Atmospheric Corrosion Investigation of Aluminum-Coated, Zinc-Coated, and Copper-Bearing Steel Wire and Wire Products

A Twenty-Year Report

Occasione/Britton/Collins

ASTM STP 585A

ATMOSPHERIC CORROSION INVESTIGATION OF ALUMINUM-COATED, ZINC-COATED, AND COPPER-BEARING STEEL WIRE AND WIRE PRODUCTS: A TWENTY-YEAR REPORT

Sponsored by
ASTM Committee A-5 on
Metallic-Coated Iron
and Steel Products

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Foreword

Committee A-5 on Metallic-Coated Iron and Steel Products[1] was organized in 1907, to investigate the corrosion of iron and steel. In 1908, the Committee sponsored its first atmospheric exposure of metallic-coated wires to evaluate their corrosion resistance. Since this date, there have been a considerable number of test programs involving wire, sheet, and hardware. Of particular interest is the program initiated in 1936 and reported on in ASTM Special Technical Publication 290 entitled "Twenty-Year Atmospheric Corrosion Investigation of Zinc-Coated and Uncoated Wire and Wire Products" by Fred M. Reinhart.

In June 1959, the Advisory Committee on Corrosion authorized Committee A-5 to conduct atmospheric corrosion tests of aluminum coated wire and wire products at seven ASTM sites in the United States (see map on next page) and an eighth site in Warrington, England. The responsibility for the latter site was assumed by Rylands Whitecross Limited.

Exposure of the wire and wire products specimens was initiated in 1961. For comparative purposes bare copper-bearing steel wire and zinc-coated steel wire and fabricated products were included in the testing program.

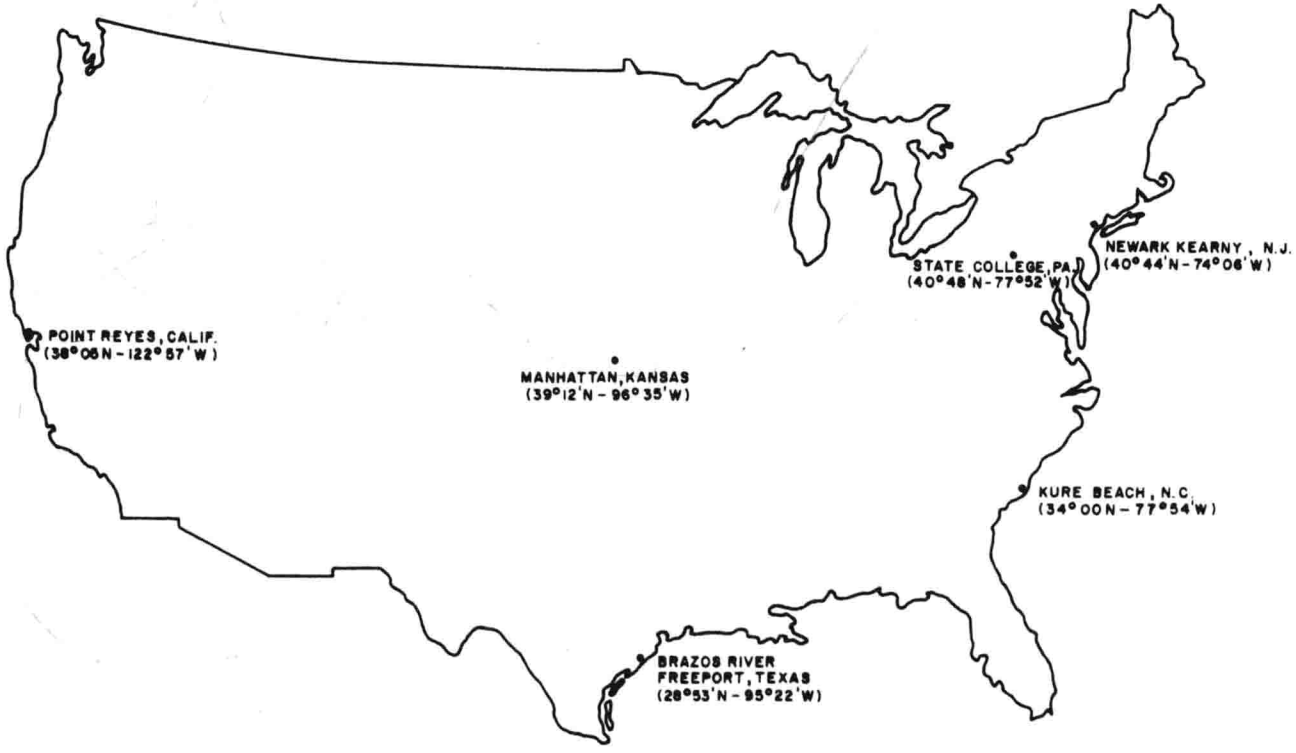
A twelve year report on the 1961 exposure program entitled ASTM STP 585 "Atmospheric Corrosion Investigation of Aluminum-Coated, Zinc-Coated, and Copper-Bearing Steel Wire and Wire Products" by V. I. Kelley was published in 1975.

This report presents the results of 20 years of exposure for the 1961 exposure program, and was prepared by John F. Occasione,[2] Thomas C. Britton, Jr.,[3] and Roy C. Collins.[3]

[1]Committee A-5 was originally titled "Corrosion of Iron and Steel."

[2]Retired in 1975 after 41 years with American Steel and Wire, Cleveland, Ohio and the U.S. Steel Corp., Pittsburgh, Pa., in various metallurgical positions.

[3]Duke Power Company, Charlotte, N.C. 28242.



MAP - LOCATION OF TEST SITES IN THE UNITED STATES

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A Note of Appreciation to Reviewers

The quality of this publication reflects not only the obvious efforts of the authors but also the unheralded, though essential, work of the reviewers. On behalf of ASTM we acknowledge with appreciation their dedication to high professional standards and their sacrifice of time and effort.

ASTM Committee on Publications

Related ASTM Publications

Corrosion of Metals in Association with Concrete, STP 818 (1983), 04-818000-27

Atmospheric Corrosion of Metals, STP 767 (1982), 04-767000-27

Corrosion of Reinforcing Steel in Concrete, STP 713 (1980), 04-713000-27

Corrosion Fatigue Technology, STP 642 (1978), 04-642000-27

Brief Summary of Results

The wire and wire product specimens were exposed at the seven U.S. sites in the spring and summer of 1961 and at Warrington, England on 1 March, 1964. There were 340 unfabricated tension test specimens exposed at each of four sites. To date, 276 have been removed and tested. Wire product specimens (field fence, barbed wire, chain-link fence, and 7-wire strand) were exposed at all eight sites.

The hot dipped aluminum-coated specimens ranged from 0.08 to 0.19 kg/m^2 (0.27 to 0.63 oz/ft^2) of surface, and the aluminum powder metallurgy clad specimen ranged from 0.54 to 1.39 kg/m^2 (1.76 to 4.54 oz/ft^2) of surface. The hot dipped zinc coatings ranged from 0.11 to 0.86 kg/m^2 (0.36 to 2.81 oz/ft^2) of surface, and the electroplated zinc coatings ranged from 0.27 to 0.91 kg/m^2 (0.87 to 2.98 oz/ft^2) of surface.

The corrosion rate of the coatings to initial rust on aluminum-coated unfabricated wires ranged from 0.01 kg/m^2 (0.03 oz/ft^2) per year at the Newark, New Jersey, site to 0.02 kg/m^2 (0.07 oz/ft^2) per year at the Warrington, England, site. In general the corrosion rates of the coatings to initial rust on aluminum-coated fabricated product specimens was within this range at all locations. The corrosion rate of the coatings to initial rust on the zinc-coated unfabricated wire ranged from 0.02 kg/m^2 (0.06 oz/ft^2) per year at State College, Pennsylvania, to 0.06 kg/m^2 (0.20 oz/ft^2) per year at Warrington, England. The corrosion rates of the coatings to initial rust on zinc-coated fabricated products varied considerably from a low of 0.01 kg/m^2 (0.03 oz/ft^2) per year at the Manhattan, Kansas, site to a high of 0.12 kg/m^2 (0.38 oz/ft^2) per year at the Kure Beach, North Carolina, 80 ft site.

The loss in breaking strength over the 20-year period varied considerably from a high in excess of 60% for uncoated and lightly zinc-coated wires exposed at Warrington to some slight gain in strength for some of the heavier aluminum-coated specimens. In general, the aluminum-coated wires sustained less loss in strength than the zinc-coated wires.

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Contents

TEXT

TABLES

FIGURES

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Scope of A-5 and Authorization

The scope of Committee A-5 on Metallic-Coated Iron and Steel Products is quoted as "The collection of engineering information relating to the serviceability of both bare and metallic-coated iron and steel products when subject to corrosion and the formulation of methods of tests and specifications, and work on related subjects." Subcommittee A05.15 is responsible for tests on the atmospheric corrosion of wire and wire products, be they bare or metallic-coated.

With the June 1959 authorization from the Advisory Committee on Corrosion, Subcommittee A05.15, Wire Tests, organized a task group composed of the following:

E. G. Baker, Steel Co. of Canada
B. A. Beery, Page Steel and Wire Division, American Chain and Cable Co., Inc.
W. W. Bradley, Bell Telephone Labs, Inc.
R. S. Dalrymple, Reynolds Metals Co.
O. B. Ellis, Armco Steel Corp.
E. T. Englehart, Aluminum Co. of America
P. M. Emmons, R. E. A.
H. H. Hormann, Consolidated Edison of New York
J. B. Horton, Bethlehem Steel Co.
R. B. Koontz, National Standard Co.
J. B. Kopec, Keystone Steel and Wire Co.
T. A. Lowe, Kaiser Aluminum and Chemical Corp.
J. F. Murphy, Olin Mathieson Chemical Corp.
F. M. Reinhart, U. S. Naval Engineering Lab
Jane H. Rigo, U. S. Steel Corp.
T. A. Schneider, J. A. Roebling's Sons Division
C. W. Straitor, Detroit Edison Co.
C. E. Topping, Consumers Power Co.
L. C. Whitney, Copperweld Steel Co.

Seven producers contributed the aluminum-coated steel wire test samples for the exposure program. These producers were: Bethlehem Steel Co., Copperweld Steel Co., Keystone Steel and Wire Co., National Standard Co., Page Steel and Wire Division, J. A. Roebling's Sons Division, and U.S. Steel Corp. Copper-bearing steel and zinc-coated steel wires were also provided for comparative purposes. Southern Electrical Co., Division of Olin Mathieson Chemical Corp., contributed to the program in the stranding of the steel-reinforced aluminum conductors. Preformed Line Products Co. supplied the dead-end fittings used in the test installations of high-strength strand and steel-reinforced aluminum conductors.

Fabricated items were exposed at eight exposure sites. At four of the sites, unfabricated wires were also exposed. Five types of fabricated wire products

are under test. These are barbed wire, chain-link fencing, field fence, high-strength steel wire strand, and steel-reinforced aluminum conductor. The latter two products are referred to as "7-wire strand" in this document. The relative corrosion resistance of the various test items in the several atmospheres will be established by visual inspection of the unfabricated and fabricated wire items and by periodic determination of percentile loss in breaking strength of the 3.760 and 2.515 mm (0.148 and 0.099-in.) unfabricated wires.

Test Plan

The test plan involved the exposure of specimens representing the following:

1. *Unfabricated Wires*—Evaluation by visual observation and by loss in breaking strength
   Number of replicates: 20
   Test length: 990.6 mm (39 in.)
   Materials
   (*a*) Bare copper-bearing steel wire 3.760 mm (0.148 in.) diameter
   (*b*) Zinc-coated steel wire 3.760 mm (0.148 in.) diameter
      Hot dipped
      Electroplated
   (*c*) Aluminum-coated steel wire 3.760 mm (0.148 in.) diameter
      Hot dipped
      Powder metallurgical technique
   (*d*) Aluminum-coated steel wire 2.515 mm (0.099 in.) diameter
      Hot dipped
      Powder metallurgical technique
2. *Fabricated Wire Products*—Evaluation by visual observation
   Number of replicates: 1
   Test length: 3.05 m (10 ft)
   Materials
   (*a*) Field fence—two sizes: 939-6-11 and 939-6-9
      Zinc-coated steel wire—Hot dipped-two coating weight classes
      Aluminum-coated steel wire—Hot dipped
   (*b*) Barbed wire—12½ gage: Lyman 4-point
      Zinc-coated steel wire—Hot dipped-two coating weights
      Aluminum-coated steel wire—Hot dipped-three coating weights-two wires have aluminum barbs
   (*c*) Chain-link fence—1219.2 mm (48 in.), 9 gage, 50.8 mm (2 in.) mesh, barbed top, knuckled bottom
      Zinc-coated steel wire
         Hot dipped-two coating weights
         Electroplated-two coating weights
      Aluminum-coated steel wire
         Hot dipped-two coating weights

(*d*) High-strength strand

Zinc-coated steel wire—Electroplated 9.525 mm (3/8 in.) diameter, 7 wire 3.048 mm (0.120 in.)-two coating weights

Aluminum-coated steel wire—Various processes, 9.525 mm (3/8 in.) diameter, 7-wire 3.048 mm (0.120 in.), and 7.9375 mm (5/16 in.) diameter, 7-wire, 2.642 mm (0.104 in.)

Range of coating weights

(*e*) Steel reinforced aluminum conductors

Zinc-coated, electroplated steel core wire and aluminum coated steel wire—Various processes. Seven aluminum coated wire strands [1.9609 mm (0.0772 in.)] one zinc-coated steel strand [2.6137 mm (0.1029 in.)] Conventional stranding and compacted strand.

3. *Placement of Specimens*—Figure 1 (*top, center,* and *bottom*) depicts the manner in which the unfabricated wire and fabricated wire products are exposed at the several atmospheric test sites. In all instances precautions are taken to eliminate dissimilar metal contact.

In Fig. 1 (*top*) the unfabricated test wires are racked in groups of 10 on the standard ASTM pipestand by insertion into predrilled 38.1 mm (1 1/2 in.) diameter aluminum rounds. Prior to insertion into the aluminum rounds both ends of the wire were dipped in an adhesive, EC 1099 (product of Minnesota Mining and Manufacturing Co.). The aluminum rounds are installed at center-to-center distance of approximately 1016 mm (40 in.) to accommodate the coil set of the test wires. Each round was predrilled with holes of prescribed diameters to a 6.35 (1/4 in.) depth at 51 mm (2 in.) centers.

Figure 1 (*center*) shows the exposure test setup for the high-strength steel strands and the steel reinforced aluminum conductors. Braces of 31.75 mm (1 1/4 in.) galvanized pipe are drilled at 76 mm (3 in.) centers for the strand and at 95.25 mm (3 3/4 in.) centers for the conductors. The test strands and conductors are outfitted at either end of the test lengths with galvanized or aluminum dead ends, depending upon the contact metal involved.

Field fence and chain-link fencing are erected on suitably finished fence posts as shown in Fig. 1 (*bottom*). The barbed wire specimens are also shown mounted on appropriately finished cross arms, the aluminum in contact with aluminum-coated steel and the zinc-coated fittings in contact with zinc-coated steel. Since these samples were installed by professional erectors, they are tensioned to the degree normally encountered in service.

4. *Test Locations and Exposure Sites*—Table 1 lists the exposure sites, the assigned site numbers, for future reference, the exposure dates, and the type of product, that is, fabricated or unfabricated. The type of atmosphere at each location is classified in accordance with that set forth in the 1958 Report of the Advisory Committee on Corrosion. The three major types are industrial, marine, and rural. A brief description of each site follows.

(*top*) Unfabricated wire
(*center*) Strand (7 wire)
(*bottom*) Chain-link and farm-field fence

FIG. 1—*Aluminum-coated steel wire, strand, and chain-link and field fence erected at the test sites.*

State College, Pennsylvania

This rural site was established in 1925 and is located one mile north of State College, Pennsylvania [elevation 358 m (1175 ft)]. The specimens are mounted 30 deg from the horizontal and face southeast at an azimuth of 147 deg.

Newark, New Jersey—Newark-Kearny, New Jersey

This severe industrial test site was established in 1956 to replace the Port Authority test site. The specimens are mounted at an angle of 30 deg from the

TABLE 1—*Exposure sites.*[a]

Exposure Site, Number, and Location	Type of Atmosphere	Exposure Date	Products Exposed
1. Brazos River, Tex.	marine	17 July 1961	fabricated
2. Kure Beach, N.C. (80 ft)	marine beach exposure	22 May 1961	fabricated
3. Kure Beach, N.C. (800 ft)	marine east coast	23 May 1961	fabricated and unfabricated
4. Manhattan, Kans.	rural	19 July 1961	fabricated
5. Newark, Kearny, N.J.[b]	industrial	12 June 1961	fabricated and unfabricated
6. Point Reyes, Calif.	marine west coast	21 July 1961	fabricated
7. State College, Pa.	rural	19 June 1961	fabricated and unfabricated
8. Warrington, England[c]	industrial	1 March 1964	fabricated and unfabricated

[a] Information concerning these exposure sites follows.
[b] Specimens moved to Kearny, N.J., on 2 July 1970.
[c] Warrington, England, site closed April 1977.

horizontal and face the south southwest at an azimuth of 193 deg [elevation 3 m (11 ft)]. On 2 July, 1970, the wire specimens were taken to a new test site known as Newark-Kearny, New Jersey, on the grounds of Kearny Generation Station at Public Service Electric and Gas Company.

Point Reyes, California

Point Reyes test site was established in 1950 and is located 588 m (1930 ft) from the Pacific Ocean behind low hills covered with salt grass and bushes. The specimens are mounted at an angle of 30 deg from the horizontal and face due west, toward the Pacific Ocean. The atmosphere here is characterized by salt spray and condensation exposure due to westerly winds, dense fogs, and heavy rains which keep the specimens moist during most of the winter. In summer the area is very dry by day with frequent heavy fogs at night.

Kure Beach, North Carolina

The two exposure sites at Kure Beach are under the direction of the International Nickel Co. and are located on the Cape Fear Peninsula 17 miles southeast of Wilmington, North Carolina. One test site is approximately 243 m (800 ft) and the other approximately 24 m (80 ft) from the Atlantic Ocean. The specimens are mounted 30 deg from the horizontal and face south at an azi-

muth of 177 deg at the 800 ft site. At the 24 m (80 ft) site, the specimens parallel the beach at an azimuth of 110 deg. The 24 m (80 ft) site is characterized by seawater spray falling directly on the test specimens.

Freeport, Texas (Brazos River)

In 1952, a test site was established on the Brazos River 1188 m (3900 ft) northwest of the Gulf of Mexico. The specimens are mounted at 30 deg from the horizontal and face southeast (azimuth of 144 deg). The climate in this area is noted for its consistently high humidity. The daytime relative humidity varies between 85 and 93% in the summer and averages 80% in the winter. The night-time humidity is also 100% all year with frequent heavy dews.

Manhattan, Kansas

This rural site is located in an agricultural area with very little industrial contamination. It is a continental climate with relatively large diurnal and annual temperature ranges. There is abundant sunshine as compared to the eastern United States. The elevation is approximately 335 m (1100 ft) above sea level. The annual average rain fall is 851 mm (33.52 in.).

Warrington, England

This industrial site is located on the recreation grounds at Rylands-Whitecross Ltd. at an elevation of 8.5 m (28 ft) above sea level. The location is at 53 deg-24.2′N latitude and 2 deg-34.5′ W longitude. The prevailing wind is south westerly blowing from the town over the site. The exposure racks run from east to west and face south. The town has a diversified industry which includes wire production, light and heavy engineering, hot-rolled steel products, board and paper mills, chemical processing, and extensive brewing. The average (annual) sulfur dioxide (SO_2) contamination for the years 1964 through 1973 was 0.065 ppm. The more recent years indicate a 50% reduction of SO_2 from the earlier annual figures.

Description of the Test Specimens

The following information was provided by each manufacturer for the unfabricated and fabricated wire products which each supplied:

(*a*) General description of the coating process.
(*b*) Chemical analysis of the base metal and metallic coating.
(*c*) Weight of metallic coating.
(*d*) Mechanical properties of the unfabricated wires.
(*e*) Minimum and maximum coating thicknesses as measured microscopically.
(*f*) Cross-sectional photomicrograph to illustrate structure of coating only.

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