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AF TECHNICAL REPORT 5692
SUPPLEMENT 4

AN INVESTIGATION OF ELECTRODEPOSITED ALLOYS FOR PROTECTION OF STEEL AIRCRAFT PARTS

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JULY 1953

WRIGHT AIR DEVELOPMENT CENTER

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July 1953

Materials Laboratory
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Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

FOREWORD

This report was prepared by the Battelle Memorial Institute, under USAF Contract No. AF 33(038)8750. The contract was initiated under Research and Development Order No. 611-11, "Electrodeposition and Electrochemical Treatments" and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Major L. E. Michael acting as project engineer. This is the Final Report on the phase of the work related to outdoor exposure testing of certain experimental coatings on steel.

The work was conducted by A. B. Tripler, Jr., J. Edwin Bride, Glenn Schaer, Glen Fuller, and C. L. Faust, all of Battelle Memorial Institute, Columbus, Ohio.

ABSTRACT

Pure-manganese, manganese-zinc-alloy, and zinc-tin-alloy coatings on steel were exposed for 21 months at the Battelle North Florida Research Station. Panels coated with zinc, cadmium, and chromated zinc were exposed concurrently as standards.

The pure-manganese and manganese-zinc coatings were inferior to the zinc and cadmium standards.

The zinc-tin-alloy coatings of 0.3-mil thickness and greater protected the underlying steel as well as the zinc and cadmium standards.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. E. SORTE
Colonel, USAF
Chief, Materials Laboratory
Directorate of Research

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INTRODUCTION

In a temperate climate, electrodeposited zinc or cadmium keeps steel from rusting for ten years or more. In the tropics, zinc and cadmium coatings deteriorate rapidly and the steel then corrodes. In many cases, this occurs in less than a year. During World War II, this condition became a menace to aircraft which were operating in the tropics. In addition, the storage of steel aircraft parts could not be accomplished with safety.

In 1946, the Air Force contracted with Battelle Memorial Institute to conduct an exploratory research for substitutes for zinc and cadmium coatings for steel parts of aircraft. In planning this work, two restrictions were established for the substitute coatings: (1) the coatings must provide sacrificial (cathodic) protection for SAE 4130 steel, (2) the coatings must be capable of being electrodeposited.

The practical galvanic series of metals and alloys shows that, of the metals which can be electrodeposited from aqueous solutions, there are only three expected to be more active than iron. These three metals are zinc, cadmium, and manganese.

This limited the search to alloys of cadmium or zinc, and pure manganese and its alloys. In order to keep the problem from becoming too complex, the study was further limited to binary alloys.

Although climatic conditions vary in the "tropics", the common denominator was the daily cycle of moisture condensation and drying. In accelerated laboratory tests made to simulate those conditions, pure manganese coatings, zinc-tin-alloy (20-80) coatings, and manganese-zinc-alloy (50-50) coatings showed promise of being superior to zinc and possibly also to cadmium.

This report tells what happened when panels plated with these experimental coatings were exposed outdoors at the inland site of the Battelle North Florida Research Station, Daytona Beach, Florida.

SUMMARY

Of the three experimental coatings tested at the Battelle North Florida Research Station, only the zinc-tin-alloy coatings of 0.3- and 0.5-mil thicknesses offered protection equal to the zinc and cadmium standard coatings. Because the test was discontinued after approximately 21 months' exposure, no conclusions can be drawn as to whether the zinc-tin is superior or inferior to zinc and cadmium at this exposure site.

Zinc-tin-alloy coatings of 0.1-mil thickness were inferior to both zinc and cadmium coatings of like thickness.

Pure-manganese and manganese-zinc-alloy coatings failed rapidly. A 0.5-mil coating of either one was somewhat inferior to 0.1 mil of zinc, and was not nearly so good as 0.1 mil of cadmium.

The preparation of the test panels is described in detail in the report.

DISCUSSION OF ESSENTIAL DATA

Introduction

Three thicknesses were tested for each experimental coating: 0.1 mil, 0.3 mil, and 0.5 mil. There were four 4 x 6-inch panels for each thickness. For the three experimental coatings, this added up to 36 panels.

As standards of comparison, panels coated with pure zinc, chromated zinc, and cadmium were exposed simultaneously. They were also prepared in the three thicknesses, and there were four panels for each thickness. Thus, there were 36 standard panels, making a grand total of 72 panels.

Each of the 72 panels comprised a "four-in-one" test; that is, each panel had four significant areas which were observed separately during the test period.

The surface facing the sky (the panels were mounted on ASTM racks at an angle of 30° from the horizontal) is referred to as the top, and the surface facing the ground is referred to as the bottom. Each of these two surfaces had a 4 x 4-inch area which was unmarked, and a 2 x 4-inch area which had two intersecting, diagonal scratches (see Figure 3 in Experimental Work section). The coatings were scratched in order to determine the degree of sacrificial protection given to the underlying steel. The scratches were milled to a width of 0.006 inch and a depth sufficient to expose the underlying steel.

In the tabulated results, found in Appendix A, four symbols are used to designate the four areas. T refers to the unmarked portion of the panel that faced the sky. TX refers to the scratched portion of the panel which faced the sky. B refers to the unmarked portion of the panel which faced the ground. BX refers to the scratched portion of the panel that faced the ground.

During the first four months, the panels were examined semimonthly, after that they were examined monthly.

The arrangement on the exposure rack is shown in Figure 1.

Each panel was notched according to a code illustrated in Figure 3 in the Experimental Work section.

1 Mn	5 Zn	9 Mn-Zn	13 Cd	17 Zn-Sn	21 Zn (Cr)	25 Mn	29 Zn	33 Mn-Zn	37 Cd	41 Zn-Sn	45 Zn (Cr)	49 Mn	53 Zn	57 Mn-Zn	61 Cd	65 Zn-Sn	69 Zn (Cr)
2 Mn	6 Zn	10 Mn-Zn	14 Cd	18 Zn-Sn	22 Zn (Cr)	26 Mn	30 Zn	34 Mn-Zn	38 Cd	42 Zn-Sn	46 Zn (Cr)	50 Mn	54 Zn	58 Mn-Zn	62 Cd	66 Zn-Sn	70 Zn (Cr)
3 Mn	7 Zn	11 Mn-Zn	15 Cd	19 Zn-Sn	23 Zn (Cr)	27 Mn	31 Zn	35 Mn-Zn	39 Cd	43 Zn-Sn	47 Zn (Cr)	51 Mn	55 Zn	59 Mn-Zn	63 Cd	67 Zn-Sn	71 Zn (Cr)
4 Mn	8 Zn	12 Mn-Zn	16 Cd	20 Zn-Sn	24 Zn (Cr)	28 Mn	32 Zn	36 Mn-Zn	40 Cd	44 Zn-Sn	48 Zn (Cr)	52 Mn	56 Zn	60 Mn-Zn	64 Cd	68 Zn-Sn	72 Zn (Cr)
0.1 mil						0.3 mil						0.5 mil					

FIGURE 1. SCHEMATIC DIAGRAM SHOWING ARRANGEMENT OF TEST PANELS ON EXPOSURE RACKS

In addition to the regular Laboratory Record Book entries, Kodachrome slides were made of the panels during exposure. These were made after 6 months, one year, and 21 months. Two sets were made each time. One set was retained by Battelle, the other was sent to the project engineer at Wright Field. The slides were marked according to the numerical arrangement given in Figure 1.

The tests commenced May 17, 1951, and were discontinued on February 27, 1953.

The sole criterion for judging the protective value of the experimental coatings lies in how they compare with the zinc or cadmium coatings.

Zinc-Tin-Alloy Coatings

For the twenty-one months that the panels were tested, the 0.3 mil and 0.5 mil zinc-tin-alloy coatings protected the underlying steel as well as the zinc and cadmium standard coatings of like thicknesses.

The 0.1-mil zinc-tin-alloy coatings were much inferior to the zinc and cadmium coatings of this thickness. The bottoms showed considerable rusting after two months (see Table A-1, Appendix A). Table A-2, Appendix A, shows that, after four months, rusting was severe.

The observation here, that thin coatings of zinc-tin alloy fail rapidly, confirms the findings of other observers. The thin coatings are probably more porous than thicker coatings.

Zinc-tin-alloy coatings confer about the same amount of sacrificial protection on steel that cadmium coatings do. This was shown by the early appearance of rust in the scratches. Rust was present to approximately the same extent in the scratches of the cadmium coated panels. Corrosion-current-density measurements were made several years ago when the laboratory phase of this work was in its early stages. Zinc-tin (20-80) had about the same static potential as pure zinc. Yet, when coupled with bare steel, a smaller current flowed in the cell containing the zinc-tin alloy. This is because the zinc-tin alloy polarizes to a greater extent than pure zinc, thus accounting for the lower degree of cathodic protection.

It is not recommended that zinc-tin coatings as light as 0.1 mil be used. Since the testing of the 0.3-mil and 0.5-mil coatings was discontinued before they had failed, no conclusions can be drawn concerning their relative effectiveness as compared to zinc or cadmium.

Pure-Manganese Coatings

Pure-manganese coatings were inferior to zinc or cadmium coatings. Reference to the cumulative data tabulated in Appendix A shows that 0.1 mil of either zinc or cadmium was better than 0.5 mil of manganese.

The manganese coatings failed largely due to undercutting (this was also true of manganese-zinc-alloy coatings). The point of weakness was the interface between the coating and the steel. The rust spread laterally beneath the coating, prying it loose. After the coating flaked off, rusting proceeded rapidly.

The degree of sacrificial protection given by manganese coatings is difficult to determine. Manganese corrosion products formed in the scratches, but, being brown, they masked any iron corrosion products which formed. Any sacrificial protection offered by manganese was not of long duration, because of the rapid oxidation of the manganese. The corrosion products were cathodic to steel and this may account for the undercutting which was observed.

Manganese-Zinc-Alloy Coatings

The manganese-zinc-alloy coatings were formed on the steel by plating manganese on the steel, plating zinc over the manganese, and then heating so as to cause diffusion. Details are found in the Experimental Work section. The composition of the coating approximated 50Mn-50Zn (weight per cent).

Manganese-zinc showed the same failing at the basis metal-coating interface that pure manganese did.

The manganese-zinc-alloy coatings were also inferior to zinc or cadmium coatings. Zinc or cadmium coatings of 0.1 mil were superior to the 0.5-mil manganese-zinc coatings.

EXPERIMENTAL WORK*

Preparation of Exposure Panels

General

The SAE 4130 steel on which the experimental and standard coatings were plated measured 4 inches x 18 inches x 1/32 inch as received. Because the larger size facilitated polishing and buffing, these operations were completed before cutting the steel to the 4 x 6-inch size.

The large panels were cleaned in a hot, alkaline, soak cleaner. They were then polished on 240-grit, substantially new, emery belts. The final finishing was done with a sisal buff (Tampico wheel), which produced a finish about equivalent to a 300 grit. The panels were then cut to the 4 x 6-inch size, care being taken not to mar the surfaces. The cut panels were stored under kerosene until ready to plate.

A "robber" type rack was used for plating the panels (see Figure 2). It was formed by bending 1/8 x 1-inch hot-rolled, plain-carbon steel into a rectangular frame measuring 6-1/2 inches x 4-1/2 inches, inside dimensions. The butting ends of the frame were welded together. As shown in Figure 2, the steel panel was supported within this frame by three contact points. Two of them were located on the inside of the lower 4-1/2-inch side. The third was a spring clip located on the upper 4-1/2-inch side. A 1/4-inch rod was brazed, end on, to the outside of the upper 4-1/2-inch side. The rack was suspended in the plating bath by this rod, which in turn was fastened to a reciprocating or to a stationary work rod.

The dimensions of the rack were determined experimentally as those giving uniform plate distribution. A slight modification of the rack was necessary in order to get uniform distribution when plating manganese. The one-inch strip of the "robber" was narrowed to three-quarters inch, and four, 1/4-inch holes were drilled in the top strip to allow gas to escape. Small defects in the plates occurred at the three points of contact with the rack. They were lacquered to eliminate them as foci of corrosion.

Three coating thicknesses, 0.1 mil, 0.3 mil, and 0.5 mil, were prepared for each type of coating, and there were four panels for each thickness. The Magne-Gage** was used for determining coating thicknesses. A tolerance of ±10%, relative to the nominal thicknesses given above, was allowed. A magnet was especially calibrated for measurement of manganese coating thicknesses. The method is described later in this section under Manganese Plating.

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* BMI Laboratory Record Book No. 5381, pp 64-81, and No. 6093, pp 1-88.

** American Instrument Co., Silver Spring, Maryland.

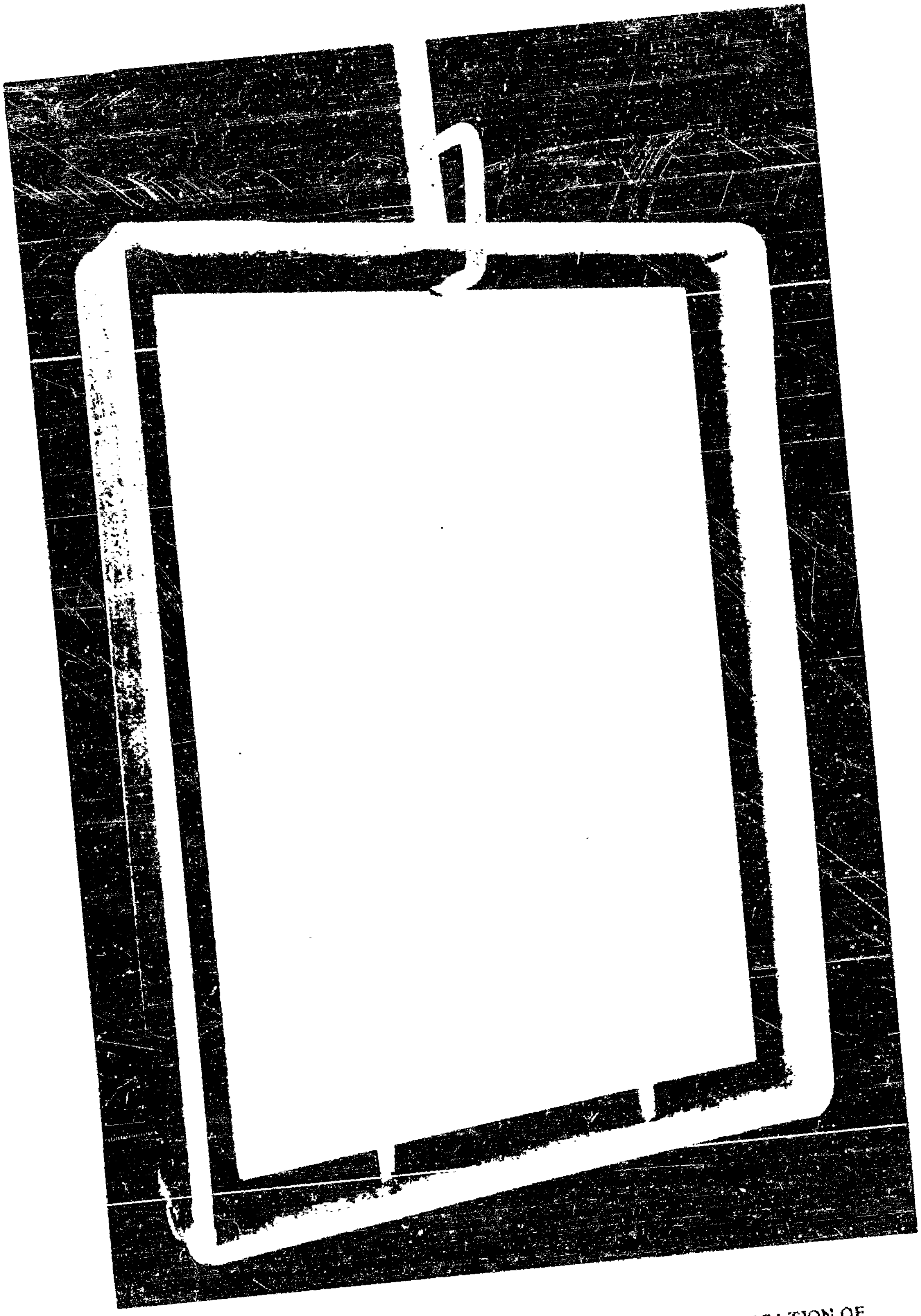


FIGURE 2. "ROBBER" TYPE PLATING RACK, USED FOR PREPARATION OF FOUR-INCH BY SIX-INCH OUTDOOR EXPOSURE PANELS

Identification of the type of coating and thickness was made on each panel by a series of V notches cut in the edge of the panel prior to plating. The code used is explained in Figure 3. The observer is looking at the top (side which faced the sky during the test) when the coating code notches are at the upper left and the thickness code notches are at the upper right. Figure 3 also shows the position of the scratches or scribe marks. The latter were made after the panels were plated. They were cut accurately on a milling machine to a width of 0.006 inch and a depth sufficient to expose the underlying steel. The milling was facilitated by use of a specially prepared jig. The diagonal cuts were made on each side of each panel.

Zinc Plating

The zinc plating on those panels having zinc alone was done from a cyanide-type bath. The composition of the solution and the conditions for plating are given in Appendix B.

Cadmium Plating

The cadmium plating was done from a proprietary cyanide-type bath. The composition of the solution and the conditions for plating are given in Appendix B.

Manganese Plating

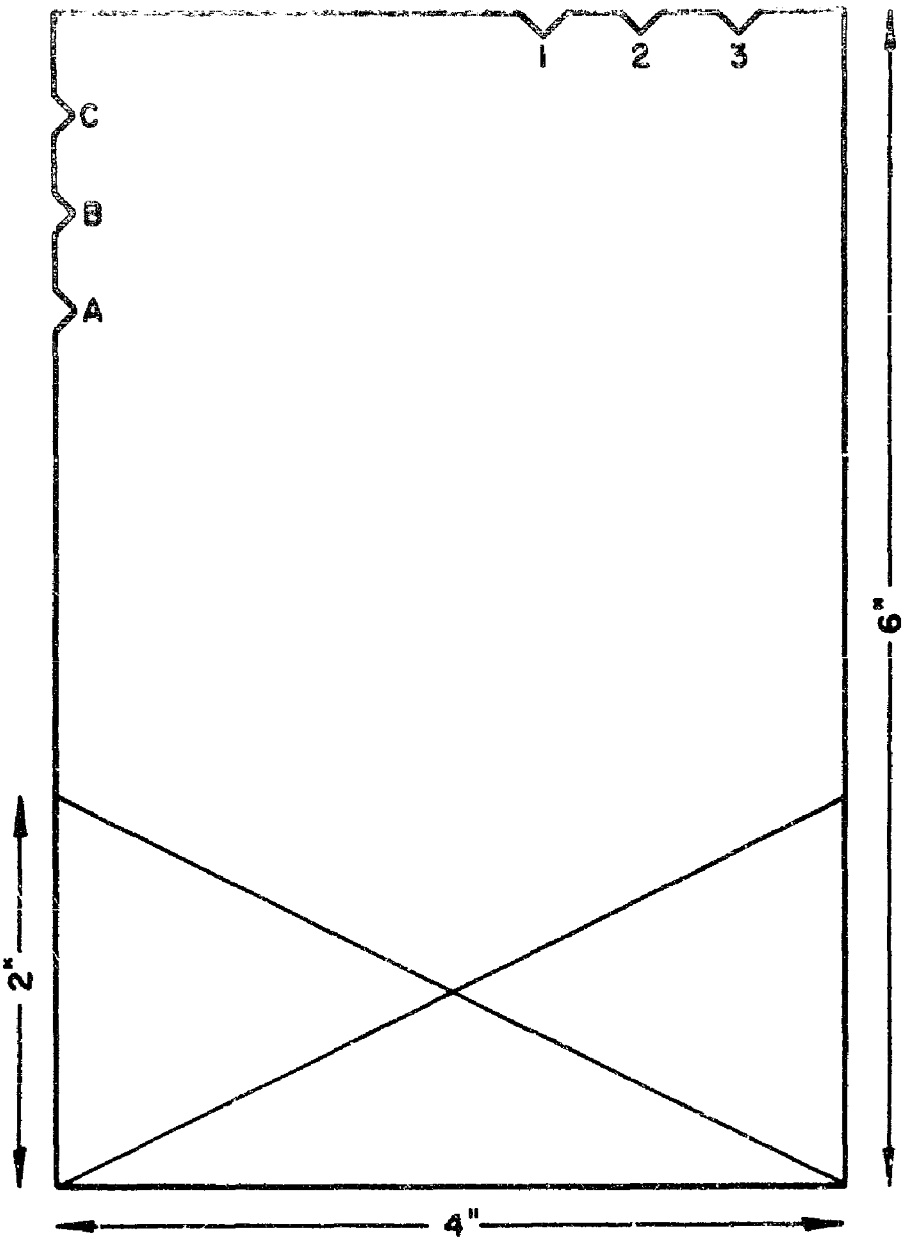
Sound, lustrous-gray deposits of manganese were obtained from a sulfate-type bath containing large amounts of ammonium ion and a very small amount of sulfite. The bath composition and plating conditions are given in Appendix B.

A calibration curve for the measurement of manganese plate thickness was not available. A calibration was made by first testing the thickness magnetically, and then, using exactly the same spot, measuring the true thickness of a microsection with a microscope. The magnetic values were plotted against the true values to obtain the curve.

Zinc-Tin-Alloy Plating

The zinc-tin alloy was deposited from a cyanide-stannate bath developed by the Tin Research Institute in England*. The alloy had a nominal composition of 80% tin and 20% zinc.

* J. Electrochem Soc., 94, 73 (1948).



Coding

A = Zinc	C = Manganese	1 = 0.1 mil
A + C = Zinc + chromate	A+B = Zinc-tin	2 = 0.3 mil
B = Cadmium	B+C = Manganese-zinc	3 = 0.5 mil

FIGURE 3. SCALE DRAWING OF TEST PANEL SHOWING CODING SCHEME FOR IDENTIFICATION AND LOCATION OF DIAGONAL SCRATCHES

Both composition and plating conditions are given in Appendix B. There is also a note regarding the importance of using high-purity sodium stannate.

Manganese-Zinc-Alloy Diffusion Process

The manganese-zinc-alloy coatings were prepared by heat treating manganese-zinc duplex coatings so as to cause interdiffusion of the two elements.

Manganese was plated directly on the steel from the regular manganese bath. A very dilute zinc cyanide bath was then used to place a zinc strike over the manganese plate. The balance of the zinc was then deposited over the strike from a special acid zinc-plating solution.

After plating, the panels were placed in a cold blower-type furnace. The temperature rose to 600 F in one hour and twenty minutes. The furnace was held at this temperature for six hours. The panels were furnace cooled to room temperature in 6-1/2 hours.

Chromate Conversion Coatings

The chromate conversion coatings were formed by the Cronak* process on 12 of the zinc-coated panels. Details of its use are given in Appendix B.

The Outdoor Exposure Site

The panels were mounted on standard ASTM racks at the inland site of the Battelle North Florida Research Station, Daytona Beach, Florida. This site is approximately two miles from the Atlantic Ocean. Salt spray is essentially nil and a heavy dew occurs nine out of ten nights.

The racks faced south and were elevated 30° from the horizontal.

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* New Jersey Zinc Co., U. S. Patent 2,035,380.

APPENDIX A. CUMULATIVE RESULTS OF OUTDOOR-EXPOSURE TESTS FOR EACH TWO-MONTH PERIOD

TABLE A-1. CUMULATIVE RESULTS OF OUTDOOR-EXPOSURE TESTS AFTER 60 DAYS' EXPOSURE(1)

Coating(2) Type	Thickness	Section of Panel(3)	Description of Corrosion
Mn	0.1	T	Scattered pin-point rusting throughout; very numerous pin points of rust on vertical edges
		TX	Numerous pin points of rust
		B	Small area of rust on lower left corners of all 4 specimens
		BX	Numerous pin points of rust on 1 specimen; a few pin points on 3 specimens
Zn	0.1	T	No rust
		TX	Very slight trace of rust in scratches; scratches mostly filled with white corrosion products
		B	No rust
		BX	Same as TX
Mn-Zn	0.1	T	No rust on 2 panels; trace on 2 panels
		TX	A few rust pin points on 1 panel; rust traces in scratches on 3; 3 panels show small rusted area
		B	One pin point and a few small rusted areas
		BX	Same as B
Cd	0.1	T	No rust
		TX	Slight scattered traces of rust in scratches
		B	No rust
		BX	Same as TX
Zn-Sn	0.1	T	Several pin points of rust
		TX	Panel 1 shows 1% rust; panel 2 shows 2% rust; panels 3 and 4 show 4% rust
		B	Pin-point rust covers 60%, 40%, 20%, and 3%, respectively
		BX	Rust spreading from scribes
Zn(Cr)	0.1	T	One small area of rust on each of 2 specimens
		TX	Same as T
		B	No rust
		BX	Traces of rust in scratches
Mn	0.3	T	No rust
		TX	One pin point of rust visible after 13 days; no longer visible after 60 days
		B	No rust
		BX	No rust
Zn	0.3	T	No rust
		TX	No rust; white corrosion products in scribes
		B	No rust
		BX	No rust; white corrosion products in scribes

Coating(2) Type	Thickness	Section of Panel(3)	Description of Corrosion
Mn-Zn	0.3	T	No rust
		TX	Very slight trace of rust in scratches after 18 days; no longer visible after 60 days
		B	No rust
		BX	No rust
Cd	0.3	T	No rust
		TX	Slight trace of rust in scratches
		B	No rust
		BX	Scattered traces in scratches
Zn-Sn	0.3	T	No rust
		TX	Traces of rust in scratches
		B	No rust
		BX	Traces of rust in scratches
Zn(Cr)	0.3	T	No rust
		TX	No rust
		B	No rust
		BX	Few traces of rust in scratches; white corrosion products in scratches
Mn	0.5	T	No rust
		TX	No rust
		B	No rust
		BX	No rust
Zn	0.5	T	No rust
		TX	Possible trace of rust in scratches; white corrosion products in scratches
		B	No rust
		BX	No rust; white corrosion products in scratches
Mn-Zn	0.5	T	No rust
		TX	Possible slight traces of rust in scratches
		B	No rust
		BX	No rust
Cd	0.5	T	No rust; 1 pin-point blister on each of 2 specimens
		TX	Numerous traces of rust in scratches; several tiny blisters on 1 specimen
		B	No rust
		BX	Rust in scratches for about 50% of length
Zn-Sn	0.5	T	No rust
		TX	Traces of rust in scratches for about 75% of length
		B	No rust
		BX	Slight traces of rust in scratches for about 25% of length

TABLE A-1. (Continued)

Coating(2) Type	Thickness	Section of Panel(3)	Description of Corrosion
Zn(Cr)	0.5	T	No rust
		TX	No rust
		B	No rust
		BX	No rust; trace of white corrosion products in scratches

(1) Test started May 17, 1951.

(2) The thickness values (0.1, 0.3, 0.5) are in terms of mils. One mil = 0.001 inch.

(3) T = Unmarked portion of panel which faces sky.
TX = Scratched portion of panel which faces sky.
B = Unmarked portion of panel which faces ground.
BX = Scratched portion of panel which faces ground.

TABLE A-2. CUMULATIVE RESULTS OF OUTDOOR-EXPOSURE TESTS AFTER 127 DAYS' EXPOSURE(1)

Coating(2) Type	Coating(2) Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Mn	0.1	T	
		TX	Uniform pin-point rusting over entire surface; about 40-50% of surface rusting
		B	About 25% of surface covered with pin-point rust
		BX	About 60% of surface covered with pin-point rust
Zn	0.1	T	No rust
		TX	Slight spread of rust from scratches
		B	No rust
		BX	Slight spread of rust from scratches
Mn-Zn	0.1	T	1%, 5%, 35%, and 35%, respectively, of surface covered with rust (four panels)
		TX	20%, 75%, 100%, and 100%, respectively, of surface covered with rust (four panels)
		B	< 1%, 2%, 15%, and 20%, respectively, of surface covered with rust (four panels)
		BX	10%, 75%, 95%, and 95%, respectively, of surface covered with rust (four panels)
Cd	0.1	T	No rust
		TX	Slight scattered traces of rust in scratches
		B	No rust
		BX	Slight scattered traces of rust in scratches
Zn-Sn	0.1	T	1%, 2%, 4%, and 20%, respectively, of surface covered with rust (four panels)
		TX	15%, 25%, 25%, and 40%, respectively, of surface covered with rust (four panels)
		B	10%, 75%, 90%, and 95%, respectively, of surface covered with rust (four panels)
		BX	70%, 70%, 80%, and 98%, respectively, of surface covered with rust (four panels)
Zn(Cr)	0.1	T	Slight traces of rust on each of two specimens
		TX	Slight traces of rust on each of two specimens
		B	No rust
		BX	No rust

TABLE A-2. (Continued)

Coating[1] Type	Coating[1] Thickness, mil[2]	Section of Panel[3]	Description of Corrosion
Mn	0.3	T	One panel has small area of rust
		TX	Three panels have small areas of rust ([illegible] each)
		B	No rust
		BX	No rust
Zn	0.3	T	Small area of pin-point rust on one panel
		TX	Small area of pin-point rust on three panels
		B	No rust
		BX	No rust; white corrosion products in scratches
Mn-Zn	0.3	T	No rust
		TX	No rust
		B	No rust
		BX	No rust
Cd	0.3	T	No rust
		TX	Slight trace of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches
Zn-Sn	0.3	T	No rust
		TX	Traces of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches
Zn(Cr)	0.3	T	No rust
		TX	No rust
		B	No rust
		BX	Few traces of rust in scratches; white corrosion products in scratches
Mn	0.5	T	No rust
		TX	No rust
		B	No rust
		BX	No rust

TABLE A-2. (Continued)

Coating(1) Type	Coating(2) Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Zn	0.5	T	No rust
		TX	Possible trace of rust in scratches; white corrosion products in scratches
		B	No rust
		BX	No rust; white corrosion products in scratches
Mn-Zn	0.5	T	No rust
		TX	Possible slight traces of rust in scratches
		B	No rust
		BX	No rust
Cd	0.5	T	No rust; one pin-point blister on each of tw[illegible] panels
		TX	Numerous traces of rust in scratches; seve[illegible] tiny blisters on one panel
		B	No rust
		BX	Rust in scratches for about 50% of length
Zn-Sn	0.5	T	No rust
		TX	Traces of rust in scratches for about 75% of length
		B	No rust
		BX	Slight traces of rust in scratches for about 25% of length
Zn(Cd)	0.5	T	No rust
		TX	No rust
		B	No rust
		BX	No rust; trace of white corrosion products in scratches

(1) Test started May 17, 1951.
(2) The thickness values (0.1, 0.3, and 0.5) are in terms of mils. One mil = 0.001 inch.
(3) T = Unmarked portion of panel which faces the sky.
TX = Scratched portion of panel which faces the sky.
B = Unmarked portion of panel which faces the ground.
BX = Scratched portion of panel which faces the ground.

TABLE A-3. CUMULATIVE RESULTS OF OUTDOOR-EXPOSURE TESTS AFTER 187 DAYS' (APPROXIMATELY 6 MONTHS') EXPOSURE (1)

Coating Type	Coating Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Mn	0.1	T	Uniform pinpoint rusting over entire surface; about 50% of surface rusting
		TX	40%-50% of area covered with pinpoint rust
		B	About 60% of area covered with pinpoint rust
		BX	
Zn	0.1	T	No rust
		TX	Slight spread of rust from scratches
		B	No rust on three panels; small area of pinpoint rust on one panel
		BX	Brown stains, spreading from scratches, cover less than 5% of area
Mn-Zn	0.1	T	Pinpoint, but nearly continuous, rusting over 5%, 75%, 75%, and 80%, respectively, of surfaces (4 panels)
		TX	Pinpoint, but nearly continuous, rusting over 75%, 75%, 100%, and 100%, respectively, of surfaces (4 panels)
		B	10%, 60%, 60%, and 60%, respectively, of surfaces covered with rust
		BX	30%, 70%, 100%, and 100%, respectively, of surfaces covered with rust
Cd	0.1	T	No rust
		TX	Slight scattered traces of rust in scratches
		B	No rust
		BX	Slight scattered traces of rust in scratches
Zn-Sn	0.1	T	30%, 40%, [illegible]0%, 90%, respectively, of surface covered with rust (4 panels)
		TX	75%, 90%, 9[illegible]%, 98%, respectively, of surface covered with rust (4 panels)
		B	85%, 85%, 95%, 98%, respectively, of surface covered with rust (4 panels)
		BX	95%, 95%, 99%, 100%, respectively, of surface covered with rust (4 panels)
Zn (Cd)	0.1	T	Slight traces of rust on each of two panels; numerous scattered pinpoint specks of white corrosion products
		TX	One small area of rust on each of three panels
		B	No rust
		BX	One small rust area on each of three panels; all panels have traces of rust in scratches

TABLE A-3. (Continued)

Coating Type	Coating Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Mn	0.3	T	Scattered pinpoint rust along vertical edges of all four panels
		TX	Scattered pinpoint rust along lower edges of all four panels
		B	Very slight traces of pinpoint rust along vertical edges of all four panels
		BX	Very slight traces of pinpoint rust in lower corners of all four panels
[illegible]	0.3	T	Small area of pinpoint rust on one panel
		TX	Small area of pinpoint rust on three panels
		B	No rust
		BX	No rust; white corrosion products in scratches
[illegible]	0.3	T	No rust
		TX	No rust
		B	No rust
		BX	No rust
[illegible]	0.3	T	No rust
		TX	Slight trace of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches
Zn-Mn	0.3	T	No rust
		TX	Traces of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches
Zn (Cr)	0.3	T	No rust
		TX	No rust; few pinpoint specks of white corrosion products along lower edges of three panels; numerous pinpoint specks of white corrosion products along lower edge of one panel
		B	No rust
		BX	Few traces of rust in scratches; white corrosion products in scratches
Zn	0.5	T	No rust
		TX	No rust
		B	No rust
		BX	No rust

TABLE A-3. (Continued)

Coating Type	Coating Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
[illegible]	0.5	T	No rust
		TX	Possible traces of rust in scratches; white corrosion products in scratches
		B	No rust
		BX	No rust; white corrosion products in scratches
[illegible]-Zn	0.5	T	No rust
		TX	Possible slight traces of rust in scratches
		B	No rust
		BX	No rust
Cd	0.5	T	No rust; one pinpoint blister on each of two panels
		TX	Numerous traces of rust in scratches; several tiny blisters on one panel
		B	No rust
		BX	Rust in scratches for about 50% of length
Zn-Sn	0.5	T	No rust
		TX	Traces of rust in scratches for about 75% of length
		B	No rust
		BX	Slight traces of rust in scratches for about 25% of length
Zn (Cd)	0.5	T	No rust
		TX	No rust
		B	No rust
		BX	No rust; trace of white corrosion products in scratches

(1) Test started May 17, 1951.

(2) The coating thickness values (0.1, 0.3, and 0.5) are in terms of mils. One mil = 0.001 inch.

(3) T = unmarked portion of panel which faces the sky.
TX = scratched portion of panel which faces the sky.
B = unmarked portion of panel which faces the ground.
BX = scratched portion of panel which faces the ground.

TABLE A-4. CUMULATIVE RESULTS OF OUTDOOR-EXPOSURE TESTS AFTER 245 DAYS' (8 MONTHS') EXPOSURE(1)

Coating Type	Coating Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Mn	0.1	T	Pinpoint to 1/8"-diameter rust spots scattered uniformly over entire surface, accompanied by micro-blistering; approximately 50% of actual surface rusting
		TX	Pinpoint to 1/8"-diameter rust spots scattered uniformly over entire surface, accompanied by micro-blistering; approximately 50% of actual surface rusting
		B	Same as T and TX
		BX	Similar to T and TX, but approximately 75% of actual surface rusting
Zn	0.1	T	No rust
		TX	Slight spread of rust from scratches; one panel has 1/4" x 1/4" rust stain near lower left corner
		B	No rust on two panels; third panel has 3/8"-diameter rust spot; fourth panel has 1"-diameter rust spot
		BX	Slight spread of rust from scratches
Mn-Zn	0.1	T	Pinpoint but nearly continuous rusting over 30%, 80%, 80%, and 80%, respectively, of the surfaces of four panels
		TX	Pinpoint but nearly continuous rusting over 80%, 80%, 80%, and 100%, respectively, of the surfaces of four panels
		B	Pinpoint but nearly continuous rusting over entire surfaces, about 75% of actual surface is rusting
		BX	Pinpoint but nearly continuous rusting over entire surfaces, about 75% of actual surface is rusting
Cd	0.1	T	No rust
		TX	Slight, scattered traces of rust in scratches
		B	No rust
		BX	Slight, scattered traces of rust in scratches
Zn-Sn	0.1	T	Panels removed from rack 12/21/51 (218 days' exposure), at which time all surfaces were covered 50% or more with rust
		TX	Panels removed from rack 12/21/51 (218 days' exposure), at which time all surfaces were covered 50% or more with rust
		B	Panels removed from rack 12/21/51 (218 days' exposure), at which time all surfaces were covered 50% or more with rust
		BX	Panels removed from rack 12/21/51 (218 days' exposure), at which time all surfaces were covered 50% or more with rust

TABLE A-4. (Continued)

Coating Type	Coating Thickness, mil[illegible]	Section of Panel[3]	Description of Corrosion
Zn (Cr)	0.1	T	Slight traces of rust on each of two panels; numerous scattered pinpoint specks of white corrosion products
		TX	One small area of rust on each of three panels
		B	No rust
		BX	Small rust area on each of four panels; all panels have traces of rust in scratches
Ni	0.3	T	Scattered pinpoint to 1/16"-diameter rust spots over 40%, 50%, 60%, and 100%, respectively, of the surfaces of all four panels, about 40% of actual surface is rusting in all cases
		TX	Scattered pinpoint to 1/16"-diameter rust spots over entire area of all four panels, about 40% of actual surface is rusting in all four cases.
		B	Traces of pinpoint rust along vertical edges of all four panels are increasing.
		BX	Traces of pinpoint rust in lower corners of all four panels are increasing.
Zn	0.3	T	Small area of pinpoint rust on one panel
		TX	Small area of pinpoint rust on three panels
		B	No rust
		BX	No rust; white corrosion products in scratches
Mn-Zn	0.3	T	No rust
		TX	Few pinpoint rust spots in lower left corner of three panels, and in lower right corner of fourth panel
		B	No rust
		BX	No rust
Cd	0.3	T	No rust.
		TX	Slight trace of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches

TABLE A-4. (Continued)

Coating Type	Coating Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Zn-Sn	0.3	T	No rust
		TX	Traces of rust in scratches
		B	No rust
		BX	Slight trac[illegible] of rust in scratches
Zn (Cr)	0.3	T	No rust; scattered pinpoint specks of white corrosion products along lower edges of all panels; few scattered white spots elsewhere on all panels
		TX	No rust; scattered pinpoint specks of white corrosion products along lower edges of all panels; few scattered white spots elsewhere on all panels
		B	No rust
		BX	Few traces of rust in scratches; white corrosion products in scratches
Mn	0.5	T	No rust: possible microblistering
		TX	No rust: possible microblistering
		B	No rust
		BX	No rust
Zn	0.5	T	No rust
		TX	Possible traces of rust in scratches; white corrosion products in scratches
		B	No rust.
		BX	No rust: white corrosion products in scratches
Mn-Zn	0.5	T	No rust; possible microblistering
		TX	Possible slight trace of rust in scratches; possible microblistering
		B	No rust; definite microblistering
		BX	No rust; definite microblistering
Cd	0.5	T	No rust; one pinpoint blister on each of two panels
		TX	Numerous traces of rust in scratches; several tiny blisters on one panel
		B	No rust
		BX	Rust in scratches for about 50% of length

TABLE A-4. (Continued)

Coating Type	Coating Thickness, mil[2]	Section of Panel[3]	Description of Corrosion
Zn-Sn	0.5	T	No rust
		TX	Traces of rust in scratches for about 50% of length
		B	No rust
		BX	Slight traces of rust in scratches for about 25% of length
Zn (Cr)	0.5	T	No rust
		TX	No rust
		B	No rust
		BX	No rust; trace of white corrosion products in scratches

(1) Test started May 17, 1951.
(2) The coating-thickness values (0.1, 0.3, and 0.5) are in terms of mils. One mil = 0.001 inch.
(3) T = Unscratched portion of panel which faces the sky.
TX = Scratched portion of panel which faces the sky.
B = Unscratched portion of panel which faces the ground.
BX = Scratched portion of panel which faces the ground.

TABLE A-5. CUMULATIVE RESULTS OF OUTDOOR-EXPOSURE TESTS AFTER 302 DAYS' (10 MONTHS') EXPOSURE[1]

Coating Type	Coating Thickness, mil[2]	Section of Panel[3]	Description of Corrosion
Mn	0.1	T	Pinpoint to 1/8"-diameter rust spots scattered uniformly over entire surface, accompanied by microblistering; approximately 50% of actual surface rusting
		TX	Pinpoint to 1/8"-diameter rust spots scattered uniformly over entire surface, accompanied by microblistering; approximately 50% of actual surface rusting
		B	Same as T and TX
		BX	Similar to T and TX, but approximately 75% of actual surface rusting
Zn	0.1	T	No rust
		TX	Slight spread of rust from scratches; one panel has 1/4" x 1/4" rust stain near lower left corner
		B	No rust on two panels; third panel has 1% rust; fourth panel has 5% rust
		BX	Rusting on about 5%, 5%, 8%, and 10%, respectively, of the surfaces of four panels; the rusting is along the scratches
Mn-Zn	0.1	T	About 95% of all surfaces actually rusted
		TX	About 95% of all surfaces actually rusted
		B	About 95% of all surfaces actually rusted
		BX	About 95% of all surfaces actually rusted
Cd	0.1	T	No rust
		TX	Slight, scattered traces of rust in scratches
		B	No rust
		BX	Slight, scattered traces of rust in scratches
Zn (Cd)	0.1	T	Slight traces of rust on each of two panels; numerous pinpoint specks of white corrosion products on the two other panels
		TX	Two panels have 15% and 45%, respectively, of the areas along the lower edges rusting; third panel has small area of rust
		B	No rust
		BX	Three panels have 1%, 5%, and 5%, respectively, of their surfaces rusting, fourth panel has small area of rust

TABLE A-5. (Continued)

Coating Type	Coating Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Mn	0.3	T	Scattered pinpoint to 1/16"-diameter rust spots over 40%, 50%, 60%, and 100%, respectively, of the surfaces of all four panels. About 40% of actual surface is rusting in all four cases. Three panels have areas where the coating has flaked off, indicating that the iron rust is undercutting the coating.
		TX	Scattered pinpoint to 1/16"-diameter rust spots over entire area of all four panels; about 40% of actual surface is rusting in all four cases
		B	9%, 10%, 20%, and 20%, respectively, of the surfaces of four panels are rusting
		BX	About 30% of the surface of each panel is rusting
Zn	0.3	T	Small area of pinpoint rust on one panel
		TX	Faint brown stains along lower edges of all four panels.
		B	No rust
		BX	No rust, white corrosion products in scratches
Mn-Zn	0.3	T	No rust
		TX	About 5% of surface shows possible slight rust
		B	No rust
		BX	Same as TX
Cd	0.3	T	No rust
		TX	Slight trace of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches

TABLE A-5. (Continued)

Coating Type	Coating Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Zn-Sn	0.3	T	No rust
		TX	Traces of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches
Zn (Cr)	0.3	T	No rust; scattered pinpoint specks of white corrosion products along lower edges of all panels; few scattered white spots elsewhere on all panels
		TX	
		B	No rust
		BX	Few traces of rust in scratches; white corrosion products in scratches
Mn	0.5	T	No rust; possible microblistering
		TX	
		B	No rust
		BX	No rust
Zn	0.5	T	No rust
		TX	Possible traces of rust in scratches; white corrosion products in scratches
		B	No rust
		BX	No rust; white corrosion products in scratches
Mn-Zn	0.5	T	No rust; possible microblistering
		TX	Possible slight trace of rust in scratches; possible microblistering
		B	No rust; definite microblistering
		BX	No rust; definite microblistering
Cd	0.5	T	No rust; one pinpoint blister on each of two panels
		TX	Numerous traces of rust in scratches; several tiny blisters on one panel
		B	No rust
		BX	Rust in scratches for about 50% of length

TABLE A-5 (Continued)

Coating			
Type	Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Zn-Sn	0.5	T	No rust
		TX	Traces of rust in scratches for about 50% of length
		B	No rust
		BX	Slight traces of rust in scratches for about 25% of length
Zn (Cr)	0.5	T	No rust
		TX	No rust
		B	No rust
		BX	No rust; trace of white corrosion products in scratches

(1) Test started May 17, 1951.

(2) The coating-thickness values (0.1, 0.3, and 0.5) are in terms of mils. One mil = 0.001 inch.

(3) T = Unmarked portion of panel which faces the sky.

TX - Scratched portion of panel which faces the sky.

B = Unmarked portion of panel which faces the ground.

BX = Scratched portion of panel which faces the ground.

TABLE A-6. CUMULATIVE RESULTS OF OUTDOOR-EXPOSURE TESTS AFTER ONE YEAR'S EXPOSURE(1)

Coating		Section of Panel(3)	Description of Corrosion
Type	Thickness, mil(2)		
Mn	0.1	T	Pinpoint to 1/8"-diameter rust spots scattered uniformly over entire surface; accompanied by microblistering, approximately 75% of actual surface rusting
		TX	
		B	Similar to T and TX but approximately 85% of actual surface rusting
		BX	
Zn	0.1	T	Uniform gray-white film of corrosion products with innumerable pinpoint to pinhead spots of heavier white corrosion products
		TX	General appearance same as T. one panel has 3/8"-diameter rust stain near lower left corner, and a second panel has a 1/4" strip of pinpoint rust along lower left edge and left bottom edge
		B	No rust on one panel, second has trace of rust, third has 1% rust, and fourth has 10% rust
		BX	Rusting on about 5%, 5%, 10% and 20%, respectively, of the surfaces of four panels; the rusting is mostly along the scratches
Mn-Zn	0.1	T	Panels removed from rack, April 17, 1952. 95% of all surfaces rusted
		TX	
		B	
		BX	
Cd	0.1	T	No rust
		TX	Slight scattered traces of rust in scratches
		B	No rust
		BX	Slight scattered traces of rust in scratches
Zn(Cr)	0.1	T	Slight traces of rust on each of two panels; all panels have varying amounts of pinpoint to pinhead spots of white corrosion products
		TX	Two panels have 20% and 35%, respectively, of the areas along the lower edges rusting; third panel has very light pinpoint rust in 1/2"-diameter area in lower left corner
		B	No rust
		BX	Three panels have 2%, 10% and 15%, respectively, of their surfaces rusting; fourth panel has a trace of pin-point rust in lower left corner along scratches

TABLE A-6. (Continued)

Coating Type	Coating Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Mn	0.3	T	Scattered pinpoint to 1/16"-diameter rust spots; about 45% of the actual surface is rusting; coating on one panel has flaked off in one 1/8" spot, coating on second panel has flaked off in 20+ 1/8" to 3/8" spots, coating on third panel has flaked off in 25+ 1/8" to 3/8" spots, coating on fourth panel has flaked off in 5 1/8" to 1/4" spots
		TX	Scattered pinpoint to 1/16"-diameter rust spots; about 45% of the actual surface is rusting
		B	10%, 20%, 20% and 25%, respectively, of the surfaces of four panels are rusting, mostly along edges
		BX	About 40% of the surface of each panel is rusting, mostly along edges
Zn	0.3	T	Small area of pinpoint rust on one panel; all panels have uniform gray-white corrosion products over entire surface with innumerable microscopic to pinhead spots of white corrosion products
		TX	Faint brown stains along lower edges of all four panels; gray-white and white corrosion products same as T
		B	No rust
		BX	No rust; white corrosion products in scratches
Mn-Zn	0.3	T	No rust
		TX	15%, 15%, 25% and 25%, respectively, of surfaces of four panels rusting; mostly along lower edges and scratches
		B	No rust
		BX	5%, 15%, 15% and 15%, respectively, of surfaces of four panels rusting; mostly along lower edges and scratches
Cd	0.3	T	No rust
		TX	Slight trace of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches
Zn-Sn	0.3	T	No rust
		TX	Traces of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches

TABLE A-6. (Continued)

Coating Type	Coating Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Zn(Cr)	0.3	T	No rust; scattered pinpoint specks of white corrosion products along lower edges of all panels, a few scattered white spots elsewhere on all panels
		TX	
		B	No rust
		BX	Few traces of rust in scratches; white corrosion products in scratches
Mn	0.5	T	Three panels have traces of pinpoint rust along edges; coating is flaking along upper edge of fourth panel and rust is forming on bared steel
		TX	Traces of pinpoint rust along edges of all four panels
		B	No rust
		BX	No rust
Zn	0.5	T	No rust
		TX	Possible traces of rust in scratches; white corrosion products in scratches
		B	No rust
		BX	No rust; white corrosion products in scratches
Mn-Zn	0.5	T	No rust; possible microblistering
		TX	Possible slight trace of rust in scratches; possible microblistering
		B	No rust; definite microblistering
		BX	Trace of rust in lower right corners of two panels; definite microblistering
Cd	0.5	T	No rust; one pinpoint blister on each of two panels
		TX	Numerous traces of rust in scratches; several tiny blisters on one panel
		B	No rust
		BX	Rust in scratches for about 50% of length
Zn-Sn	0.5	T	No rust
		TX	Traces of rust in scratches for about 50% of length
		B	No rust
		BX	Slight traces of rust in scratches for about 25% of length

TABLE A-6. (Continued)

Coating			
Type	Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Zn(Cr)	0.5	T	No rust
		TX	No rust
		B	No rust
		BX	No rust; trace of white corrosion products in scratches

(1) Test started May 17, 1951.

(2) The coating-thickness values (0.1, 0.3 and 0.5) are in terms of mils. One mil = 0.001 inch.

(3) T = Unmarked portion of panel which faces the sky.
TX = Scratched portion of panel which faces the sky.
B = Unmarked portion of panel which faces the ground.
BX = Scratched portion of panel which faces the ground.

TABLE A-7. CUMULATIVE RESULTS OF OUTDOOR-EXPOSURE TESTS AFTER 14 MONTHS' EXPOSURE(1)

Coating Type	Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Mn	0.1	T, TX	75% of actual surface rusting (Panels removed from rack 6/20/52 (approximately 13 months' exposure))
		B, BX	85% of actual surface rusting (Panels removed from rack 6/20/52 (approximately 13 months' exposure))
Zn	0.1	T	Uniform gray-white film of corrosion products with innumerable pin-point to pinhead spots of heavier white corrosion products; one panel has trace of pinpoint rust on upper edge
		TX	General appearance same as T; two panels have no rust, third panel has 2% of area rusted, and fourth panel has 5% of area rusted
		B	One panel has no rust, two panels have 1% rust, and fourth panel has 20% rust
		BX	10%, 12%, 15%, and 25%, respectively, of the surfaces of four panels rusting; the rusting has spread mostly from the scratches
Cd	0.1	T	No rust
		TX	Slight scattered traces of rust in scratches
		B	No rust
		BX	Slight scattered traces of rust in scratches
Zn (Cr)	0.1	T	No rust apparent (see text); all panels have varying amounts of pin-point to pinhead spots of white corrosion products
		TX	One panel has a trace of pinpoint rust, and the three other panels have 5%, 30%, and 3[illegible]%, respectively, of their surfaces rusting
		B	No rust
		BX	1%, 6%, 15%, and 20%, respectively, of the surfaces of the four panels rusting

TABLE A-7. (Continued)

Coating Type	Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Mn	0.3	T	<1%, 1%, 6%, and 6% of the coatings have flaked off; approximately 50% of surface is rusting on each panel
		TX	< 1% of the coating has flaked from each panel; approximately 50% of surface is rusting on each panel
		B BX	Estimation of rust difficult because of undercutting, so that rust is not apparent Panels removed from rack 7/17/52 (approximately 14 months' exposure)
Zn	0.3	T	Small area of pinpoint rust on one panel; all panels have uniform gray-white corrosion products over entire surface, with innumerable microscopic to pinhead spots of white corrosion products
		TX	Faint brown stains along lower edges of all four panels; gray-white and white corrosion products same as T
		B	No rust
		BX	No rust; white corrosion products in scratches
Mn-Zn	0.3	T	Trace of scattered pinpoint rust on 2 panels; 5% of area is rusting on third panel
		TX	25% of surfaces of each of three panels covered with scattered pinpoint rust, and 30% of fourth panel covered with scattered pinpoint rust
		B	The coatings on two panels have lost adhesion to the extent of 25% and 10%, respectively, of their areas; underlying steel is presumably rusting. The two remaining panels show a trace of rust and no rust, respectively

TABLE A-7. (Continued)

Coating			
Type	Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Mn-Zn	0.3	BX	One panel has 15% of area covered with scattered pinpoint rust, and three panels each have 20% of area covered with scattered pinpoint rust
Cd	0.3	T	No rust
		TX	Slight trace of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches
Zn-Sn	0.3	T	No rust
		TX	Traces of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches
Zn (Cr)	0.3	T, TX, B	No rust; scattered pinpoint specks of white corrosion products along lower edges of all panels; a few scattered larger white spots elsewhere on all panels
		B	No rust
		BX	Few traces of rust in scratches; white corrosion products in scratches
Mn	0.5	T	Each of two panels is rusting on 30% of area where coating has flaked off; third panel has trace of pinpoint rust, and fourth panel has no rust.
		TX	1%, 2%, 3%, and 15%, respectively, of surfaces of four panels rusting where coating has flaked off
		B	Two panels have trace of rust; two panels have no
		BX	No rust

TABLE A-7. (Continued)

Coating			
Type	Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Zn	0.5	T	No rust
		TX	Possible traces of rust in scratches; white corrosion products in scratches
		B	No rust
		BX	No rust; white corrosion products in scratches
Mn-Zn	0.5	T	No rust
		TX	Each of three panels has 6% of area rusting; one panel has 2%
		B	No rust apparent; coatings on two panels each losing adhesion in one 1/2" x 1" area
		BX	Each of three panels has 25% of area rusting; one panel has 20%
Cd	0.5	T	No rust; one pinpoint blister on each of two panels
		TX	Numerous traces of rust in scratches; several tiny blisters on one panel
		B	No rust
		BX	Rust in scratches for about 50% of lengths
Zn-Sn	0.5	T	No rust
		TX	Traces of rust in scratches for about 50% of lengths
		B	No rust
		BX	Slight traces of rust in scratches for about 25% of length
Zn (Cr)	0.5	T	No rust
		TX	No rust
		B	No rust
		BX	No rust; trace of white corrosion products in scratches

Footnotes for Table A-7.

(1) Test started May 17, 1951.

(2) The coating-thickness values (0.1, 0.3, and 0.5) are in terms of mils. One mil = 0.001 inch.

(3) T = Unmarked portion of panel which faces the sky.
TX = Scratched portion of panel which faces the sky.
B = Unmarked portion of panel which faces the ground.
BX = Scratched portion of panel which faces the ground.

TABLE A-8. CUMULATIVE RESULTS OF OUTDOOR-EXPOSURE TESTS AFTER 16 MONTHS' EXPOSURE(1)

Coating Type	Coating Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Zn	0.1	T	Uniform gray-white film of corrosion products with innumerable pinpoint to pinhead spots of heavier white corrosion products; one panel has trace of pinpoint rust on upper edge
		TX	General appearance same as T; two panels have no rust, third panel has 2% of area rusted, and fourth panel has 5% of area rusted
		B	One panel has no rust, two panels each have 1% rust, and fourth panel has 20% rust
		BX	10%, 12%, 15%, and 25%, respectively, of the surfaces of four panels rusting; the rusting has spread mostly from the scratches
Cd	0.1	T	No rust
		TX	Slight scattered traces of rust in scratches
		B	No rust
		BX	Slight scattered traces of rust in scratches
Zn (Cr)	0.1	T	No rust; all panels have varying amounts of pinpoint to pinhead spots of white corrosion products
		TX	1%, 8%, 40%, and 40%, respectively, of the surfaces of four panels have moderate to heavy rust
		B	No rust
		BX	1%, 10%, 25%, and 30%, respectively, of the surfaces of four panels have moderate to heavy rust

TABLE A-8. (Continued)

Coating			
Type	Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Zn	0.3	T	Small area of pinpoint rust on one panel; all panels have uniform gray-white corrosion products over entire surface, with innumerable microscopic to pinhead spots of white corrosion products
		TX	Faint brown stains along lower edges of all four panels; gray-white and white corrosion products same as T
		B	No rust
		BX	No rust; white corrosion products in scratches
Mn-Zn	0.3	T	6%, 8%, 10%, and 45%, respectively, of the surfaces of four panels covered with pinpoint to 2 millimeter rust spots
		TX	50%, 70%, 90%, and 90%, respectively, of the surfaces of four panels rusting
		B	12%, 85%, 80%, and 90%, respectively, of the surfaces of four panels rusting
		BX	75%, 95%, 95%, and 95%, respectively, of the surfaces of four panels rusting
Cd	0.3	T	No rust
		TX	Slight trace of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches
Zn-Sn	0.3	T	No rust
		TX	Traces of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches

TABLE A-8. (Continued)

Coating Type	Coating Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Zn (Cr)	0.3	T, TX	No rust; scattered pinpoint specks of white corrosion products along lower edges of all panels; a few scattered large white spots elsewhere on all panels
		B	No rust
		BX	Few traces of rust in scratches; white corrosion products in scratches
Mn	0.5	T	< 5%, 18%, 90%, and 90%, respectively, of coatings on four panels have flaked off, and the bare steel is rusting
		TX	2%, 12%, 90%, and 90%, respectively, of coatings on four panels have flaked off, and the bare steel is rusting
		B	Rust undercutting all four panels to an unknown extent
		BX	Coatings on all four panels have lost adherence on narrow zone along lower edge
Zn	0.5	T	No rust
		TX	Possible traces of rust in scratches; white corrosion products in scratches
		B	No rust
		BX	No rust; white corrosion products in scratches

TABLE A-8. (Continued)

Coating Type	Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Mn-Zn	0.5	T	Two panels have no rust; two have 1% and 8%, respectively, of their surfaces covered with pinpoint to moderately heavy rust
		TX	8%, 25%, 30%, and 30%, respectively, of the surfaces of four panels covered with pinpoint to moderately heavy rust. The coatings are flaking off the panel, with 30% rust
		B	10%, 15%, 15%, and 15%, respectively, of the areas of four panels show light rust beneath the coatings which have lost adherence and are flaking
		BX	60%, 70%, 70%, and 75%, respectively, of the areas of four panels show light rust beneath the coatings which have lost adherence and are flaking
Cd	0.5	T	No rust; one pinpoint blister on each of two panels
		TX	Numerous traces of rust in scratches; several tiny blisters on one panel
		B	No rust
		BX	Rust in scratches for about 50% of lengths
Zn-Sn	0.5	T	No rust
		TX	Traces of rust in scratches for about 50% of lengths
		B	No rust
		BX	Slight traces of rust in scratches for about 25% of lengths

TABLE A-8. (Continued)

Coating			
Type	Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Zn (Cr)	0.5	T	No rust
		TX	No rust
		B	No rust
		BX	No rust; trace of white corrosion products in scratches

(1) Test started on May 17, 1951.

(2) The coating-thickness values (0.1, 0.3, and 0.5) are in terms of mils. One mil = 0.001 inch.

(3) T = Unmarked portion of panel which faces the sky.
TX = Scratched portion of panel which faces the sky.
B = Unmarked portion of panel which faces the ground.
BX = Scratched portion of panel which faces the ground.

TABLE A-9. CUMULATIVE RESULTS OF OUTDOOR-EXPOSURE TESTS AFTER 18 MONTHS' EXPOSURE(1)

Coating Type	Coating Thickness, mil(2)	Section of panel(3)	Description of Corrosion
Zn	0.1	T	All panels have a uniform gray-white film of corrosion products with innumerable pinpoint to pinhead spots of heavier white corrosion products. One panel has no rust, two panels each have a trace of scattered pinpoint to light rust at top edge, the fourth panel has a 1% area at top edge showing scattered pinpoint to light rust
		TX	Three panels have 2%, 8%, and 12%, respectively, of their surfaces showing scattered pinpoint to moderate rust; general appearance same as T
		B	1%, 3%, 5%, and 35%, respectively of the surfaces of four panels showing moderate to heavy rust
		BX	15%, 20%, 25%, and 30%, respectively, of the surfaces of four panels showing moderate to heavy rust
Cd	0.1	T	No rust
		TX	Slight scattered traces of rust in scratches
		B	No rust
		BX	Slight scattered traces of rust in scratches
Zn (Cr)	0.1	T	No rust; all panels have varying amounts of pinpoint to pinhead spots of white corrosion products
		TX	2%, 10%, 50%, and 50%, respectively, of the surfaces of four panels have moderate to heavy rust
		B	No rust
		BX	3%, 12%, 35%, and 35%, respectively, of the surfaces of four panels have moderate to heavy rust
Zn	0.3	T	Small area of pinpoint rust on one panel; all panels have uniform gray-white corrosion products over entire surface, with innumerable microscopic to pinhead spots of white corrosion products
		TX	Faint brown stains along lower edges of all four panels; gray-white and white corrosion products; same as T
		B	No rust
		BX	No rust; white corrosion products in scratches
Mn-Zn	0.3	T	50%, 75%, 88%, 90%, respectively, of surfaces of four panels covered with thickly clustered pinpoint to 2-millimeter rust spots

TABLE A-8. (Continued)

Coating		Section	
Type	Thickness, mil(2)	of Panel(3)	Description of Corrosion
		TX	100% of surfaces of all four panels rusting
		B	80% of one panel, and 100% of three remaining panels have rust breaking through coating or undercutting coating which has lost adhesion
		BX	98% of one panel, and 100% of three remaining panels have rust breaking through coating or undercutting coating which has lost adhesion.
Cd	0.3	T	No rust
		TX	Slight trace of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches
Zn-Sn	0.3	T	No rust
		TX	Traces of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches
Zn(Cr)	0.3	T TX	No rust; scattered pinpoint specks of white corrosion products along lower edges of all panels; a few scattered large white spots elsewhere on all panels
		B	No rust
		BX	Few traces of rust in scratches; white corrosion products in scratches
Mn	0.5	T	10%, 65%, 95%, and 95%, respectively, of coatings on four panels have flaked off and the exposed steel is rusting
		TX	15%, 40%, 90%, and 90%, respectively, of coatings on four panels have flaked off and the exposed steel is rusting
		B	3%, 8%, 12%, and 40%, respectively, of four panels have rust (mostly along edges) undercutting the coating or where coating has already flaked off
		BX	10%, 12%, 15%, and 15%, respectively, of four panels have rust (mostly along edges) undercutting the coating or where coating has already flaked off

TABLE A-9. (Continued)

Coating Type	Coating Thickness, mil[2]	Section of Panel[3]	Description of Corrosion
Zn	0.5	T	No rust
		TX	Possible traces of rust in scratches; white corrosion products in scratches
		B	No rust
		BX	No rust; white corrosion products in scratches
Mn-Zn	0.5	T	15%, 15%, 85%, and 100%, respectively, of the coatings of four panels either flaked off or being undercut by rust
		TX	85%, 90%, 100%, and 100%, respectively, of the coatings of four panels either flaked off or being undercut by rust
		B	90%, 95%, 95%, and 95%, respectively, of the coatings of four panels either flaked off or being undercut by rust
		BX	100% of the coatings of all four panels either flaked off or being undercut by rust
Cd	0.5	T	No rust; one pinpoint blister on each of two panels
		TX	Numerous traces of rust in scratches; several tiny blisters on one panel
		B	No rust
		BX	Rust in scratches for about 50% of lengths
Zn-Sn	0.5	T	No rust
		TX	Traces of rust in scratches for about 50% of lengths
		B	No rust
		BX	Slight traces of rust in scratches for about 25% of lengths
Zn(Cr)	0.5	T	No rust
		TX	No rust
		B	No rust
		BX	No rust; trace of white corrosion product in scratches

(1) Test started on May 17, 1951.

(2) The coating thickness values (0.1, 0.3, and 0.5) are in terms of mils. One mil = 0.001 inch.

(3) T = Unmarked portion of panel which faces the sky.
TX = Scratched portion of panel which faces the sky.
B = Unmarked portion of panel which faces the ground.
BX = Scratched portion of panel which faces the ground.

TABLE A-10. CUMULATIVE RESULTS OF OUTDOOR-EXPOSURE TESTS AFTER 20 MONTHS' EXPOSURE(1)

Coating Type	Coating Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Zn	0.1	T	All panels have a uniform gray-white film of corrosion products with innumerable pinpoint to pinhead spots of heavier white corrosion products. One panel has no rust, two panels each have a trace of light to moderate rust at top edges, and the fourth panel has 1% area at top edge showing light to moderate rust
		TX	Two panels have no rust, two panels have 8% and 12%, respectively, of their surfaces showing light to moderate rust; general appearance same as T. See text for explanation of apparent discrepancy between data of this report and those of Tenth Bimonthly Progress Report
		B	3%, 6%, 10%, 40%, respectively, of the surfaces of four panels showing light to moderate rust
		BX	15%, 25%, 30%, 40%, respectively, of the surfaces of four panels showing light to moderate rust
Cd	0.1	T	No rust
		TX	Slight scattered traces of rust in scratches
		B	No rust
		BX	Slight scattered traces of rust in scratches
Zn(Cr)	0.1	T	No rust; all panels have varying amounts of pinpoint to pinhead spots of white corrosion products
		TX	3%, 12%, 50%, and 50%, respectively, of the surfaces of four panels have moderate to heavy rust
		B	No rust
		BX	5%, 12%, 35%, and 35%, respectively, of the surfaces of four panels have moderate to heavy rust
Zn	0.3	T	Small area of pinpoint rust on one panel; all panels have uniform gray-white corrosion products over entire surface, with innumerable microscopic to pinhead spots of white corrosion products
		TX	Faint brown stains along lower edges of all four panels; gray-white and white corrosion products; general appearance same as T
		B	No rust
		BX	No rust; white corrosion products in scratches

Coating Type	Coating Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
Mn-Zn	0.3	T	92%, 95%, 95%, and 100%, respectively, of the surfaces of four panels covered with thickly clustered 1- to 3-mm rust spots
		TX	100% of surfaces of all four panels covered with thickly clustered 1- to 3-mm rust spots
		B	100% of surfaces of all four panels have moderately heavy rust breaking through coating or undercutting coating
		BX	100% of surfaces of all four panels have moderately heavy rust breaking through coating or undercutting coating. NOTE: The 0.3-mil manganese-zinc-coated panels were removed from the test rack on January 18, 1953
Cd	0.3	T	No rust
		TX	Slight trace of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches
Zn-Sn	0.3	T	No rust
		TX	Traces of rust in scratches
		B	No rust
		BX	Slight trace of rust in scratches
Zn(Cr)	0.3	T TX	No rust; scattered pinpoint specks of white corrosion products along lower edges of all panels; a few scattered large white spots elsewhere on all panels
		B	No rust
		BX	A few traces of rust in scratches; white corrosion products in scratches
Mn	0.5	T	15%, 75%, 97%, and 97%, respectively, of coatings on four panels have flaked off and the exposed steel is rusting
		TX	25%, 50%, 95%, and 95%, respectively, of coatings on four panels have flaked off and the exposed steel is rusting
		B	10%, 10%, 15%, and 40%, respectively, of four panels have rust (mostly along edges) undercutting the coating or where coating has already flaked off

TABLE A-18 (Continued)

Coating Type	Coating Thickness, mil(2)	Section of Panel(5)	Description of Corrosion
Mn		BX	12%, 25%, 25%, and 30%, respectively, of four panels have rust (mostly along edges) undercutting the coating or where rust has already flaked off
Zn	0.5	T	No rust
		TX	Possible traces of rust in scratches; white corrosion products in scratches
		B	No rust
		BX	No rust; white corrosion products in scratches
Mn-Zn	0.5	T	15%, 25%, 85%, and 100%, respectively, of the coatings of four panels either have flaked off or are being undercut by rust
		TX	85%, 90%, 100%, and 100%, respectively, of the coatings of four panels either have flaked off or are being undercut by rust
		B	95%, 95%, 100%, and 100%, respectively, of the coatings of four panels either have flaked off or are being undercut by rust
		BX	100% of the coatings of all four panels either have flaked off or are being undercut by rust
Cd	0.5	T	No rust; one pinpoint blister on each of two panels
		TX	Numerous traces of rust in scratches; several tiny blisters on one panel
		B	No rust
		BX	Rust in scratches for about 50% of lengths
Zn-Sn	0.5	T	No rust
		TX	Traces of rust in scratches for about 50% of lengths
		B	No rust
		BX	Slight traces of rust in scratches for about 25% of lengths
Zn(Cr)	0.5	T	No rust
		TX	No rust
		B	No rust
		BX	No rust; traces of white corrosion products in scratches

Footnotes appear on the following page.

Footnotes for Table A-10

(1) Test started on May 17, 1951.

(2) The coating thickness values (0.1, 0.3, and 0.5) are in terms of mils. 1 mil = 0.001 inch.

(3) T = Unmarked portion of panel which faces the sky.
TX = Scratched portion of panel which faces the sky.
B = Unmarked portion of panel which faces the ground.
BX = Scratched portion of panel which faces the ground.

APPENDIX B. DETAILS OF PLATING AND CLEANING PROCEDURES USED IN PREPARING PANELS FOR THE OUTDOOR-EXPOSURE TEST

APPENDIX B

Cleaning

After removing the panels from the kerosene in which they were stored, they were degreased in hot trichloroethylene vapors. Following degreasing, they were cleaned cathodically in Anodex* for 3 minutes at 50 asf and 200 F, brushed with hot Anodex solution, and then given an additional minute of cathodic cleaning. After rinsing, they were dipped in 6N HCl solution (70 F) for 30 seconds.

Zinc Plating

The zinc-coated panels and the zinc-plus-chromate coated panels were plated in the following solution:

$Zn(CN)_2$	90 g/l
NaCN	37.5 g/l
NaOH	90 g/l

Temperature: 100 F

Current: 10 amperes**

Anodes: Horse Head Special Zinc enclosed in cotton bags

Plating Times:

0.1 mil	5 minutes
0.3 mil	17.5 minutes
0.5 mil	28 minutes

Cadmium Plating

Cadolyte Single Salt*** 120 g/l

Temperature: 90 F

Current: 10 amperes

Anodes: Steel

Bath was continuously filtered.

*McDermid, Inc., Waterbury, Connecticut.

**In this and all other plating, the current is that per 4"x6" panel plus its "robber-type" rack.

***The Udylite Corporation, Detroit 11, Michigan.

Plating Times:

0.1 mil	4.7 minutes
0.3 mil	16 minutes
0.5 mil	25 minutes

Manganese Plating

$MnSO_4 \cdot H_2O$	40 g/l
$(NH_4)_2SO_4$	135 g/l
$Na_2SO_3 \cdot 7H_2O$	0.5 g/l

Temperature: 100 F

Current: 30 amperes

Anodes: Carbon rods in porous Alundum cups

Anolyte: $(NH_4)_2SO_4$ 135 g/l

pH: 7.5

Plating Times:

0.1 mil	3.5 minutes
0.3 mil	11 minutes
0.5 mil	19 minutes

Manganese-Zinc Duplex Plating

The steel panels were first plated with manganese, using the manganese bath which has been described.

Zinc could not be plated directly on electrodeposited manganese from the ordinary zinc baths, so a special strike solution was devised. Its composition is as follows:

$Zn(CN)_2$	5 to 7.5 g/l
NaCN	5 g/l
NaOH	5 g/l

Temperature: 80 F

Current: 30 amperes

Anodes: Stainless steel

In using the strike solution, the manganese-coated panel must be immersed with the current on.

After the strike coating, the balance of the required zinc was deposited from a special acid-type zinc solution developed here for other applications. Since the manganese-zinc coating did not perform well in exposure tests, release of information on the zinc deposition is not needed.

Plating Times:

Total Thickness	Time, minutes Manganese	Zinc Strike	Zinc Plate
0.1 mil	1.75	1.0	1.5
0.3 mil	5.5	1.0	4.7
0.5 mil	9.5	1.0	8.3

Zinc-Tin-Alloy Plating

The bath used for plating the zinc-tin alloy has been described by Cuthbertson*. Its composition is as follows:

Tin (as sodium stannate)**	30 g/l
Zinc (as zinc cyanide)	2.5 g/l
NaOH (free)	4 to 6 g/l
Total cyanide (as NaCN)	25 to 28 g/l
Free NaCN	17.5 g/l

Temperature: 140 F

Anodes: Cast 20% zinc-80% tin alloy

Current: 15 amperes

*J. Electrochem. Soc., 94, 73 (1948).

**High purity stannate is essential. The usual commercial material was not pure enough. Material of suitable quality was obtained from Metal and Thermit Corp., Rahway, New Jersey, and J. T. Baker Chemical Co., Phillipsburg, New Jersey.

The bath should be made up as follows: fill the container to two-thirds of its volume with water, preferably distilled or deionized softened, and heat to 140 F. Dissolve the NaCN, NaOH, and $Zn(CN)_2$, in that order. Finally, add the sodium stannate. Analyze the solution and adjust the components. It is well to hold the bath at temperature for 2 to 3 days before plating.

Chromate Coating on Zinc Plate

The Cronak* process was used to produce a chromate conversion coating on 12 of the zinc-coated panels.

H_2SO_4 (Conc.)	30 ml/l
$Na_2Cr_2O_7$	200 g/l

Temperature: 70 F

The zinc-coated panels were immersed wet for 10 to 15 seconds with slight agitation, removed, drained for 15 to 20 seconds, rinsed in 70 F water, then in 150 F water, and finally dried.

ABT:JEB:GS:GF:CLF/mas/pjs/nlh
March 18, 1953

*New Jersey Zinc Co., U. S. Patent 2,035,380.

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