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**CORROSION TESTS
OF FLAME-SPRAYED
COATED STEEL
19-YEAR REPORT**



AMERICAN WELDING SOCIETY

CORROSION TESTS OF FLAME-SPRAYED COATED STEEL 19-YEAR REPORT

Prepared by
AWS Committee on Thermal Spraying

Under the Direction of
AWS Technical Activities Committee

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PART I

TEST PROGRAM, RESULTS, AND CONCLUSIONS

INTRODUCTION

This report presents the results of a 19-year study of the corrosion protection afforded by wire-flame-sprayed aluminum and zinc coatings applied to low-carbon steel. The program was initiated in July 1950 by the Committee on Metallizing (now the Committee on Thermal Spraying) of the American Welding Society. The first panels were exposed in January, 1953. This report presents the results of an inspection of the flame-sprayed coated steel panels made after all panels had been exposed for 19 years.

Originally, exposure periods of one, three, six, and twelve years were scheduled. At the end of each of the above periods, a complete set of panels, consisting of three identical panels of each type, was to be removed from the exposure racks for laboratory examination. At the same time, the panels of each type remaining on site were to be inspected and their condition recorded. However, the results of early inspections indicated that nearly all coatings would last for more than twelve years, at each site. Accordingly, the panels scheduled for removal at six years were exposed for twelve years, and the twelve-year set was exposed for nineteen years. Results of the six-year and twelve-year inspections are reported in AWS publications C2.8-62 and C2.11-67, respectively.

The initial program details discussed here, with minor deletions, were taken directly from the AWS 12-Year Report, C2.11-67.

TEST SITES

Test sites were selected to provide a wide variety of environmental conditions. These exposure sites and the exposure dates for the panels in this program are listed in Table 1. All locations were recognized ASTM test areas. No rural exposures were included; some degree of atmospheric contamination, either saline or industrial, exists at all sites. Sea water tests included full and half-tide immersion in quiet sea water, and full immersion in flowing sea water (approximately three knots).

Test panels for atmospheric exposure were mounted on racks inclined 30 deg from the horizontal.

Panels for sea water immersion were mounted in a vertical position.

TEST PANELS

Test panels were made of low-carbon steel sheet (carbon—0.08%; manganese—0.30%; phosphorous—0.08%; sulfur—0.03%; silicon—0.003%; copper—0.30%). The sizes of the steel panels for atmospheric and sea water exposure were 4 x 6 x 1/8 in. (102 x 152 x 3.2 mm) and 4 x 12 x 1/8 in. (102 x 305 x 3.2 mm), respectively.

The aluminum and zinc wire-flame-sprayed coating thicknesses for atmospheric exposure tests were 0.003, 0.006, 0.009, 0.012, and 0.015 in. (0.08, 0.15, 0.23, 0.30, and 0.38 mm). In addition to these, a coating thickness of 0.018 in. (0.46 mm) was included in sea water exposure tests.

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PANEL PREPARATION

The panels were hot-rolled steel which had been pickled to remove mill scale. Surfaces were inspected and panels showing gross defects were rejected.

The next operation was the marking of the panels using a suitable and enduring identification system, a primary requirement in any test program. Experience had shown that notching the edges of the test panels was the most suitable method of identification. All notching was done before blast cleaning and metallizing.

The panels were then thoroughly blast cleaned using a force-fed blast generator and minimum pressure of 90 psi (620 kPa) at the generator with the types and mesh sizes of abrasives shown in Table 2.

The flame-spraying operation was done with a

special automatic machine on which 36 panels were flame-sprayed at once. The speeds of rotation and traverse of both panels and wire flame-spray-gun across the surface were automatically controlled in order to obtain uniformity of coating thickness.

Coating thickness on all panels was checked with a magnetic thickness gage and by weight gain. Complete records were kept. The edges of the panels were then coated separately.

Three types of wire were used:

- (1) $\frac{1}{8}$ in. (3.2 mm) diam aluminum—99.0% min purity.
- (2) $\frac{1}{8}$ in. (3.2 mm) diam zinc—99.9% min purity.
- (3) $\frac{1}{8}$ in. (3.2 mm) diam steel, SAE 1010 grade; carbon—0.08-0.12%; phosphorus—0.04% max; sulfur—0.05% max.

TABLE 1—TEST SITE DESCRIPTION

Test Site and Environment	No. of Panels		Date Exposed
Atmospheric Exposure	Aluminum	Zinc	
Brazos River, Texas (salt air)	156	156	March 1954
Columbus, Ohio (industrial)	120	120	November 1953
East Chicago, Indiana (industrial)	120	120	November 1953
Kure Beach, North Carolina			
*80-ft (24 m) lot (severe marine)	336	336	January 1953
**800-ft (244 m) lot (salt air)	156	156	January 1953
New York City Area (industrial)	120	120	November 1953
Point Reyes, California (salt air)	156	156	December 1953
4 x 6 in. (102 mm x 152 mm) panels reserved	156	156	
Sea Water Exposure			
Freeport, Texas	156	156	October 1953
Wrightsville Beach, North Carolina			
below-low-tide	156	156	October 1953
mean-tide	336	336	October 1953
4 x 12 in. (102 mm x 305 mm) panels reserved	156	156	
Total	2124	2124	

*80 ft (24 m) from shoreline

**800 ft (244 m) from shoreline

TABLE 2—TYPES OF ABRASIVE USED FOR BLAST CLEANING SPECIMENS IN THIS TEST PROGRAM*

Types of Abrasive	Mesh Distribution	Description
Coarse Silica Sand	<i>Tyler Screen Sieve Analysis</i>	Abrasive is washed angular silica sand, dry and free of feldspar, clay or other friable constituents.
	+14 mesh $\leq 5\%$	
	-14+20 " 48% $\pm 10\%$	
	-20+28 " 40% $\pm 10\%$	
	-28+35 " 10% $\pm 10\%$	
Fine Silica Sand	-35 " $\leq 5\%$	Abrasive is washed angular silica sand, dry and free of feldspar, clay or other friable constituents.
	<i>U.S. Standard Screen Analysis</i>	
	+20 mesh $\geq 5\%$	
	-20+30 " 67% $\pm 10\%$	
Chilled Iron Grit	-30+40 " 24% $\pm 10\%$	Abrasive is angular chilled iron grit.
	-40 " $\geq 10\%$	
	Conforms to SAE specification for G-25 angular chilled iron grit.	

*The precise mesh distributions shown would probably not be obtainable in all areas, and they should not be used for specification purposes.

The steel wire was used for a flash-bonding coat on some specimens and was applied automatically to a thickness of 0.001 in. (0.03 mm). This bonding coat is not considered part of the coating thickness.

Sealing treatments, where used, were applied by spraying. Table 3 shows the composition of the sealing materials. These formulations were thinned sufficiently to ensure good penetration and were applied sparingly. The purpose was to fill the surface and subsurface pores of the sprayed metal, rather than to overcoat. By actual measurements, the sealers used added little to the coating thickness.

The types of aluminum- and zinc-sprayed panels exposed are listed in Tables 4 and 5; Types 14 through 28 were included in order to determine the effect of preparation of the steel on the life of the coating. All of these panels had a coating thickness of 0.009 in. (0.23 mm) and were located at only two of the test sites: Kure Beach, North Carolina (80 ft [24m] lot) for atmospheric exposure and Wrightsville Beach, North Carolina (mean tide) for sea water exposure.

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. When the present program was adopted, it was felt that the appearance and condition of the coating itself should be fully described to accurately assess the status of coating deterioration. In this connection, the inspectors reported separately on the condition of the seal coats, the flame-sprayed coatings, and the base metal, as well as on any other conditions. The panels were inspected visually, and therefore the results depended on the interpretation of the individual inspectors. To avoid this, the inspections for the 19-year report were made using a standardized inspection form (see Table 6). Where factors other than normal corrosion processes affected the panels, the results were noted. For example, at one site (Kure Beach 80 ft [24m] lot) some of the racks were damaged by a hurricane. A few panels were lost, but most were recovered;

TABLE 3 — COMPOSITION AND DESCRIPTION OF SEAL COATS

Seal Coat	Composition	Description
Wash Primer	Resin component: Pigment: insoluble type, inert, zinc chromate 8.2% Nonvolatile vehicle: polyvinyl butyral 9.5% Volatile vehicle: butyl and isopropyl alcohol 82.3% Acid component: Phosphoric acid 16.0% Ethyl (or isopropyl) alcohol plus water Balance	An air drying, two-part, acid-zinc chromate wash coat primer
Mix four parts of the resin component with one part of the acid component to obtain final primer composition.		
Aluminum Vinyl	Pigment: nonleafing aluminum flake 10% Nonvolatile vehicle: vinyl copolymer and plasticizer 20% Volatile vehicle: toluene and ketones 70%	A vinyl copolymer aluminum flakes, air-drying type of coating material
Clear Vinyl	Pigment: none Nonvolatile vehicle: vinyl chloride-acetate Resin 16 % Plasticizer 1.4% Volatile vehicle: ketones 37.6% aromatic hydrocarbons (toluene, benzol, xylol) 45.0%	A clear, vinyl copolymer, air-drying coating material
Chlorinated Rubber	Solids: chlorinated rubber—plus two types of chlorinated paraffins plus a stabilizer 34% Solvents: aromatic petroleum solvents 66%	A clear, air-drying, chlorinated rubber type coating material

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TABLE 4—PANEL TYPES FOR ATMOSPHERIC EXPOSURE¹

ALUMINUM FLAME-SPRAYED PANELS				ZINC FLAME-SPRAYED PANELS			
Panel Type	Panel Preparation ²	Coating Thickness, in. (mm)	Seal Coat ³	Panel Type	Panel Preparation ²	Coating Thickness, in. (mm)	Seal Coat ³
1	1	0.003 (0.08)		1	1	0.003 (0.08)	
2	1	" "	WP+AV—1	2	1	" "	WP+AV—1
3	1	" "	WP+AV—2	3	1	" "	CR—2
4	1	0.006 (0.15)		4	1	0.006 (0.15)	
5	1	" "	WP+AV—1	5	1	" "	WP+AV—1
6	1	" "	WP+AV—2	6	1	" "	CR—2
7	1	0.009 (0.23)		7	1	0.009 (0.23)	
8	1	" "	WP+AV—1	8	1	" "	WP+AV—1
9	1	" "	WP+AV—2	9	1	" "	CR—2
10	2	0.012 (0.30)		10	2	0.012 (0.30)	
11	2	" "	WP+AV—1	11	2	" "	WP+AV—1
12	2	" "	WP+AV—2	12	2	" "	CR—2
13	2	0.015 (0.38)		13	2	0.015 (0.38)	
14	2	0.009 (0.23)		14	2	0.009 (0.23)	
15	2	" "	WP+AV—1	15	2	" "	WP+AV—1
16	2	" "	WP+AV—2	16	2	" "	CR—2
17	4	" "		17	4	" "	
18	4	" "	WP+AV—1	18	4	" "	WP+AV—1
19	4	" "	WP+AV—2	19	4	" "	CR—2
20	6	" "		20	6	" "	
21	6	" "	WP+AV—1	21	6	" "	WP+AV—1
22	6	" "	WP+AV—2	22	6	" "	CR—2
23	3	" "		23	3	" "	
24	3	" "	WP+AV—1	24	3	" "	WP+AV—1
25	3	" "	WP+AV—2	25	3	" "	CR—2
26	5	" "		26	5	" "	
27	5	" "	WP+AV—1	27	5	" "	WP+AV—1
28	5	" "	WP+AV—2	28	5	" "	CR—2

¹If a comparison between the aluminum- and zinc-sprayed panels in a certain environment is desirable, it should only be made between panels where coating thickness, panel preparation, and seal coat are the same.

²Types of Surface Preparation

1. Coarse silica sand
2. Coarse silica sand and steel flash
3. Fine silica sand
4. Fine silica sand and steel flash
5. Chilled iron grit
6. Chilled iron grit and steel flash

³Types of Seal Coat

- WP — Wash primer
 AV — Aluminum vinyl
 CR — Chlorinated rubber
 —1 — One coat of specified seal coat
 —2 — Two coats of specified seal coat

some of these had sustained minor mechanical damage.

All panels were removed from the exposure sites, assembled in one location, and inspected by the committee that reviewed the observations of field inspectors.

CONCLUSIONS

(1) Aluminum-sprayed coatings 0.003 in. to 0.006 in. (0.08 mm to 0.15 mm) thick, both sealed and unsealed, gave complete base metal protection from corrosion in sea water and also in severe marine and industrial atmospheres.

(2) Unsealed zinc-sprayed coatings required 0.012 in. (0.30 mm) minimum thickness for complete protection in sea water for 19 years. In severe marine and industrial atmospheres, 0.009 in. (0.23 mm) of unsealed zinc or 0.003 in. to 0.006 in. (0.08

mm to 0.15 mm) of sealed zinc are needed for 19-year protection.

(3) In severe marine atmospheres, the application of one coat of wash primer plus one or two coats of aluminum vinyl enhanced the appearance and extended the life of zinc coatings at least 100%. With aluminum, the sealing system primarily enhanced appearance, because both systems showed no base metal rust after 19 years.

(4) Thin coats of aluminum perform better because they have less tendency to develop pits and blisters and therefore extended life is expected. Vinyl also seems to perform better because it must penetrate to the base metal.

(5) Where aluminum coatings showed damage such as chips or scrapes, corrosion did not progress, suggesting the occurrence of galvanic protection.

(6) The corrosion protection afforded by zinc and aluminum coatings is not affected by the

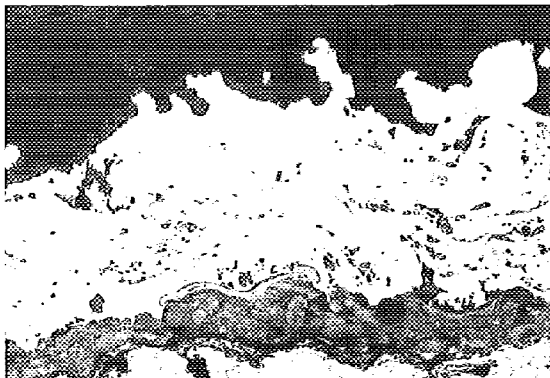


Fig. 1a—Flame-sprayed aluminum coating 0.006 in. (0.15 mm) thick, no sealer, over a flash coat of carbon steel. This photomicrograph illustrates the condition of the aluminum coating after exposure for 18 years at Wrightsville Beach, N.C. in sea water at mean tide level, 250X Nital etch. (Reduced 22% in reproduction.)

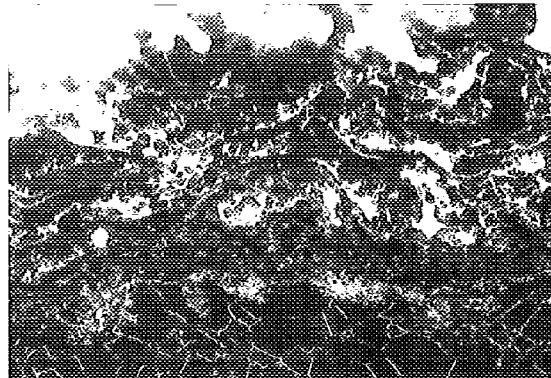


Fig. 1b—Same area, as shown in Fig. 1a, but under polarized light to show the amount of coating that has converted to aluminum corrosion product (white) and remaining aluminum (black). (Reduced 22% in reproduction.)

TABLE 5 — PANEL TYPES FOR SEA-WATER EXPOSURE¹

ALUMINUM FLAME-SPRAYED PANELS				ZINC FLAME-SPRAYED PANELS			
Panel Type	Panel Preparation ²	Coating Thickness, in. (mm)	Seal Coat ³	Panel Type	Panel Preparation ²	Coating Thickness, in. (mm)	Seal Coat ³
1	2	0.003 (0.08)	WP+CV-1	1	2	0.003 (0.08)	CR-1
2	2	" "	WP+CV-2	2	2	" "	CR-2
3	2	0.006 (0.15)	" "	3	2	0.006 (0.15)	" "
4	2	" "	WP+CV-1	4	2	" "	CR-1
5	2	" "	WP+CV-2	5	2	" "	CR-2
6	2	0.009 (0.23)	" "	6	2	0.009 (0.23)	" "
7	2	" "	WP+CV-1	7	2	" "	CR-1
8	2	" "	WP+CV-2	8	2	" "	CR-2
9	2	0.012 (0.30)	" "	9	2	0.012 (0.30)	" "
10	2	" "	WP+CV-1	10	2	" "	CR-1
11	2	" "	WP+CV-2	11	2	" "	CR-2
12	2	0.015 (0.38)	" "	12	2	0.015 (0.38)	" "
13	2	0.018 (0.46)	" "	13	2	0.018 (0.46)	" "
14	1	0.009 (0.23)	" "	14	1	0.009 (0.23)	" "
15	1	" "	WP+CV-1	15	1	" "	CR-1
16	1	" "	WP+CV-2	16	1	" "	CR-2
17	3	" "	" "	17	3	" "	" "
18	3	" "	WP+CV-1	18	3	" "	CR-1
19	3	" "	WP+CV-2	19	3	" "	CR-2
20	5	" "	" "	20	5	" "	" "
21	5	" "	WP+CV-1	21	5	" "	CR-1
22	5	" "	WP+CV-2	22	5	" "	CR-2
23	4	" "	" "	23	4	" "	" "
24	4	" "	WP+CV-1	24	4	" "	CR-1
25	4	" "	WP+CV-2	25	4	" "	CR-2
26	6	" "	" "	26	6	" "	" "
27	6	" "	WP+CV-1	27	6	" "	CR-1
28	6	" "	WP+CV-2	28	6	" "	CR-2

¹If a comparison between the aluminum- and zinc-sprayed panels in a certain environment is desirable, it should only be made between panels where coating thickness, panel preparation, and seal coat are the same.

²Types of Surface Preparation

1. Coarse silica sand
2. Coarse silica sand and steel flash
3. Fine silica sand
4. Fine silica sand and steel flash
5. Chilled iron grit
6. Chilled iron grit and steel flash

³Types of Seal Coat

- WP — Wash primer
 CV — Clear vinyl
 CR — Chlorinated rubber
 —1 — One coat of specified seal coat
 —2 — Two coats of specified seal coat

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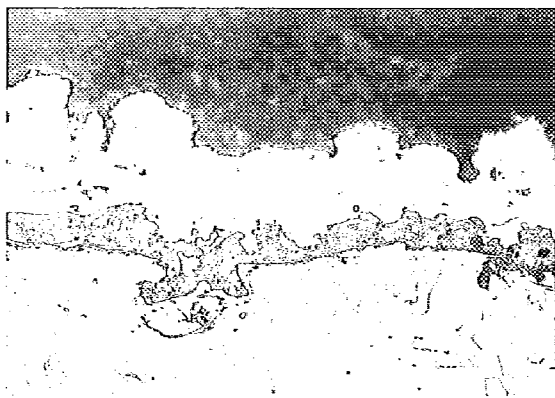


Fig. 2a—Flame-sprayed aluminum coating 0.003 in. (0.08 mm) thick plus one coat of primer and two coats of vinyl. This photomicrograph illustrates the overall condition of the aluminum coating after exposure for 18 years below low tide at Wrightsville Beach, N.C. 250X. Nital etch. (Reduced 22% in reproduction.)

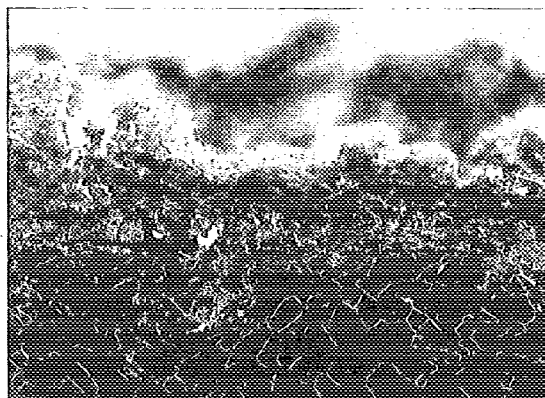


Fig. 2b—This photomicrograph shows the same area as in Fig. 2a, but under polarized light to illustrate the relatively small amount of aluminum corrosion. (Reduced 22% in reproduction.)

TABLE 6 — TERMINOLOGY USED TO DESCRIBE CONDITION OF TEST PANELS (BY INSPECTORS)

Appearance and Condition Terms

- R — *Red rust*, originating from the base metal. Usually well-defined and entirely different from red rust stain.
- W — *White rust*, the corrosion product of zinc or aluminum. Not necessarily white in color; may be stained by contamination.
- D — *Foreign deposit*, such as dirt, etc.
- S — *Stain*, any discoloration other than white rust or red rust stain.
- RS — *Red rust stain*, originating from the base metal with no evidence of blisters, coating failure, or loss of adhesion.
- DS — *Deposit stain*, originating from some source other than panel.
- B — *Blisters* in seal coats or sprayed metal.
- P — *Pits* in sprayed metal, resulting from corrosion.
- N — *Nodes*, well-defined growths or lumps of corrosion product.
- F — *Flakes*, loose segments of seal coat or sprayed metal.

Degree and Descriptive Terms

- b — **Large defect* over $\frac{3}{8}$ in. (9.5 mm) diam.
- me — **Medium defect* over $\frac{1}{8}$ to $\frac{3}{8}$ in. (3.2 - 9.5 mm) diam.
- s — **Small defect* less than $\frac{1}{8}$ in. (3.2 mm) diam.
- p — **Pinpoint defect*.
- f — *Few*—less than 6 per sq in. (6.45 sq cm) of surface.
- i — *Intermediate*—6 to 20 per sq in. (6.45 sq cm) of surface.
- m — *Many*—over 20 per sq in. (6.45 sq cm) of surface.
- g — *General*—covering all or most of the panel.
- bl — *Blotchy*—any irregular pattern.
- gr — *Gray* in color.
- d — *Dark* in color.

*These terms generally used to describe size of nodes, pits, blisters, or spots.