective value of these primings when applied to treated and untreated galvanized and plain steel panels. Particularly effective protection against corrosion was observed when primings of the synthetic resin zinc chromate type were used over a phosphate-treated surface. Special attention was given to the effect of pretreating new galvanized steel before painting. More than 2,000 galvanized and plain steel panels were prepared for exposure in the various tests. The relative durability to outdoor exposure of 15 topcoat paints is also discussed.

I. INTRODUCTION

As part of the general research program ot the National Bureau of Standards on building materials and structures, a study has been made of the surface treatment and painting of steel for protection against corrosion. The results obtained in the early phases of the work have been published as two Building Materials and Structures Reports, BMS8 and BMS44.[1] This paper concludes the investigation with a description of the results of the tests on priming-coat and topcoat paints.

In the painting of steel structures, durability of the paint film is a recognized factor in preventing corrosion. Climatic conditions, the composition and preparation of the metal, the adherence and composition of the paint coating, as well as the conditions under which the coating was applied, influence the serviceability of the paint film. Nearly all steel structures are painted either for protective or decorative purposes, and the paint coating must remain as a continuous film over the metal if it is to fulfill these functions properly.

For practical purposes, corrosion tests are made to ascertain which of a number of processes or coatings will protect the metal most completely. It is clear that no laboratory test can fully take the place of a long-period, full-scale service test, and it is not to be expected that these tests, reduced in scale to economize space and increased in intensity to save time, will produce results directly measurable in terms of so many years of actual service. However, it is believed that comparisons can be made from the results of accelerated tests which will indicate to some degree the relative protective value of paint systems. The conclusions in this paper are drawn on the basis of factors affected by conditions peculiar to the individual test, and the results of the outdoor exposure tests may not correlate those in other parts of the country.

II. PRIMING-COAT PAINTS

The fundamental factors governing the retention of paint film integrity on metal may be expressed in a few essential requirements; namely, permanent adhesion, distensibility, water resistance, chemical inertness, and the presence of a rust-inhibitor. The extent to which these characteristics are manifested in paint coatings determines their efficacy for protecting metal against corrosion. The advent of synthetic resins and the proper formulation of these for use in paint vehicles has made possible the improvement of some of these properties.

A synthetic resin may be defined as a resin made by synthesis from nonresinous organic compounds. The alkyd resins, used princi-

[1] BMS8. Rolla E. Pollard and Wilbur C. Porter, Methods of investigation of surface treatment for corrosion protection of steel.
BMS44. Rolla E. Pollard and Wilbur C. Porter, Surface Treatment of Steel Prior to Painting.

607349°—44

pally in paints, varnishes, and lacquers, are a group of condensation products synthesized by reacting polyhydric alcohols, such as glycerine and the glycols, with dibasic organic acids, such as phthalic, maleic, succinic, and sebacic. The condensation product is almost always modified to give properties to the resin desirable or essential to the specific application contemplated. The modifying agent may be a drying, semidrying, or nondrying oil; the fatty acid of an oil; a natural resin, such as rosin; a synthetic resin of the phenolic group or of the urea-formaldehyde type. Good adhesion, color and gloss retention, durability, toughness, and flexibility are some of the outstanding characteristics imparted to primings containing properly formulated alkyd vehicles. They are exceptionally well adapted for the baking type of priming and enamel.

The phenolic resins used in paints, varnishes, and other surface coatings are usually oil-soluble types. Modified phenolic resins are phenol-formaldehyde condensation products rendered oil soluble by chemical combination or by physical dispersion in other materials, such as rosin and copal. Unmodified or 100-percent soluble phenolic resins are condensation products made from tar acids other than simple phenol, which are themselves soluble in drying oils and thinners. The unmodified resins are extensively used in long-oil chinawood varnishes, to which they impart greater drying speed, durability, and resistance to alkalis and gases. The modified types impart the same properties to tung-oil varnishes but to a lesser extent. In addition, they possess considerable hardness and gloss. In general, the phenolic vehicles have very good water, acid, and alkali resistance. The long-oil unmodified types are especially useful in the formulation of exterior marine finishes, which require superior resistance to severe water and weathering conditions.

Oil and phenol modified alkyds are very versatile and combine many of the qualities needed to produce durable paints for general interior and exterior use on metal.

More than 60 priming paints for steel and galvanized surfaces were tested in this investigation. Because some of these primings were duplicates or near duplicates and others were considered unsuitable, only 41 have been included in this report. The primings have been rated in groups according to their protective value, which in this paper means the extent to which the paint coatings fulfill the function of protecting the underlying metal. The ratings are discussed under the results of the tests and for convenience are included in table 1. The following table gives the designation, description, and group ratings of these primings:

TABLE 1.—*Designation, description, and group ratings of the priming-coats*

Designation	Description of primings	Group rating[1]		
		Plain steel (pickled in HCl)	Galvanized steel	
			Untreated	Phosphate treated
1	Red lead paint. Federal Specification TT-R-191a, Type 1, Grade B Dry red lead ... 20 pounds. Raw linseed oil ... 5 pints. Turpentine ... 2 gills. Liquid drier ... 2 gills. 25.2 pounds per gallon.	2	2	1
2	Blue lead paint Blue lead paste in oil ... 100 pounds. Raw linseed oil ... 2⅜ gallons. Turpentine ... 1¾ gallons. Liquid drier ... 1 quart. 18.2 pounds per gallon.	3	3	2
3	International orange paint. Federal Specification TT-P-59. Type A. 18.0 pounds per gallon	2	2	1
4	Metallic lead and carbon paint 38 percent pigment by weight: 90 percent metallic lead. 10 percent carbon black. 62 percent vehicle by weight, oil and phenol modified glyceryl phthalate resin varnish: 56 percent nonvolatile. 44 percent volatile.	3	2	1
5a	Iron oxide-zinc chromate metal priming. Post Office Department Specification, revised as of April 7, 1937	1	3	1
6	Aluminum paint. 2 pounds aluminum powder Federal Specification TT-A-476, Type A, per gallon of varnish Federal Spec. TT-V-81	----	2	1
7	Quick-drying red lead in alkyd (oil type) vehicle. 19.4 pounds per gallon	2	2	1
8	Zinc chromate priming. Navy Aeronautical Specification P-27b, June 1, 1937	1	2	1
9	Zinc dust-zinc-oxide-glyceryl phthalate paint. Federal Specification TT-P-641. Type II, Class A	----	1	1
11	Asphalt varnish, Federal Specification TT-V-51	4	3	3
12	Metallic lead and carbon in phenolic resin vehicle	----	2	1
13	Metallic lead in phenolic resin vehicle	----	3	3
14	Graphite in linseed oil paint	4	3	2
15	Metallic lead in phenolic resin vehicle	3	3	----
17	Metallic lead-blue lead in phenolic resin vehicle 52 percent metallic lead in pigment. 48 percent blue lead in pigment.	3	3	----
21	Zinc dust-zinc oxide priming 68 percent pigment by weight: 60 percent zinc dust. 26 percent zinc oxide. 11 percent siliceous matter. 3 percent white lead. 32 percent vehicle-vegetable oil and spar varnish.	----	2	2
23	Zinc dust-zinc oxide priming 76 percent pigment by weight: 35 percent zinc dust. 65 percent zinc oxide. 24 percent vehicle-vegetable oil and spar varnish.	----	3	2
24	Gray paint for galvanized steel 56 percent pigment by weight: 59 percent zinc oxide. 9 percent white lead. 29 percent siliceous matter. Carbon tinting material present. 44 percent vehicle-vegetable oil and thinner.	----	3	2
25	Natural rubber clear priming. (Aluminum paint in natural rubber vehicle. Topcoat for number 25)	4	3	2
27	Pigmented natural rubber priming. (Aluminum paint in natural rubber vehicle. Topcoat for number 27)	4	3	2
29	Iron oxide-zinc chromate priming 52 percent pigment by weight: 50 percent iron oxide (85% Fe_2O_3). 25 percent zinc chromate. 15 percent asbestine. 10 percent silica. 48 percent vehicle by weight: Phenol-formaldehyde resin-chinawood oil varnish.	1	3	----

See footnote at end of table.

TABLE 1.—*Designation, description, and group ratings of the priming-coats*—Continued

Designation	Description of primings	Group rating[1]: Plain steel (pickled in HCl)	Group rating[1]: Galvanized steel: Untreated	Group rating[1]: Galvanized steel: Phosphate treated
30	Zinc chromate priming 45 percent pigment by weight: 80 percent zinc chromate. 20 percent magnesium silicate. 55 percent vehicle by weight: Phenol-formaldehyde resin-chinawood oil varnish.	1	3	1
31	Zinc chromate priming 45 percent pigment by weight: 80 percent zinc chromate. 20 percent magnesium silicate. 55 percent vehicle by weight: Para phenyl phenol-formaldehyde resin. Oil is 50 percent linseed oil and 50 percent chinawood oil.	1	3	1
32	Zinc chromate-aluminum priming. Similar to No. 31 with the addition of one pound of aluminum powder per gallon of primer	1	3	1
33	Zinc dust-zinc-oxide priming 60 percent pigment by weight: 80 percent zinc dust. 20 percent zinc oxide. 40 percent vehicle by weight: V-10 Naval Aircraft Specification Spar Varnish.	----	3	1
34	Zinc dust-zinc oxide-linseed oil paint. Federal Specification TT-P-641, Type I, Class B	3	1	1
35	Zinc dust-zinc oxide-phenolic resin paint. Federal Specification TT-P-641. Type III, Class B	3	2	1
36	Zinc dust-zinc oxide-iron oxide paint 60 percent pigment by weight: 50 percent zinc dust. 20 percent zinc oxide. 30 percent iron oxide. 40 percent vehicle by weight: Phenolic resin-chinawood oil varnish.	2	2	1
37	Chlorinated rubber paint pigmented with 27 percent aluminum, 41 percent zinc chromate, 14 percent black iron oxide and 18 percent carbon black	2	3	2
38	Chlorinated rubber paint pigmented with 56 percent zinc chromate, 19 percent black iron oxide, and 25 percent carbon black	2	3	2
39	Chlorinated rubber paint pigmented with 88 percent metallic lead, 7 percent zinc chromate, 2 percent black iron oxide, and 3 percent carbon black	3	3	2
54	Red chromate priming 43 percent pigment by weight: 32 percent lead chromate. 10 percent lead sulfate. 37 percent iron oxide. 21 percent siliceous matter. 57 percent spar varnish vehicle by weight.	2	----	----
56	Iron oxide-zinc chromate priming 48 percent pigment by weight: 41 percent zinc chromate. 38 percent iron oxide. 21 percent siliceous material. 52 percent vehicle by weight: Oil and phenol modified glyceryl phthalate resin varnish. 60 percent nonvolatile. 40 percent volatile.	1	----	----
60	Iron oxide-zinc oxide paint 60 percent pigment by weight: 59 percent metallic brown (68% Fe_2O_3). 18 percent Spanish iron oxide (86% Fe_2O_3). 12 percent zinc oxide. 11 percent ashestine. 40 percent vehicle by weight: Long oil spar varnish. 65 percent nonvolatile. 35 percent volatile.	3	2	2
61	Zinc dust-zinc oxide-linseed oil paint 79 percent pigment by weight: 78 percent zinc dust. 20 percent zinc oxide. 2 percent litharge. 21 percent vehicle by weight: Linseed oil, thinner and drier. 90 percent nonvolatile. 10 percent volatile.	----	1	1
68	Aluminum-zinc dust paint 30 percent pigment by weight: 58 percent zinc dust. 22 percent aluminum. 8 percent zinc oxide. 12 percent inert pigment. 70 percent vehicle by weight: Treated oils and natural resin varnish. 64 percent nonvolatile. 36 percent volatile.	3	1	----
74	Metallic lead in alkyd resin varnish 39 percent pigment by weight. 61 percent vehicle by weight: 46 percent nonvolatile containing 38 percent of glyceryl phthalate. 54 percent volatile.	3	2	----
75	Metallic lead-red lead in alkyd resin varnish 51 percent pigment by weight: 75 percent metallic lead. 25 percent red lead. 49 percent vehicle by weight (same as 74).	3	----	----
77	Iron oxide-zinc chromate in alkyd resin varnish 38 percent pigment by weight: 67 percent spanish iron oxide (84% Fe_2O_3). 33 percent zinc chromate. 62 percent vehicle by weight: 45 percent nonvolatile containing 44 percent glyceryl phthalate. 55 percent volatile.	1	----	----
82	Blue lead in phenolic resin varnish 72 percent pigment by weight. 28 percent vehicle by weight.	3	----	----
83	Blue lead in ester gum modified alkyd resin varnish 72 percent pigment by weight. 28 percent vehicle by weight.	3	----	----

See footnote at end of table.

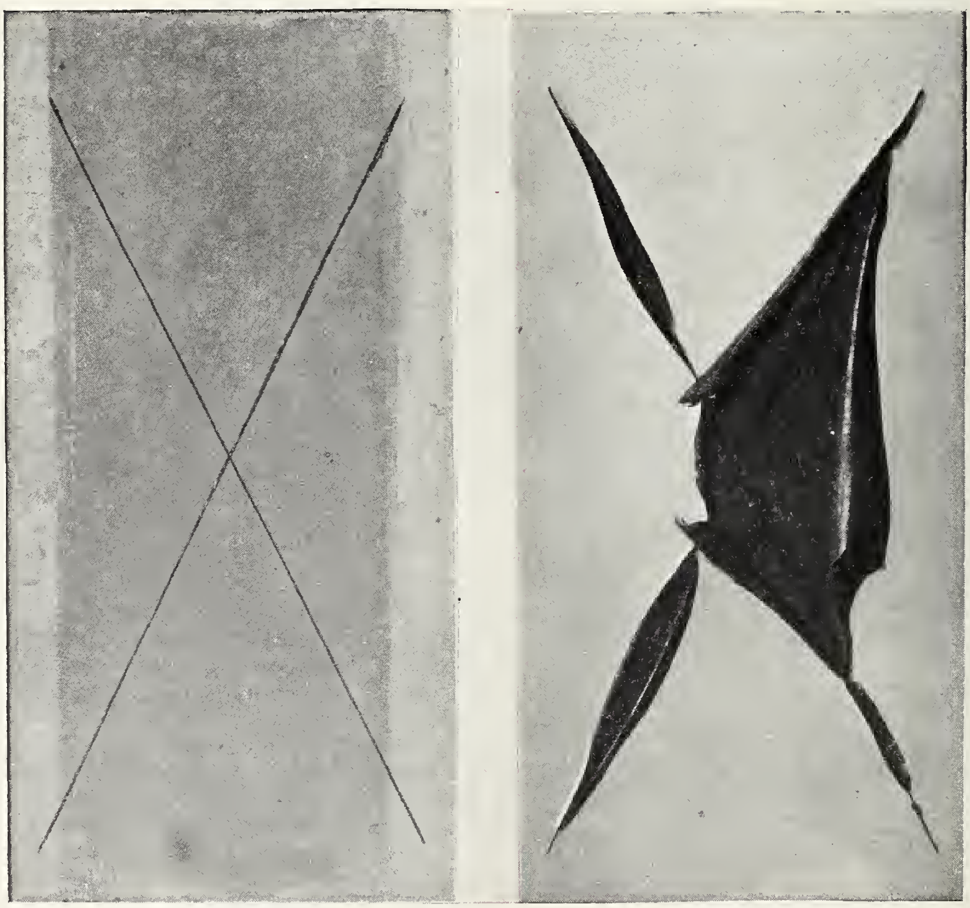
[1] 1 is the best group; 2, the second best group, etc.

III. PAINTING PLAIN STEEL SURFACES

1. PREPARATION OF THE SURFACE

Several theories have been advanced to explain the mechanism of corrosion, but the electrochemical theory is now generally accepted as the best explanation of most types of corrosion. The ordinary metallic surface is not truly homogeneous, chemically and physically, and points of potential difference are sure to exist. In the presence of moisture containing small amounts of dissolved salts, which serve as the electrolyte, a tiny electrolytic cell is formed between anodic and cathodic areas. Under proper conditions, an electric current flows through the electrolyte from the anode to the cathode and from the cathode back to the anode through the metal itself, thus completing the circuit. This electrochemical action causes the metal to dissolve at the anode and hydrogen to be evolved from the electrolyte at the cathode. Obviously, if this action continues, the metal at the anodic areas will gradually disintegrate. The complete absence of moisture precludes the possibility of corrosion by electrochemical action. In other words, the presence of moisture to form an electrolytic medium through which an electric current can flow is necessary for corrosion to take place. Accepting this theory, it is evident that the less water permitted to come in direct contact with the metal, the less corrosion will take place. Since no paint film today is absolutely impervious to moisture, the need for a pigment possessing sufficient rust inhibitive power is obvious. The flow of eletric currents between the anodic and cathodic areas can be retarded by using chemical treatments that form a nonmetallic coating on the metal.

The fundamental requisite of a priming coat paint for any metal surface is that it adheres permanently to the metal. This important requirement should be kept in mind constantly in preparing the surface, and certain precautions should be taken to insure the best performance of the priming coat. All steel surfaces to be painted should be thoroughly cleaned free of grease, rust, loose mill scale, dirt, and other foreign materials that might cause inferior bonding of the priming. Usually this may be accomplished by the use of scrapers, wire brushes, pickling, sandblast, mineral spirits, or other methods that produce a satisfactory surface. In addition to having a clean surface, it has also been found beneficial to treat the metal with certain chemical solutions. The main objective of these chemical treatments is to form a nonmetallic coating, intimately attached to the metal, which retards corrosion and provides greater adhesion of applied paints. Building Materials and Structures Report BMS44, Surface Treatment of Steel Prior to Painting, discusses the pretreatment processes which were included in this



Panel *Fe–H–77*　　Panel *Fe–77*

Figure 1.—*Comparison of treated and untreated steel panels with same priming and topcoat.*

Panel *Fe–H–77:* Hot-dip phosphate treatment; accelerated-weathering, 12 months' exposure.
Panel *Fe–77:* No cleaning or treatment; accelerated-weathering, 2 months' exposure.
(Panels as shown are three-fourths actual size.)

investigation. The hot-dip phosphate treatment showed outstanding merit in improving the protective value of paints in all the tests. Particularly effective protection was obtained when this treatment was used in combination with a priming of the inhibitive type, such as zinc chromate. Reference should be made to Report BMS44 for a detailed discussion of the pretreatment processes tested. Figure 1 shows two panels having the same priming and topcoat, but the panel on the left was cleaned and given a hot-dip phosphate treatment before painting, whereas the panel on the right was neither cleaned nor treated. The left-hand panel was exposed 12 months to the accelerated-weathering cycle, the right-hand panel 2 months. Extremely poor adhesion is illustrated by the panel at the right. The comparison is shown to emphasize the importance of properly preparing the surface before painting.

2. Results of Accelerated-Weathering and Outdoor-Exposure Tests of Priming Coats on Plain Steel

Of the primings listed in table 1, 32 were tested on plain-steel panels. The panels were cut from hot-rolled, 22-United States Gage sheet steel and were pickled in an acid solution to remove rust and mill scale. The kind of acid used for pickling—whether hydrochloric, sulfuric or phosphoric—made no perceptible difference in the results. The hot-dip phosphate treatment improved the protective value of the primings, but the relative ratings are essentially in the same order whether the primings were applied to phosphate-treated or to acid-pickled steel. After pretreatment, the panels were brushed with two coats of priming, a week being allowed for drying between application of coats. A topcoat of outside finish paint was then applied, in some cases to one-half and in other cases to the entire surface of each panel. The painted panels were scratched diagonally to the metal before being tested. All panels exposed to the accelerated-weathering and outdoors were 3 by 6 inches.

According to the results obtained from the accelerated-weathering machine and the outdoor exposure tests, the primings on steel have been rated in groups in the following decreasing order of merit with regard to durability and effectiveness in protecting the metal:

Group 1: Primings 5a, 8, 29, 30, 31, 32, 56, and 77.
Group 2: Primings 1, 3, 7, 36, 37, 38, and 54.
Group 3: Primings, 2, 4, 15, 17, 34, 35, 39, 60, 68, 74, 75, 82, and 83.
Group 4: Primings 11, 14, 25, and 27.

The primings in group 1 are composed of zinc chromate or a combination of zinc chromate and iron oxide in a water-resistant, tough, very adherent, hard-drying vehicle. Synthetic resin varnishes, such as the phenol-formaldehyde and glyceryl phthalate types, undoubtedly play an important role in the performance of these primings. A paint system consisting of this type of priming over a phosphate-treated surface, and having a properly formulated top coat, combines to a high degree the essential properties governing paint-film protection of steel against corrosion. The primings in group 2 gave very good results in the outdoor-exposure test, but in the more severe accelerated-weathering test they were less effective than those in group 1. The primings in groups 3 and 4 were definitely inferior to those in groups 1 and 2.

The rating of any paint coatings on steel is necessarily influenced by the degree of such conditions as chalking, checking, cracking, flaking, scaling, peeling, and rusting. Since the failure of a paint film is usually a gradual deterioration from one condition to another, it is very difficult to designate the transition point at which the film suffers a finite change. It is admitted that some of these ratings might possibly be shifted to a neighboring group, and it is also emphasized that all the primings in any one group are not to be construed as being equal in protective value. However, it is believed that the primings in groups 1 and 2 will last longer and give better protection against corrosion than those in groups 3 and 4 under equal service conditions.

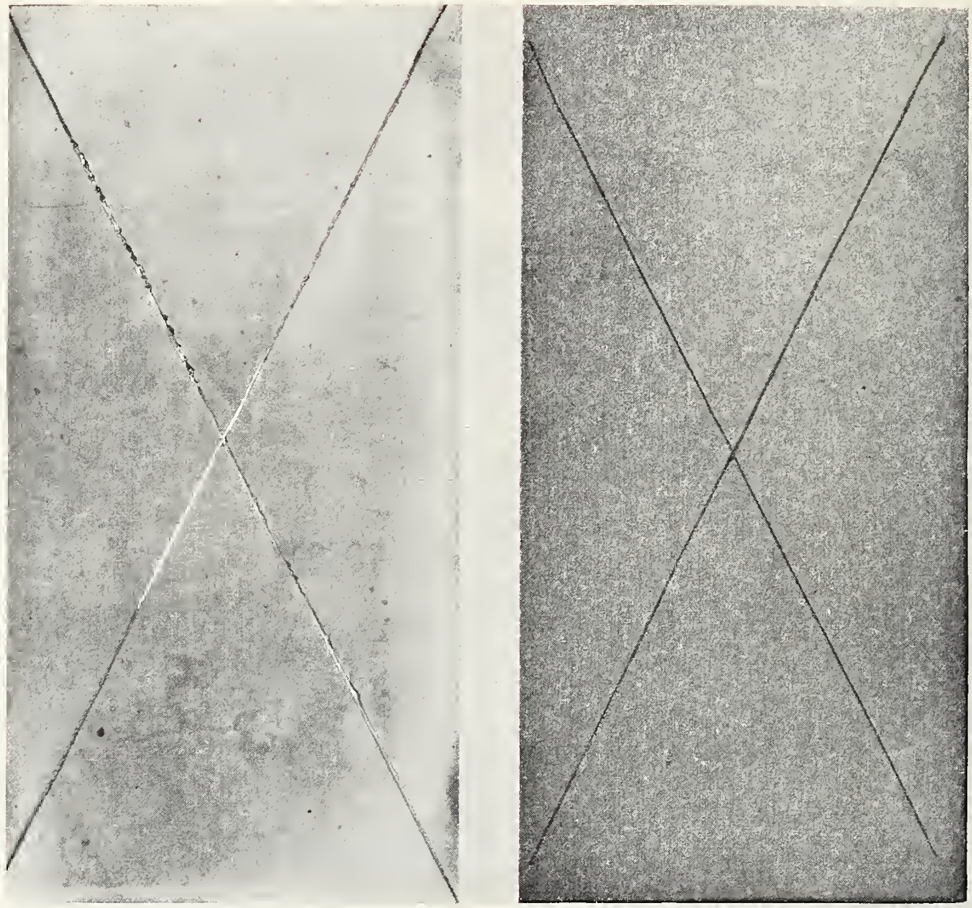
IV. PAINTING GALVANIZED-STEEL SURFACES

1. Preparation of the Surface

Hot-dip galvanizing ordinarily produces a smooth and spangled structure, to which organic finishes do not readily adhere. It is well known that it is difficult to get paint to adhere satisfactorily to new zinc-coated surfaces. Many explanations have been advanced for this lack of adhesion. For example, zinc salts may be left on the surface during the galvanizing process, certain chemical reactions may take place in the paint film itself, and reactive decomposition products in the presence of moisture may react with the metal at the interface. Zinc formate has been isolated [2] at the interface between the paint and the metal zinc surface. This formation of zinc formate has been suggested as one of the possible causes for the poor adherence of paints to galvanized steel.

Pretreating new galvanized steel before painting it was found beneficial. Many chemical solutions have been recommended for this pur-

[2] H. J. Wing, Ind. Eng. Chem. 28, 242 (1936)



Panel *A–9* Panel *A–68*

Figure 2.—*Panels showing paint in good condition after 5 years' outdoor exposure.*

Panel *A–9:* Untreated galvanized surface; two coats priming 9.
Panel *A–68:* Untreated galvanized surface; two coats priming 68.
(Panels as shown are three-fourths actual size.)

pose. Some of these merely etch and roughen the surface. The test results in Report BMS44, indicate that the best treatments do more than merely roughen the surface to hold paint—they change the surface chemically, depositing a nonmetallic film that prevents reaction between metal and paint, increases the adherence of the applied paint, and retards corrosion under the paint film. Solutions of the zinc-phosphate type, sold under proprietary brands, apparently accomplish these functions to a great extent. Galvanized-steel panels treated with such zinc-phosphate solutions showed marked improvement when compared with untreated panels in increasing the protective value of paints applied over them and gave the best results in all the tests. Phosphate-treated galvanized steel sheets are available commercially.

Dirt or greasy material should be removed by cleaning with a solvent, such as turpentine or mineral spirits, before pretreating or painting.

2. Results of Accelerated-Weathering and Outdoor-Exposure Tests of Priming Coats on Galvanized Steel

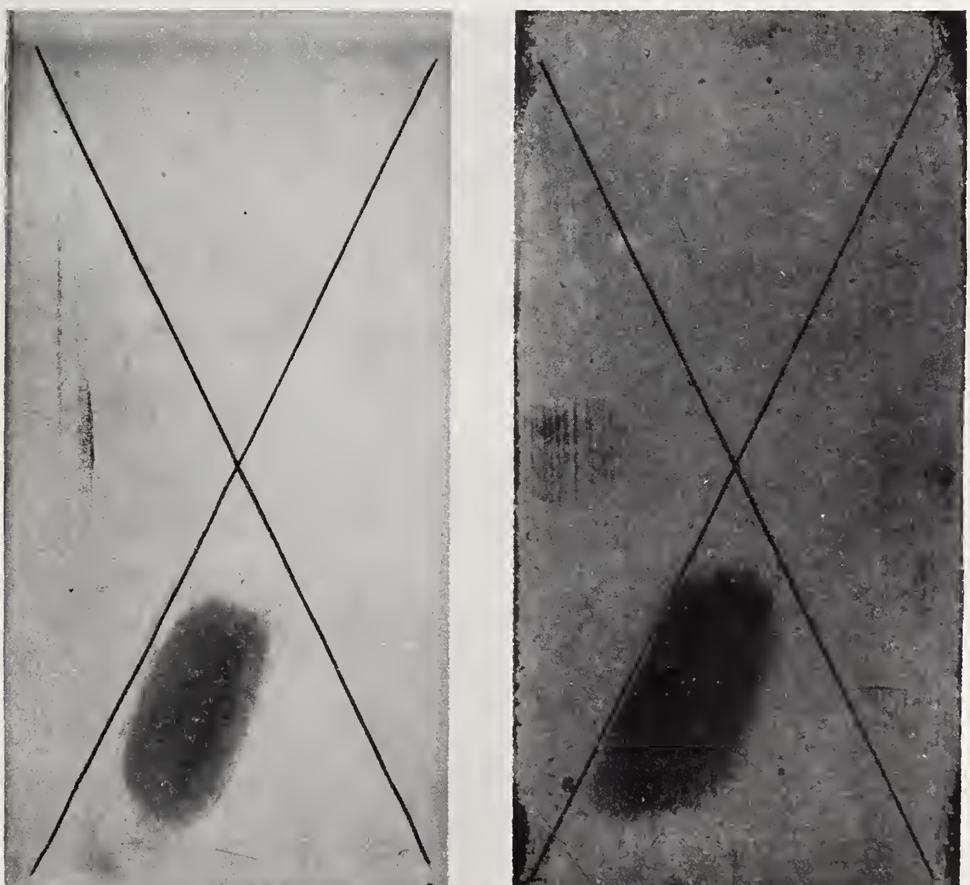
Of the primings listed in table 1, 35 were tested on galvanized-steel panels. The results indicate that great care should be exercised in the selection of a priming coat to be applied to the smooth, spangled surface of hot-dip galvanized steel. Very few primings proved to have satisfactory adhesion on the untreated panels. For this reason two ratings have been given, one for primings on untreated panels and the other for primings on phosphate-treated panels. It should be noted that there is a decided difference in the two ratings. The property of adhesion was given major importance in classifying the performance of primings on galvanized steel. The ratings on untreated galvanized panels are given in groups in order of decreasing merit as follows:

Group 1: Primings 9, 34, 61, and 68.
Group 2: Primings 1, 3, 4, 6, 7, 8, 12, 21, 35, 36, 60, and 74.
Group 3: Primings 2, 5a, 11, 13, 14, 15, 17, 23, 24, 25, 27, 29, 30, 31, 32, 33, 37, 38, and 39.

Here again, as in the rating of the primings on plain steel, it is admitted that some of the primings might be shifted to a neighboring group, and that all the primings in any one group are not to be construed as being equal in protective value. There are many factors to be considered in the interpretation of the results of exposure tests, and the importance attached to each will influence the final rating of the paint. All the primings under group 1 on untreated galvanized panels have good adhesion and are satisfactory for use on untreated galvanized metal. They are also satisfactory as finish coats under normal outdoor conditions and may be used in one or more coats. One coat hides completely and is adequate for many service conditions on new galvanized steel. Two coats are ample for old and slightly rusted galvanized steel surfaces, except under exposure conditions that may require added protection by special finish coats. These primings retain their color very well on prolonged exposure. Number 9 is a zinc dust–zinc oxide alkyd type paint conforming to Federal Specification TT–P–641, Type II, and is especially suitable for use on zinc coated metal.

The primings in group 2 showed fairly good adhesion, especially when a soft drying topcoat, such as lampblack in oil was used over them. However, when they were coated with a hard-drying white topcoat, the tendency to flake, scale, or peel was evident from the results of the accelerated weathering machine. Primings 4, 6, 12, 35, 36, and 60 are suitable for use without a topcoat finish, and when used alone in one or two coats will give good service under ordinary climatic conditions.

In group 3, under untreated galvanized panels, the zinc chromate and iron oxide-zinc



Panel *B–8* Panel *B–1*

Figure 3.—*Panels showing chalking after 3 years' outdoor exposure.*

Panel *B–8:* Phosphate treated galvanized surface; two coats of priming 8 and one of topcoat paint 113.
Panel *B–1:* Phosphate-treated galvanized surface; two coats of priming 1.
(Panels as shown are three-fourths actual size.)

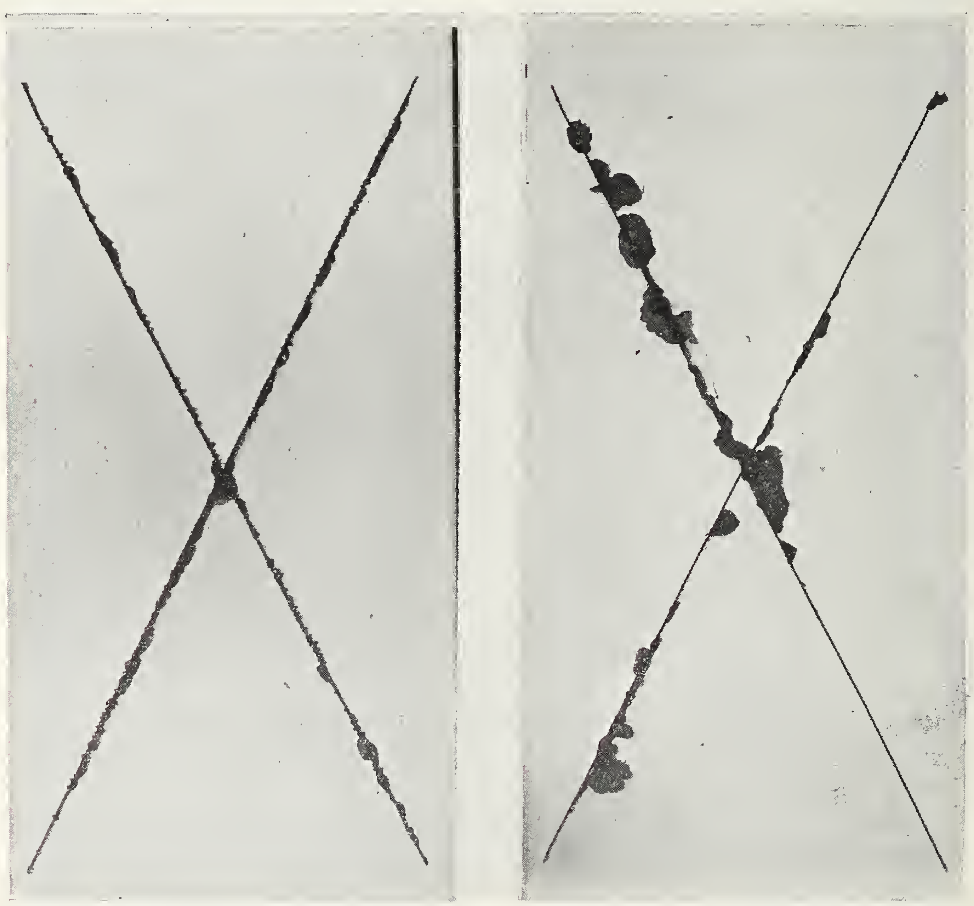
chromate primings failed by lack of adhesion. As will be shown below, the performance of the primings in groups 2 and 3 is much better when applied to a phosphate-treated surface. In testing primings on untreated galvanized metal it was noticed that thin coats adhere much better than thick coats. Since lack of adhesion is one of the chief causes of failure of paints on new galvanized metal, it is advisable to use as few and as thin coats as will give the desired appearance.

The ratings of primings on phosphate-treated galvanized panels are given in groups in order of decreasing merit as follows:

Group 1: Primings 1, 3, 4, 5a, 6, 7, 8, 9, 12, 30, 31, 32, 33, 34, 35, 36, and 61.
Group 2: Primings 2, 14, 21, 23, 24, 25, 27, 37, 38, 39, and 60.
Group 3: Primings 11 and 13.

Primings 15, 17, 29, 68, and 74 were not tested on phosphate-treated panels. From the above ratings it will be seen that the protective value of most primings on galvanized metal is distinctly improved when applied to a phosphate-treated surface. Many of the primings that fell in groups 2 and 3 under the ratings of untreated panels are placed in group 1 on phosphate-treated panels. The improvement in the adherence of zinc chromate and iron-oxide–zinc chromate primings wasp articularly significant. These primings were found to have good rust-inhibitive properties and were very effective in preventing corrosion on phosphate-treated galvanized steel.

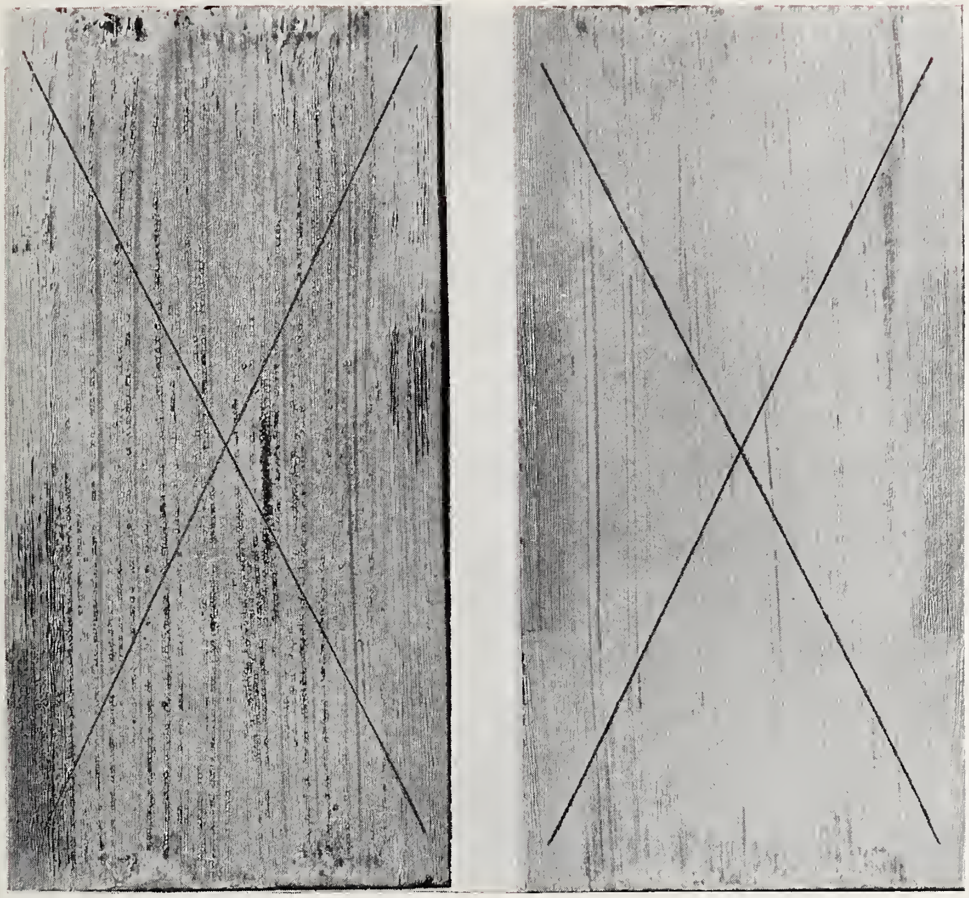
Economy, availability, type of surface (treated or untreated), and climatic conditions are important factors to consider in selecting a paint. By referring to the description of the primings in table 1 and their ratings given above, the painting of galvanized steel should present no great problem. In some cases



Panel *A–1* Panel *A–5a*

Figure 4.—*The panel on the left shows slight flaking along the scratches. and the panel on the right shows peeling after 3 years' outdoor exposure.*

Panel *A–1:* Untreated galvanized surface; two coats of priming 1 and one of topcoat paint 113.
Panel *A–5a:* Untreated galvanized surface; two coats of priming 5a and one of topcoat paint 113.
(Panels as shown are three-fourths actual size.)



Panel *B–7* Panel *B–9*

Figure 5.—*Panels showing checking and cracking after 1 year's exposure in the accelerated-weathering machine.*

Panel *B–7:* Phosphate-treated galvanized surface; two coats of priming 7 and one of topcoat paint 114.
Panel *B–9:* Phosphate-treated galvanized surface; two coats of priming 9 and one of topcoat paint 114.
(Panels as shown are three-fourths actual size.)

Federal specification paint may be required, but for the general buying public, similar products are usually available under trade brands from most paint dealers.

Figures 2 to 5, inclusive, are shown to illustrate the different stages of breakdown in a paint film. Figure 2 shows two panels in good condition after 5 years of outdoor exposure. The two panels in figure 3 show chalking and discoloration. To accentuate this effect, the paint film was rubbed intentionally in one spot before photographing. The left-hand panel in figure 4 shows slight flaking along the scratches, and the right-hand panel shows peeling along the scratches. In figure 5 the left-hand panel shows checking and cracking; the panel on the right shows checking only.

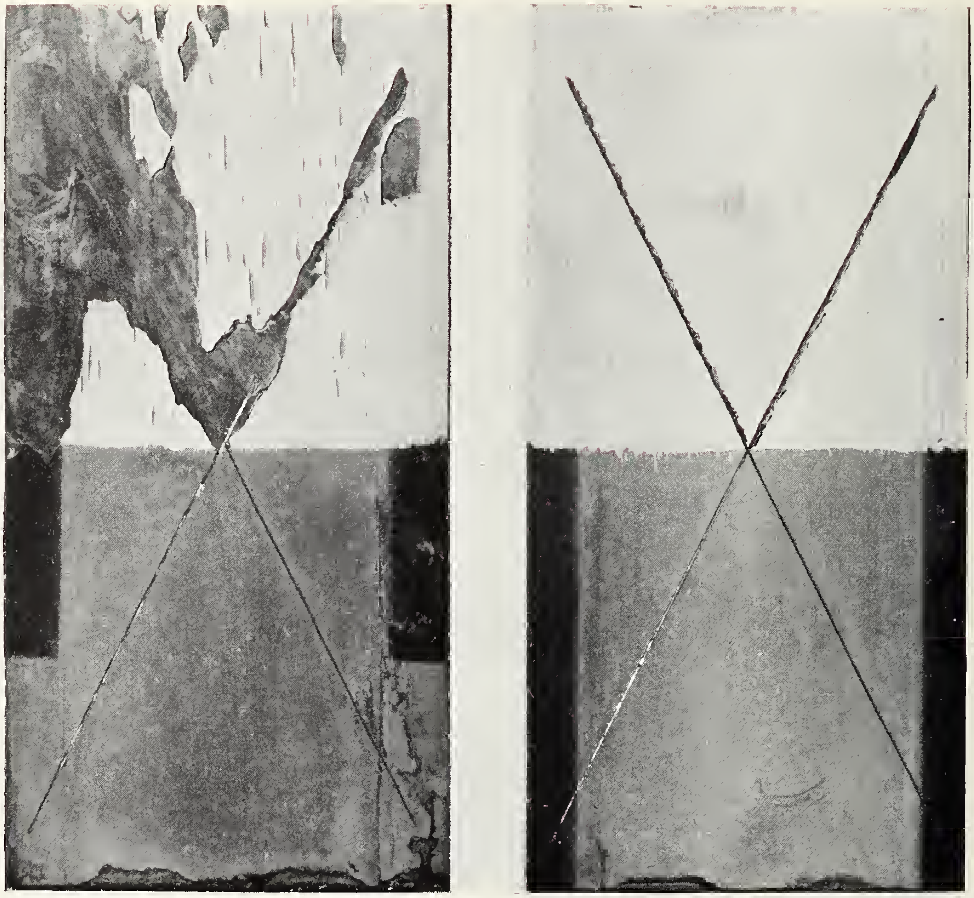
The effect of a phosphate treatment is illustrated in figure 6. The panel on the left was untreated before painting, whereas the panel on the right was phosphate treated. Both panels have the same priming and topcoat and were exposed for 6 months in the accelerated-weathering machine.

V. TOPCOAT PAINTS

In table 2 is given the designation, description, and group rating of the topcoat paints tested.

Table 2.—*Designation, description, and group rating of topcoat paints*

Designation	Description of paint	Group rating
101	Aluminum paint. 2 pounds aluminum powder Federal Specification TT–A–476, Type A, per gallon of varnish, Federal Specification TT–V–81	1
102	Black paint in oil vehicle. Federal Specification TT–P–61, Type B. March 31, 1931	1
103	Lampblack in oil paint 13 percent lampblack pigment by weight. 87 percent linseed oil, thinner and drier.	1
104	Black iron oxide paint 39 percent pigment by weight: 94 percent black iron oxide. 6 percent red lead. 61 percent vehicle by weight: 85 percent linseed oil. 15 percent thinner and drier.	1



Panel *A–33* Panel *B–33*

Figure 6.—*Comparison of untreated and phosphate-treated galvanized-steel panels. Both panels have two coats of priming 33 and the top half of each panel is covered with one topcoat of outside white paint 114.*

Panel *A–33:* Untreated galvanized surface; accelerated-weathering, 6 months' exposure.
Panel *B–33:* Phosphate-treated galvanized surface; accelerated-weathering, 6 months' exposure.
(Panels as shown are three-fourths actual size.)

Table 2.—*Designation, description, and group rating of topcoat paints*—Continued

Designation	Description of paint	Group rating
105	Iron oxide paint 43 percent pigment by weight: 100 percent spanish iron oxide (84% Fe_2O_3). 57 percent vehicle by weight (oil and phenol modified alkyd resin varnish): 45 percent nonvolatile containing 19 percent of glyceryl phthalate. 55 percent volatile mineral spirits.	1
106	Olive green enamel, glyceryl phthalate type, Post Office Department Specification, revised as of October 31, 1939	1
107	Titanium barium-zinc oxide (cream) in alkyd resin vehicle 46 percent pigment by weight: 50 percent titanium-barium. 40 percent zinc oxide. 10 percent asbestine. 54 percent vehicle by weight: 57 percent nonvolatile oil-resin, containing 31 percent glyceryl phthalate. 43 percent volatile mineral spirits. The paint was tinted cream with yellow oxide in oil.	2

Table 2.—*Designation, description, and group rating of topcoat paints*—Continued

Designation	Description of paint	Group rating
108	Gray house paint 64 percent pigment by weight: 20 percent lead titanate. 25 percent basic lead carbonate. 26 percent zinc oxide. 29 percent magnesium silicate. 36 percent vehicle by weight: 87 percent processed linseed and tung oil. 13 percent thinner and drier.	2
109	International Orange Paint 70 percent pigment by weight: 90 percent basic lead chromate. 10 percent magnesium silicate. 30 percent vehicle by weight: 80 percent raw linseed oil. 10 percent spar varnish, TT–V–121a. 10 percent drier.	2
110	Chrome Green Paint. Federal Specification TT–P–71, Type B. August 19, 1930	2
111	Titanium dioxide-zinc oxide (cream) in alkyd resin vehicle 36 percent pigment by weight: 80 percent titanium dioxide, nonchalking. 20 percent zinc oxide.	2

Table 2.—*Designation, description, and group rating of topcoat paints*—Continued

Designation	Description of paint	Group rating
111	Titanium dioxide-zinc oxide—Continued. 64 percent vehicle by weight: 50 percent nonvolatile oil-resin, containing 20 percent glyceryl phthalate. 50 percent volatile mineral spirits.	
112	Lead titanate-zinc oxide (cream) in alkyd resin vehicle 48 percent pigment by weight: 80 percent lead titanate. 20 percent zinc oxide. 52 percent vehicle by weight: 50 percent nonvolatile oil-resin, containing 20 percent glyceryl phthalate. 50 percent volatile mineral spirits.	2
113	Titanium dioxide-zinc oxide (white) in alkyd resin vehicle 34 percent pigment by weight: 80 percent titanium dioxide. 20 percent zinc oxide. 66 percent vehicle by weight: 50 percent nonvolatile oil-resin containing 20 percent glyceryl phthalate. 50 percent volatile mineral spirits.	3
114	White lead-zinc oxide in oil paint. Federal Specification TT-P-36a, Type 11, Class B. July 23, 1938	3
115	Titanium-zinc-lead in oil paint. Federal Specification TT-P-101a, Type A. March 11, 1936	3

1. Results of Tests of Topcoat Paints

All the paints listed in table 2 were exposed outdoors on primed steel panels. A selected number were exposed in the accelerated-weathering machine on galvanized and plain-steel panels, both primed before application of the topcoat.

The function of the final coat on structural steel is to protect the underlying coats and to give the desired color. In one case the protective value of the finish coat may be of major importance, whereas in another case the decorative effect may hold prominence. From the results obtained in these tests it was found that aluminum, black, and dark-colored paints are more durable than white or light-colored paints. This appears to be in general agreement with actual service performance. Also, it was noted that, if a white lead–zinc oxide base paint is tinted, for example to a light- or medium-gray color, the durability is improved. The retention of color, gloss, and general appearance of dark-colored linseed-oil paints can be improved by adding a small amount of spar varnish to the paint. This should not exceed 1 pint of varnish to 1 gallon of paint, and care should be taken to select a varnish that will mix properly with the particular paint. Some of the newer specification paints contain a small amount of varnish in the ready-mixed paint as received. For example, Federal Specification TT–P–71a, April 9, 1941, superseding TT–P–71, states that the liquid in the ready-mixed paint shall be a fortified linseed-oil vehicle consisting of a mixture of 70 percent of linseed oil, 20 percent of nonreactive spar varnish, and 10 percent of combined drier and thinner.

From the exposure results, the topcoat paints have been rated in groups in the following decreasing order of merit with regard to durability:

Group 1: Paints 101, 102, 103, 104, 105, and 106.
Group 2: Paints 107, 108, 109, 110, 111, and 112.
Group 3: Paints 113, 114, and 115.

In group 1 will be found aluminum, iron oxide, olive drab, and black paints. These paints have exceptional resistance to the effects of sunlight and outdoor weathering. They are recommended particularly for structures where the maximum protective value is desired and decoration is of minor importance. Aluminum paint would be the best where moisture and high humidity prevail.

Group 2 contains the tinted and dark-colored paints.

Paint 109, International Orange, and paint 110, Chrome Green, are very durable and are recommended where their respective colors are desired. On exposure, these paints show fairly good color retention, but the color becomes rather "dead" and somewhat "faded" because of mild chalking. In the latest Federal specifications covering these types of paints, the vehicle contains a small amount of spar varnish, which improves the color retention. Paint 108 is a house paint of the slow-drying oil type tinted to a light-gray color. It dries overnight to a soft film, and several days should be allowed for drying between coats. Paint 107, 111, and 112 are cream tinted, synthetic resin alkyd (oil) type topcoats, which dry to a smooth, glossy finish. They dry faster than the orthodox type of oil paint and on outdoor exposure tend to show some chalking and fading.

All the paints in group 3 are white. Paint 114 and 115 are the linseed-oil type and are widely used house paints. The white lead-zinc oxide paint, No. 114, can be obtained in a great variety of tints that will remain fairly stable. Federal Specification TT–P–101a, Type A, represented by paint 115, covers the requirements for a white oil paint for general outside use. Since tints made with this type of paint are likely to show early fading, it should be used only as white. A paint conforming to Federal Specification TT–P–40, Type I, Class B (not included in these tests), is a special fume-proof (lead-free) paint intended for use where sulfide fumes, which will darken paints containing lead, may be encountered. Federal Specification TT–P–40, May 19, 1943, entitled Paint; Oil, Exterior, Ready-Mixed, Light-Tints and White, now supersedes Federal Specifications TT–P–36a, TT–P–101a and TT–P–156. Paint 113, in group 3, is an alkyd (oil) type of white paint that dries to a smooth, glossy finish. From a decorative point of view, this paint retains its whiteness for a long time as it chalks rather freely, and any accumulation of dust or dirt on the surface is readily washed off by rain. Although not as durable as the tinted paints in group 2, it does have the advantage of giving a very white appearance especially during its early exposure period.

In many cases, the selection of a finish-coat paint for metal structures, buildings, and equipment is entirely a matter of choice, and depends on whether the protective value or the decorative effect is of primary significance. For warehouses, storage houses, bridges, water tanks, agricultural implements, and industrial buildings, the paints in group 1 above would probably be most satisfactory. On the other hand, for residences and dwellings, the less durable white and tinted paints will be preferred for esthetic reasons.

VI. SUMMARY AND CONCLUSIONS

A large number of priming- and finish-coat paints, representing various types, were tested for durability and protective value against corrosion by means of accelerated laboratory and outdoor-exposure tests. The composition of the paints and the relative ratings, based on their performance in these tests, are discussed in detail in this publication. Many paints have satisfactory properties that make them suitable for use in protecting metal structures. Locality, temperature, humidity, kind of surface (galvanized or plain-steel), interior or exterior exposure, and general climatic conditions should be considered before selecting a protective coating.

Careful cleaning and preparation of the surface are considered more important than the quality of the paint. The performance of the best paint materials available will be doubtful if little or no attention is given to cleaning and preparing the surface. The tests showed that clean phosphate-treated surfaces materially improve the adherence and protective value of paints.

Zinc chromate and iron oxide–zinc chromate primings, when properly formulated with a synthetic-resin vehicle, make very good rust-inhibitive coatings. A system composed of phosphate-treated galvanized steel, zinc chromate priming, and aluminum topcoat paint combines to a high degree the essential requirements necessary to withstand corrosive atmospheres.

The types of primings rated in group 1 for plain steel surfaces should be used where atmospheric conditions may be severe. For locations where climatic conditions tend less to induce corrosion, the primings in group 2 should be satisfactory.

Treating new galvanized steel before painting is recommended. Emphasis is given to the importance of preparing the metal surface, and the improved performance of synthetic resin primings when applied to phosphate-treated surfaces.

The zinc dust primings rated in group 1 under untreated galvanized steel, are intended for application on new or old galvanized surfaces, and no chemical treatment of the metal is contemplated before using these primings, but accepted treatments may be used if it seems desirable.

Under the ratings on phosphate-treated galvanized steel, primings in both groups 1 and 2 have satisfactory adhesion and will give good service when applied to such surfaces. Naturally, in the more corrosive atmospheres, the rust-inhibitive primings in group 1 should be given preference.

Appearance and local custom will likely be the dominating factors in choosing finish paints for low-cost steel houses. Except in the neighborhood of industrial centers or marine atmospheres, the conventional white or tinted linseed-oil house paints will be satisfactory. In some cases the enamel-like long oil alkyd topcoats may be preferred. As long as the metal is protected from attack by the elements, the question of when to repaint a house depends largely upon individual opinion, but painting should be often enough to keep the appearance consistent with local standards.

Since the cost of application is the major item in painting any structure, price should not be the deciding factor in selecting the materials. However, higher initial cost of materials may in the end be more economical.

Grateful appreciation is hereby expressed of the very helpful assistance given by Rolla E. Pollard in the planning of the investigation and in the correlation of the different phases of the work. Acknowledgment is given to the manufacturers, who submitted paint and pretreatment solutions, for their cooperation and helpful suggestions in this investigation. It is regretted that more specific acknowledgment cannot be given, but in accordance with the initial agreement, all references to products and treatments have been made by code.

VII. SELECTED REFERENCES

R. M. Burns and A. E. Schuh, Protective Coatings for Metals, (Reinhold Publishing Corporation, 330 West 42 St., New York, N. Y., 1939).

Ulick R. Evans, Metallic Corrosion Passivity and Protection, (Edward Arnold & Co., London, 1937).

Frank N. Speller, Corrosion: Causes and Prevention (McGraw-Hill Book Co., Inc., New York. N. Y., 1935).

Improved Maintenance of Metal Surfaces with Zinc Dust Paints, (The New Jersey Zinc Co., 160 Front Street, New York, N. Y., 1939).

A. H. Sabin and F. M. Hartley, Structural Metal Painting, (National Lead Co., 111 Broadway, New York, N. Y., 1934).

The Painting of Structural Metal (Steel, Galvanized Metal, Tin Plate and Copper). National Bureau of Standards Letter Circular LC422. Obtainable free from Bureau.

WASHINGTON, May 1, 1944.

BUILDING MATERIALS AND STRUCTURES REPORTS

[Continued from cover page II]

[List continued on cover page IV]

*Out of print

BUILDING MATERIALS AND STRUCTURES REPORTS

[Continued from cover page III]