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# AN INVESTIGATION OF ELECTRODEPOSITED ALLOYS FOR PROTECTION OF STEEL AIRCRAFT PARTS

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BATTELLS MEMORIAL INSTITUTE

1117 1953

WRIGHT AIR DEVELOPMENT CENTER

### AF TECHNICAL REPORT 5692 SUPPLEMENT 4

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## AN INVESTIGATION OF ELECTRODEPOSITED ALLOYS FOR PROTECTION OF STEEL AIRCRAFT PARTS

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Battelle Memorial Institute

July 1953

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### 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, Clen Fuller, and C. L. Faust, all of Battelle Memorial Institute, Columbus, Ohio. TOACT 201

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

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

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

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER : won E. SORTE ¥. Colonel, USAF Chief, Meterials Laboratory Directorate of aparch

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### INTRODUCTION

In a temperate climate, electrodeposited zine or cadmium keeps steel from rusting for ten years or more. In the tropics, zine and cadmium coatings deteriorate rapidly and the steel then corrodes. In many cases, this occurs in less then 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 costings 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 h130 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 mangenese 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 zine-tin-alloy coatings of 0.3- and 0.5-mil thicknesses offered protection equal to the zine and cadmium standard coatings. Because the test was discontinued after approximately 21 months' exposure, no conclusions can be drawn as to whether the zinetin is superior or inferior to sine and cadmium at this exposure site.

Zinc-tin-alloy coatings of O.1-mil thickness were inferior to both zinc and cadmium coatings of like thickness.

Pure-manganese and manganese-zino-alloy ocatings failed rapidly. A 0.5-mil coating of either one was somewhat inferior to 0.1 mil of zino, 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 mul, 0.3 mil, and 0.5 mil. There were four  $4 \times 6$ -inch panels for each thickmess. 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  $30^{\circ}$  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  $4 \times 4$ -inch area which was unmarked, and a  $2 \times 4$ -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 rnilled 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.

		·····		
	72 Zn (C1)	71 Zn (Cr)	20 CC	89 74 (Cr)
	بلا ج- 88 ۲	67 Zr—Sn	66 Z5-S1	65 Zı - Sı
	33	នរ	8 8	3 5
0.5 mil	69 1754	69 - 59 - 59	58 161-75	57 57
	55 Zi 25	ین ت	<b>3</b> -5	នេះភ្
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	کہ (Cر)	47 Zn (Cc)	46 Zn (Cr)	45 Zh (Ci)
	¥ 42 74-57	43 Zn-Sn	42 Zn-Sn	41 Zn-Sn
	දුරි	R 3	æ S	3) Cq
	ж.5 Ж.	35 161-21	34 27 27	85 - کم کم
	32	33 Zh	នភ	& ኤ
	83 <b>5</b> 2	12 12	X <u>y</u>	<u>۶</u> ۶ پ
	24 Zn (Cr)	23 Zn (Cr)	22 Zn (Cr)	21 Zn (Cr)
	ZD Zn-Sn	ei Zn-Sn	18 Zn-Sr	11 Zn-Sn
	<del>к</del> 2	SI D	≊ 5	C D
0.1 ml	12 Mn-Zn	11 Mn-Zn		9 14 12 12
	8 <sup>L</sup> Z	2u Zu	S 6	ς μ
	- 2	۲۳ ع	5 - <del>M</del>	- 5
			and the second s	

# FIGURE 1. SOMEMATIC DIAGRAM SHOPPING ADDANGEMENT OF TEST PARELS ON EXPOSIBLE 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. Corrosioncurrent-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.

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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  $4 \ge 6$ -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  $4 \times 6$ -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  $1/8 \ge 1$ -inch hot-rolled, plain-carbon steel into a rectangular frame measuring 6-1/2 inches  $\ge 4-1/2$  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  $\pm 10\%$ , 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.

Bill Laboreruy Record Book Ne. 5381, pp 54-81. and No. 5093, pp 1-88.

<sup>\*</sup> American Iranumont "2, , Silvor Spring, Maryland,



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.

<sup>•</sup> J. Electrochem Soc., 94, 73 (1948).



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

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Both composition and plating conditions are given in Appendix B. There is also a note regarding the importance of using high-purity acdium 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 zine cyanide bath was then used to place a zine strike over the manganese plate. The balance of the zine was then deposited over the strike from a special acid zine-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.

<sup>\*</sup> New Jersey Zinc Co., U. S. Patent 2,035,380.

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

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### Coating(2) Section of Panel<sup>(3)</sup> Description of Corrosion Type Thickness Mn 0.1 Scattered pin-point rusting throughout; very numerous pin points of T rust on vertical edges ТΧ Numerous pla points of rust Small area of rist on lower left comers of all 4 specimens B Numerous plu points of rust on 1 specimen; a few pin points on 3 BX spectness Zn 0.1 T No runt TX Very slight trace of rust in scratches; scratches mostly filled with white corrosion products No rust B Same as TX EX Mn-Zn 0.1 T No rust on 2 panels; trace on 2 panels тχ A few sust pin points on 1 panel; sust traces in scratches on 3; 3 panels show small rusted area 8 One pin point and a few small rusted areas 9X Same as B Cd 0.1 Т No rust ТΧ Slight scattered traces of rust in scratches B No rust 8X Same as TX Zn-Sn 0.1 Τ Several pin points of rust ТΧ Panel 1 shows 1% rust; panel 2 shows 2% rust; panels 3 and 4 show 4% rust B Pin-point rust covers 80%, 40%, 20%, and 3%, respectively BX Rust spreading from scribes Zn(Cr) 0.1 Т One small area of rust on each of 2 specimens ŤΧ Same as T No rust R BX Traces of rust in scratches Mn 0.3 Т No rust тх One pin point of rust visible after 13 days; no longer visible after 60 days 8 No rust BX No rust í.n 0.3 Т No rust тх No rust; white corrosion products in scribes R No nust эΧ No rust; white corresion products in scribes \_ .\_ . . . . . . . . . . . .

### TABLE A \*1, CUMULATIVE RESULTS OF OUTBOOR\*EXPOSURE TESTS AFTER 60 DAYS' EXPOSURE<sup>(1)</sup>

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Coating <sup>(2)</sup>		Section						
<u>1'Y6-3</u>	Thickness	of Panei <sup>(3)</sup>	Description of Correston					
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	т	No rusc					
		ŤΧ	Slight trace of rust in scratches					
		B	No rust					
		BX	Scattered traces in scratches					
Zn-Sn	0.3	т	No rust					
		ТХ	Traces of rust in scratches					
		B	No rust					
		BX	Traces of rust in scratches					
Zn(Cr)	0.3	Т	No rust					
		тх	No rust					
		В	No rust					
		BX	Few traces of rust in scratches; white corrosion products in scratches					
Mn	0.5	Т	No rust					
		TX	No rust					
		В	No runt					
		BX	No rust					
Zn	0.5	T	No rust					
		ТХ	Possible trace of rust in scratches; white corresion products in scratches					
		8	No rust					
		BX	No rust; white corresion products in scratches					
Mn-Zn	0.5	Т	No rust					
		TX	Possible slight traces of rust in scratches					
		B	No rust					
		BX	No rust					
Cd	0,5	Т	No rust; 1 pin-point blister on each of 2 specimens					
		тх	Numerous traces of rust in scratches; several tiny blisters on 1 specimen					
		8	No rust					
		BX	Rust in scratches for about 50% of length					
Zn-Sn	0,5	т	No rust					
		тх	Traces of rust in scratches for about 75% of length					
		B	No ruit					
		BX	Slight traces of rust in scratches for about 25% of length					

.

Coat	ung <sup>(2)</sup>	Section	
Туре	Thickness	of Panei <sup>(3)</sup>	Description of Conosion
Zn(Cr)	0.5	т	No rust
		TX	No rust
		B	No rust
		9X	No rust; trace of white corrosion products in scratches
_		tx B 9x	No rust No rust 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.

TVE RESULTS OF OUTDOOR-EXPOSURE TESTS AFTER 127 DAYS' EXPOSURE <sup>(1)</sup>		Description of Cornston	Uniform pin-point rusting over entire surface; about 40-50% of surface rusting	About 25% of surface covered with pin-point rust	About 69% of surface covered with pin-point rust	No rusi	Slight spread of rust from scratches	No Triet	Silght spread of rust from sciatches	1%. 5%, 35%, and 35%, respectively. of anface covered with rus flour namely.	20%, 75%, 100%, and 100%, respectively. of surface covered with nut (four name)	< 15, 25, 15%, and 20%, respectively, of azizce covered with rust (four panels)	10%. 75%, 35%, and 35%, respectively, of surface covered with rust (four panels)	No rust	Slight scattered maces of rust in acratches	No rust	Slight scattered traces of rust in scratches	$15^{\circ}$ , $25^{\circ}$ , $45^{\circ}$ , and $205^{\circ}$ , respectively, of surface covered with run flow ranels)	15%, 25%, 25%, and 46%, respectively, of surface covered with russ (sour names)	10%, 75%, 30%, and 35%, nespectively, of surface covered with rust four panels)	70%, 70%, 20%, and 98%, respectively, of surface covered with run (four panels)	Slight traces of met on each of new menimers	Statit market of mark on each of markets was	No russ	No rust	
CUMULAT	Section of	Panel <sup>(3)</sup>	т хг	8	X	ţ٩	ΤX	£	BX	ч	TX	92	<b>B</b> X	H	TX	æ	BX	н	ТX	63	3X	H	ТX	<b>6</b> 2	ВХ	
TABLE A-2,	Coating(2)	Thickness, mil(2)	0, 1			0,1				1 0 <b>.</b> 1				0.1				0.1				0, 1				
		Type	MA			ΠZ				Mn-Zn				ß				us-uz				Zn(Cr)	•			

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TABLE A-2. (Continued) TABLE A-2. (Continued) Section of Pacel(3) No rust T possible trace of rust in scratches; white corrotion products is scratches T possible trace of rust in scratches T possible trace of rust in scratches	<ul> <li>BX</li> <li>BX</li> <li>NO rust: while corrossory</li> <li>BX</li> <li>NO rust</li> <li>NO rust<th>TX     No rust     Sourcises for about 50% of seven       BX     Rust in scratches for about 75% of length       T     Tesces of rust in scratches for about 25% of length       T     Yesces of rust in scratches for about 25% of length       B     Slight traces of rust in scratches for about 25% of length</th><th>T No ruet T No ruet TX No ruet BX No ruet: uace of white corrosion products in sera ches ho ruet: uace of white corres in sera ches ho ruet: uace of mile of mile</th><th>d May 17, 1951. Des values (0. 1. 0. 3, and 0. 5) are hit which faces the sky. marked portion of panel which faces the skound. ratched portion of panel which faces the ground. Imarked portion of panel which faces the ground.</th></li></ul>	TX     No rust     Sourcises for about 50% of seven       BX     Rust in scratches for about 75% of length       T     Tesces of rust in scratches for about 25% of length       T     Yesces of rust in scratches for about 25% of length       B     Slight traces of rust in scratches for about 25% of length	T No ruet T No ruet TX No ruet BX No ruet: uace of white corrosion products in sera ches ho ruet: uace of white corres in sera ches ho ruet: uace of mile	d May 17, 1951. Des values (0. 1. 0. 3, and 0. 5) are hit which faces the sky. marked portion of panel which faces the skound. ratched portion of panel which faces the ground. Imarked portion of panel which faces the ground.
Coentag(E) Trucknes. mil(3)	2.0 2.2	در. 2n-5a	2.3(C:) 2.5	(E) Test terred (E) Test terred (E) Test terred (E) T = Uterr (E) T = State (E) T = St

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CUMULATIVE RESULTS OF OUTLOOR-EXPOSURE TESTS AFTER 187 DAYS' (APPROXIMATELY & MONTHS') EXPOSURE (1)	Description of Corrosion	Surface; about 50% of surface runsurface.	Unitiates pinerias evered with pineoiat rust digs 50% of area covered with pineoiat rust About 50% of area covered with pineoiat rust	No ruit Sught spread of rust from scratches Sught spread of rust from scratches, cover hese than 5% of area No rust on three pamets; small area of pinpoint rust than 5% of area No rust on three pamets; small area of pinpoint rust of the 5% of area Scown stains, spreading from scratches, cover 5%, 75%, 75%, and 80%, respectively, of surjaces (* 2000) prown stains, spreading from stratches, rusting ower 5%, 75%, 100%, and 20%, respectively, of surjaces (* 2000)	purpoint but nearly continuous, runting of surfaces covered with rulf purpoint but nearly continuous, respectively, of surfaces covered with rulf 10%, 70%, 2nd 100%, respectively, of surfaces covered with rulf	No ruit Slight scattered traces of rust in scratches No rust Slight scatttred traces of rust in scratches Slight scatttreed traces of sustance overed with rust (4 parts 1)	30%, 40%, 10%, 50%, respectively, of sursection with rust (* practs) 15%, 30%, 8%, 96%, respectively, of surface covered with rust (* practs) 85%, 85%, 96%, respectively, of surface covered with rust (* practs) 95%, 90%, 96%, respectively, of surface covered propont specks of white correstance of a 95%, 90%, 96%, 100%, respectively, of surface covered propont specks of white correstance of a	Slight traces of sust on each of three parels One small area of rust on each of three parels, all parels have traces of sust in scratches No rust One small rust area on each of three parels; all parels have traces of sust in scratches
таяце А-3.		Sector of Panel (3)	ьхож	<b>雅 a 以 小</b>	T X B X	P X B X	י, אָד ש אָ <b>צ</b>	H X 0 X
		Contina Trickess.	1.10 0.1	1 6 1 1	1.0 Ma-2n	3.5	ید. S.a تدری	0 ( ) ( ) ( )
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Ő	bating		
Чр.	Thickness. mil(2)	Section of Panel(3)	Description of Corrosion
ניזר.	0.3	Т	Scattered pippoint rust along vertical edges of all four panels
		TX	Scattered pippoint rust along lower edges of all four namels
		£	Very slight traces of pinpoint rust along vertical edges of all four namels
		BX	Very slight traces of pinpoint rust in lower corners of all four panels
•••	6.0	н	Small area of pinpoint rust on one panel
		ч т х	Small area of pinpoint rist on three panels
		8	No rust
		ах	No rust: white corresion products in scratches
	3.0	T	No rust
		тх	No rust
		en	No rust
		X	No rust
	0.C	Т	No rust
		TX	Slight trace of rust in scratches
		23	No rust
		ВХ	Stight trace of rust in scratches
	0.3	Т	No rue:
		XI	Traces of rust in scratches
		<b>m</b> )	No rust
		ВХ	Slight trace of rust in scratches
5 5 5	0. C	н	No rust
		ТX	No rust; few pinpount specks of white corrosion products along lower edges of three panels; rum rous purpount
			specks of white comparion products along lower edge of one panel
		ß	No rust
		BX	Few traces of rust in scratches; white corrosion products in scratches
	0.5	T	No rust
		TX	No rust
		80	No rust
		BX	No rust

TABLE A-3. (Continued)

TABLE A-3. (Continued) Description of Corresion	No rust possible traces of rust in scratches; white correction products in scratches no rust No rust: white correction products in scratches	No rust possible slight mades of sust in scratches No sust No sust	No rust: one puppoint of rust in scratchus; several unit Numerous traces of rust in scratchus; several unit No rust Rust in scratches for about 50% of length	No rust Traces of rust in scratches for about 75% of length Morust Slight traces of rust in scratches for about 25% of iength	T No tust TX No rust B No rust, wate of white corrotion products in scratches BX	r (0.1.0.3, and 0.5) arr in terms of mils. One mil = 0.001 inch. Del which faces the s <sup>1</sup> .y. anel which faces the ground. nel which faces the ground.
	Section Di Farrel (3) TX B B	чхвх	h T m j	8 6 T 7 8	a ••• j ••	lay 17, 1951. hickness values ( d partion of pare ed partion of pare id portion of pare red portion of pare
	0000000	10 2	9° 9	а С		<ul> <li>M Dennesternester</li> <li>M Dennesternester</li> <li>M Dennester</li> <li>M Dennest</li></ul>
5. 78 S			ŏ	å 21.	1.	9 <b>*</b> .

E RESULTS OF OUTDOOR-EXPOSURE TESTS AFTER 245 DATS' (8 MONTHS') EXPOSURE <sup>(1)</sup>		Pupolar to 1/8diamene nur apour matematic uniformaly over centre surface, accompanied by micro- blinering: approximately 50% of actual surface reating	wenter to T and T.K. But approximantly 15% of actual muthore runting No runt	weget spread of mer from accatchers; whe panel has 1/4 <sup>- x</sup> 1/4 <sup></sup>	Panels panels Plapoint out marily continuous runting over 36%, 80%, 60%, and 80%, respectively, of the surfaces of fee four panels Plapoint has an	is rusting No rust Mosture Stight, scattered traces of rust.	No rue Silght, scattered traces of runt in accessing	Panels removed from rack 12/21/51 (218 deys <sup>e</sup> exponse), at which time all surfaces were covered 50% or	
4. CUMULATI	Section of Panel (3)	тхаў	T TX	аў. Н	T B	X L S X X	T BX	X m X	
TABLE A	ai(2) 0. k		м С	7 °0		0. Y	0. 1		
	T y pue		and a second	भ्रह्म - ट्राप्ट		Cġ	217 - BB		

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Description of Contestion	i of two panels; numerous scattered pinpoint specks of whits corrosion (). It of three panels four panels; all panels have traces of rug in scratches	-diameter rust spots over 40%, 50%, 60%, and 100%, asspectively, of z , about 40% of actual surface is rusting in all cases -diameter rust spots over entire area of all four panels. about 40% of ac ar cases. g vertical edges of all four panels are increasing.	on one parel on three parels ducts in scratches	wer left comer of three panels, and in lower right comer of fourth pane	thes
	Slight traces of rust on each o One small area of rust on each No rust Small rust area on each of fo	Scattered pinpoint to 1/16" surfaces of all four panels. Scattered pinpoint to 1/16" surface is rusting in all four Traces of pinpoint rust along Traces of pinpoint rust in low	Small area of pinpoint rust or Small area of pinpoint rust or No rust No rust	No rust Few pinpoint rust spots in low No rust No rust	No rust. Slight trace of rust in scratch
Section of Panel (3)	T X X X5	т т 88 88 т т	л Х Х Х	H T S X	T TX
aring. Thiosaress. Ind(3)	** .1	e e	్. స	ମ ପ	e. G
Type	Zr. (Cz.)	сі — — —	â	No - Za	ö

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(de <b>tues</b> ,	Socritan of Pares(3)	Description of Corrotion
<b>ମ</b> ବ	┍╬╺┇	No rust Traces of rust in scratches for about 50% of length No rust Slight traces of rust in scratches for about 25% of length
3 0	H H m M	No ruet. No ruet. No ruet. teace of white corrotion products in accatches.

TABLE A-4. (Continued)

Tera suarted May 17, 1951.

The crating-thickness values (3.1, 0.3, and 0.5) are in memo of mila. One mil = 0.001 (nch. 0\$8

" = Ustratical precises of passel which faces the ary.

TIL = Semerical protesn of passel which faces the sky.

 $\mathfrak{B}=\mathfrak{U}$  and the second of gauged which faces the ground.

 $\omega_{ij}^{\prime}=\omega_{cra} \cos \omega_{ij}$  partices of ganes) which faces the ground.

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JLTS OF OUT DOOR EXPOSURE TESTS AFTER 302 DATS' (10 MOHTHS') EXPOSURE <sup>(1)</sup>	Description of Complete Market Complete Street Stre	Puppoint to 1/8"-diatrocter run aport saturation approximately 50% of actual surface rusting same as T and TX. but approximately 75% of actual surface rusting Similar to T and TX. but approximately 75% of actual surface	No rust Stight spread of rust from actatches : one panel has 1/4" x 1/4" rust stain near lower left corner. No rust on two panels: third panel has 1% rust fourth parsel has 9% rust Rusting on about 5%, 5%, 9%, and 10%, acspectively. of the susfaces of four panels, the rusting as along the scratches	About 96% of all mufaces actually remode	No sust Sught, scattered traces of nust in scratches No sust Stight, scattered traces of rust in scratches	Sight traces of rust on each of two panels, accorded, accorded and a lower edges rusting; third panel has other panels Two panels have 15% and 45%, supportively, of the areas along the lower edges rusting; third panel has and a standard and bit was been also also also also also be and also also also also also also also also	No ruit Three panels have 1%, 5%, and 5%, sequectively, of their services runs of runs
CUMULA TIVE RES	Section of Panel <sup>(3)</sup>	н х <sup>в</sup> у	н Хв Х	T T B B X X X	K X X	T XX	e Xi
TABLË A -5.	Dickness. mi(2)	0.1	0.1	0.1	м. С	i i	
	Costh	R R	až	3.60 × 1.50	ö	ZP (C2)	

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TABLE A-5. (Continued)	Description of Corrodion Scattered physical to 1/16" diameters runt apous over 40%. 50%, 60%, and 100%, respectively, of the Scattered physical to 1/16" diameters runt apous over 40%. 50%, 60%, and 100%, respectively, of the scattered physical to 1/16" diameters runt apous over 40% of actual scatteres of all four panels. About 40% of actual unface is runting in undercutting the coating.	areas where the controlsdisaraters rust spore scenaries plappoint to 1/16disaraters article is remained in all fore cases article is remained in all fore cases article is remained in all fore cases article is rusting Above 30% of the vertaces of each panel is rusting	geneil aans of pingolint reek on one proves adges of all four parels. Fairs benown scatzs along kower adges of all four parels. No rust, while corruston products in arranches	No runk Albour 1916 of surface aboves powelble alight runk No state Salbe as TX	No teed Stight made of real in actatches No real Stight made of real in actatches	
	socioa of Punei(3) I	¥ -1	- <sup> </sup>		H H H H	
	icheea.	r. '0	ي. م	5 8	0,3	
	Type (	3	z	87- <b>2</b> 4	8	
			2			

TABLE A-5. (Continued) Description of Corrogon	No rue Traces of rust in scratches No rust Slight trace of rust in scratches No rust; scattered purpoint specks of white corrosion products in scratches No rust; scattered white spots elewhere on all panels No rust No rust No rust Few traces of rust in scratches; white corrosion products in scratches	Mo rust: possible microbinstrituß No rust No rust No rust possible traces of rust in scratches; white corrosion products in scratches no rust No rust Mo rust: white corrosion products in scratches No rust Mo rust: white corrosion products in scratches No rust	No rust: powibie the fuer in wrattine. The powible thigh under of fuer in wrattine incrobingenting No rust: definite interoblisterning No rust: definite interoblisterning No rust: one pinpoint blister on cach of two panels No rust: one pinpoint blister on cach of two panels No rust: one pinpoint blister on cach of two panels numerous traces of rust in scratches; wveral cuty blisters on one panel Numerous traces of rust in scratches; wveral cuty blisters on one panel numerous traces of rust in scratches; wveral cuty blisters on one panel numerous traces of rust in scratches; wveral cuty blisters on one panel numerous traces of rust in scratches; wveral cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one panel numerous traces of rust in scratches; were a cuty blisters on one numerous traces of rust in scratches; were a cuty blisters on one numerous traces of rust in scratches; were a cuty blisters on one numerous	
Section of Parnel (3)		T T B B T T B B A T B A T B B A T B A	трад нед.	
Contlag Thickness	Type 0.3 Lu-Su 0.3 Zn (Ct) 0.3	2.5 Ln 0.5	<b>W</b> n <sup>.</sup> <b>Z</b> n <b>U</b> . 5 U. 5	

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Liew.     Section       2)     of Panel(3)       5     T       5     T       7     No runt       8     No runt       8     No runt       8     No runt       17     No runt       18     No runt       17     No runt       18     No runt       17     No runt       17     No runt       18     No runt       17     No runt       18     No runt       17     No runt       18     No runt       17     No runt
aung Thườuncar, míl (2) 0. 5

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ATTYE RESULTS OF OUTDXXR-EXPOSURE TESTS AFTER ONE YEAR'S EXPOSURE <sup>(1)</sup>		Description of Corrosion Phypoint to 1/8 <sup></sup> -diameter rust spots scattered uniformly over entire surface; accompanied by addrobilitations Peptoximately 75% of actual surface rusting	Similar to T and TX but approximately 85% of actual surface rusting Uniform gray-white film of corrotion products with innumerable pinpoint to pinhead spots of braying above	octorial appearance same as T, one panel has 3/8diameter rust stain near lower left contart, and a necond panel has a 1/4" strip of pinpolar rust along lower left edge and left bottom edge No rust on one panel, necond has trace of rust, third has 1% rust, and fourth has 10% rust Rutting on about 5%, 5%, 10% and 20%, respectively, of the surfaces of four panels; the susting is montry along the acratches	Panela removed from rack, April 17, 1952, 95% of all surfaces rusted	No rust Slight scattered traces of rust in scratches No rust Slight scattered traces of rust in scratches	Slight traces of tust on each of two panels; all panels have varying amounts of pin <sub>i</sub> wint to pinhead spots of white corronon products. White corronon products I'wo panels have 20% and 35%, respectively. Of the areas along the lower edges rusting; third panel has very light pinpoint rust in 1/2 <sup></sup> -diameter area in lower left corner. Pirce panels have 2%, 10% and 15%, respectively. Of their surfaces rusting; fourth panel has a race of pan-
	Section of Panel <sup>(3)</sup>		BX T BX	BX	۲ × ۳ ۳ ۲	T TXX B BX	т <mark>ж</mark> <sup>8</sup> Х
0.411 ng	Thickness, mil <sup>(2)</sup>	0, 1	0.1	ç	1.	0. 1	<b>1</b> ಲ
692 S 10	er la	Min	Ż'n	Min - Zn		Cd	

Attick Thicknew. Section (1), 3 T (2),	Description of Corrouton	Scattered pinpoint to 1/16"-diameter rust spots, about 45% of the actual surface to Justing; conting on one panel has flaked off in one 1/8" spots coating on accord 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.	5 1/8" to 1/4" spots Scattered pinpoint to 1/16"-diameter rust spots; about 45% of the actual furface is nusting 10%, 20% 20% and 25%, respectively. of the surfaces of four panels are rusting, mostly along edges About 40% of the surface of each panel is rusting, mostly along edges	Small area of pinpoint rust on one panel; all panels have uniform gray-white corrouon products over ent aurface with innumerable microscopic to pinhead spots of white corroadon products Faint brown stains along lower edges of all four panels; gray-white and white corrosion products same as	No rust, white corrosion products in scratches No rust; white corrosion products in scratches	No rust 15%, 15%, 25% and 25%, respectively, of surfaces of four partels rusting; mostly along lower edges and scratches	No rust 54, 15%, 15% and 15%, respectively, of surfaces of four panels rusting; mostly along lower edges and scratches	No rust Shght trace of rust in scratches No rust Slight trace of rust in scratches	No rust Traces of rust in scratches No rust sticht rrace of rust in scratches
0.3 0.3 0.3 0.3 0.3 0.3	Section of Panel <sup>(3)</sup>	н	XI. XI.	T TX	B BX	T TX	R BX	T TX B BX	л т Х
	Thicknew.	<b>6</b> .0		0,3		0.3		0°.	0.3

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TABLE A - 6. (Continued)		Deteription of Curtonion	No rust, scattered pinpount specks of white corrosion products along lower edges of all panels, a few scattered the spots elsewhere on all panels.	from traces of rust in scratches; white contenuon products in scratches	Three panels have traces of pinpoint rust along edges: coating is fluking along upper edge of fourth panel and rust is forming on bared steel Traces of pinpoint rust along edges of all four panels	No rust	No rust Possible traces of rust in acratches; white corrosion products in scratches. No rust	No rust; white contotion products in actatches	No rust; possible microblistering Possible slight trzce of rust in scratches; possible microblistering No rust; definite microblistering Trace of rust in lower right corners of two panels; definite microblisterion	No rust; one purpoint blister on each of two panels Numerous traces of rust in scratches; reveral tury blisters on one panel	Num in scratches for about 50% of length No russ	No rust in actatches for about 50% of length No rust Slight traces of rust in scratches for about 25% of length
	Section of Paner(3)		, XI e	Xa +	T X B	ι τ	X B	Xa e	L X B X	- X a Xa	T TX	æ Xa
	ostng Ducknen, mu[(2)	0_3		9°0		0,5		0.5	. s	•	0.5	
		Zu(C·)	ARTE :	ž		Zn	32	Ma-Zn	PO		Zasan	

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Type	Thicknew. nuff <sup>(2)</sup>	Section of Paref <sup>(3)</sup>	Description of Corrosion
Zn(Cr)	0.5	1	No rust
		Ĕ	No rust
		£	No rust
		BX	No rust; trace of white corrosion products in scratches

TABLE A-6. (Continued)

(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.

 $B=Unimarised portion of panel which faces the ground. BX <math display="inline">\approx$  Scratched portion of panel which faces the ground.

MULATIVE RESULTS OF OUTDOOR-EXPOSURE ESTS AFTER 14 MONTHS' EXPOSURE(1)	Description of Carrosian	75% of actual surface rusting Panels removed from rack 6/20/52	85% of actual surface rusting (approximately 13 months' exposure)	Uniform gray-white film of corrosion products with innumerable pin- point to pinhead spots of heavier white corrosion products; one pane has trace of pinpoint rust on upper edge	General appearance same as T; two panels have no rust, third panel has 2% of area rusted, and fourth panel has 5% of area vacual	One panel has no rust, two panels have 1% rust, and fourth panel has 20% rust	10%, 12%, 15%, and 25%, respectively, of the surfaces of four panels rusting; the rusting has spread mostly from the scratches	No rust Slight scattered traces of some	No rust	Slight scattered traces of rust in scratches	No rust apparent (see text); all panels have varying amounts of pin-	point to pinhead spots of white corrosion products One panel has a trace of pinpoint rust, and the three other must	have 5%, 30%, and 37%, respectively, of their surfaces rusting No rust	1%, 6%, 15%, and 20%, respectively, of the surfaces of the four	paners rusting
TE A-7, CU	Section of Panel(3)	T T T	BX }	4	TX	đ.	BX	T TX	B	ВХ П	Ŧ	ТХ	В	вх	
	ating Thickness, mil(2)	0.1	0, 1				-	0.1			1.0				
	Type	uw	uZ				Ţ (	5		2-11-2					

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Thickness, Discription of CorrosionDescription of CorrosionTypemil(2)of Panel(3)Mn0.3TA-1%, 1%, 6%, and 6% of the coatings have flaked off, approximately 50% of surface is rusting on each panelTX-1% of the coating has flaked from each panel; approximately 50% of surface is rusting on each panelBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBConstant of rust difficult because of undercuting, so that rust is apparentBBBBConstant and bots of rust difficult because of undercuting, so that rust is apparentConstant and approximately 50% of surfacesConstant and approximately 14 months' extSSmall area of pinpoint rust on one panel; all panels hare uniform guite corrosion products or entire surface, with immureable-scopic to pinhead spots of white corrosion productsBNo rustBNo rustBNo rustBNo rustBNo rustBNo rustBNo rustConstruct on two panels and so for the extend with scattered pinpoint rustBNo rustBNo rust, and 30% of fourth panel covered with scattered pinpoint rustConstruction, of their areas inderlying stel is presumable	Coati	ing		
Min       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.       sproximately 50% of surface is rusting on each panel.         B       surface is rusting on each panel.       sproximately 50% of surface is rusting on each panel.         B       surface is rusting on each panel.       sproximately 50% of surface is rusting on each panel.         B       B       surface is rusting on each panel.       sproximately 50% of surface is rusting on each panel.         B       B       B       panels removed from rack 7/17/52 (approximately 14 months' exponence going to pinped to a surface, with innumerable surface, with innumerable surface, with innumerable surface.         Cincolation       0.3       T       Small area of pinpoint rust on one panel, all panels have uniform g white corrosion products over entire surface, with innumerable scopic to pinbead spots of white corrosion products same as T         B       No       No rust       No         B       No rust       No rust       No         B       No rust       No rust       No         Mon-Zn       0.3       T       Do nust       Small area is rusting         Mon-Zn       0.3       T       Tace of scattered pinpoint rust on 2 panels; 5% of area is rusting         Mon-Zn       0.3 <th>Type</th> <th>Thickness, mil(2)</th> <th>Section of Panel(3)</th> <th>Description of Corrosion</th>	Type	Thickness, mil(2)	Section of Panel(3)	Description of Corrosion
TX       <1% of the coating has flaked from each panel; approximately 50% o surface is rusting on each panel	Min	0.3	H	<1%, 1%, 6%, and 6% of the coatings have flaked off, approximately 50% of surface is rusting on each panel
B       Estimation of rust difficult becauze of undercutting, so that rust is apparent         BX       Bx       apparent         BX       Panels removed from rack 7/17/52 (approximately 14 months' exponsion products over entire surface, with innumerable uniform g white corrosion products over entire surface, with innumerable scopic to pinhead spots of white corrosion products or entire surface, with innumerable scopic to pinhead spots of white corrosion products of all four panels; gray-whit white corrosion products same as T         Mn-Zn       0.3       T         B       No rust       Faint brown stains along lower edges of all four panels; gray-whit white corrosion products same as T         B       No rust       No rust         B       No rust       No rust         B       No rust       Trace of scattered pinpoint rust on 2 panels; 5% of area is rusting third panel         C       30% of fourth panel covered with scattered pinpoint rust       25% of surfaces of each of three panels covered with scattered pinpoint rust         B       T       25% of surfaces of each of three panels covered with scattered pinpoint rust       25%         B       T       25% of fourth panel       25%         B       10%, respectively, of their areas; underlying steel is presumable restored in the coverted with scattered pinpoint rust       25%			ТX	<1% of the coating has flaked from each panel; approximately 50% of surface is rusting on each panel
<ul> <li>BX</li> <li>Panels removed from rack 7/17/52 (approximately 14 months' expsure)</li> <li>Zn 0.3 T</li> <li>Small area of pinpoint rust on one panel; all panels have uniform g white corrosion products over entire surface, with innumerable scopic to pinhead spots of white corrosion products over entire surface, with innumerable scopic to pinhead spots of white corrosion products over entire surface, with innumerable matches</li> <li>TX</li> <li>Faint brown stains along lower edges of all four panels; gray-whit white corrosion products same as T</li> <li>B</li> <li>No rust</li> <li>No rus</li></ul>				Estimation of rust difficult because of undercutting, so that rust is not apparent
<ul> <li>Zn 0.3 T Small area of pinpoint rust on one panel; alt panels have uniform g white corrosion products over entire surface, with innumerable scopic to pinhead spots of white corrosion products</li> <li>TX F aint brown stains along lower edges of all four panels; gray-whit white corrosion products same as T</li> <li>B No rust</li> <li>Mo rust</li> <li>Mo rust</li> <li>No rust</li> <li>No rust; white corrosion products in scratches</li> <li>Mn-Zn 0.3 T Trace of scattered pinpoint rust on 2 panels; 5% of area is rusting third panel</li> <li>Tx</li> <li>25% of surfaces of each of three panels covered with scattered pinpoint rust</li> <li>B The coatings on two panels have lost adhesion to the extent of 25% in the runt panels where are and so and a state of rust and 00%.</li> </ul>			BX	Panels removed from rack 7/17/52 (approximately 14 months' expo- sure)
TXFaint brown stains along lower edges of all four panels; gray-whitBwhite corrosion products same as TBNo rustBXNo rust; white corrosion products in scratchesBXNo rust; white corrosion products in scratchesBXTTTrace of scattered pinpoint rust on 2 panels; 5% of area is rustingMn-Zn0.3TX25% of surfaces of each of three panels covered with scattered pinpoint rustBThe coatings on two panels have lost adhesion to the extent of 25%BThe coatings on two panels have lost adhesion to the extent of 25%b10%, respectively, of their areas; underlying steel is presumable	Zn	0.3	μ	Small area of pinpoint rust on one panel; alk panels have uniform gray- white corrosion products over entire surface, with innumerable micro scopic to pinhead spots of white corrosion products
<ul> <li>B. No rust; white corrosion products in scratches.</li> <li>B.X. No rust; white corrosion products in scratches.</li> <li>B.X. T. Trace of scattered pinpoint rust on 2 panels; 5% of area is rusting third panel</li> <li>T.X. 25% of surfaces of each of three panels covered with scattered pinpoint rust, and 30% of fourth panel covered with scattered pinpoint rust.</li> <li>B. The coatings on two panels have lost adhesion to the extent of 25% log, respectively, of their areas; underlying steel is presumable rust.</li> </ul>			тх	Faint brown stains along lower edges of all four panels; gray-white and white corrosion products same as ${\bf T}$
<ul> <li>Mn-Zn 0.3 T Trace of scattered pinpoint rust on 2 panels; 5% of area is rusting third panel</li> <li>Tx 25% of surfaces of each of three panels covered with scattered pinpoint rust, and 30% of fourth panel covered with scattered pinpoint rust, and 30% of fourth panel covered with scattered pinpoint rust, and 30% of fourth panel covered with scattered pinpoint rust, and 30% of fourth panel covered with scattered pinpoint rust, and 30% of fourth panel covered with scattered pinpoint rust, and 30% of fourth panel covered with scattered pinpoint rust, and 30% of fourth panel covered with scattered pinpoint rust, and 30% of fourth panel covered with scattered pinpoint rust, rust, and 30% of fourth panel covered with scattered pinpoint rust, rust, and 30% of fourth panel covered with scattered pinpoint rust, rust, and 30% of fourth panel covered with scattered pinpoint rust, rust, and 30% of fourth panel covered with scattered pinpoint rust, rust, and 30% of fourth panel covered with scattered pinpoint rust, rust, rust, and 30% of fourth panel covered with scattered pinpoint rust, rust, rust, and 30% of fourth panel covered with scattered pinpoint rust, r</li></ul>			B	No rust
<ul> <li>TX 25% of surfaces of each of three panels covered with scattered pin TX 25% of surfaces of each of three panels covered with scattered pinpoint rus rust, and 30% of fourth panel covered with scattered pinpoint rus R The coatings on two panels have lost adhesion to the extent of 25% 10%, respectively, of their areas; underlying steel is presumable rust, and no suppoint run remaining panels show a trace of rust and no suppoint runce.</li> </ul>	ar ald	ţ.	нх т	Trace of scattered pinpoint rust on 2 panels; 5% of area is rusting on
B The coatings on two panels have lost adhesion to the extent of 25% 10%, respectively, of their areas; underlying steel is presumable two remaining panels show a trace of rust and no present.		•	TX	third panel 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,

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TABLE A-7. (Continued)			One panel has 15% of area county	three panels each have 20% of area covered with scattered pinpoint rust, and rust No rust	ought trace of rust in scratches No rust Slight trace of rust in scratches No rust	Traces of rust in scratches No rust Slight trace of rust in scratches No rust: scattored	lower edges of all panels; a few scattered larger white spots else. No rust	Few traces of rust in scratches; white corrosion products in scratches 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.	1%, 2%, 3%, and 15%, respectively, of surfaces of four panels rusting where coating has flaked off Two panels have trace of rust; two panels have no No rust
		. Section of Panel(3)	ВХ	r TX	aa FF X X	ч В В С	A R R R R R R R R R R R R R R R R R R R	с н	B BX
	ting	Thickness, mil(2)	0.3	0.3	0.3	0.3		0.5	
	Coa	Type	Mn-Zn	Cd	Zn-Sn	Zn (C <i>r</i> )		Ma	

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TABLE A-7. (Continued)		Description of Corrosion	No rust	Possible traces of rust in scratches; white corrosion products in	scratches	No rust	No rust; white corrosion products in scratches	No rust	Each of three panels has 6% of area rusting; one panel has 2%	No rust apparent; coatings on two panels each losing adhesion in one 1/2" x 1" area	Each of three panels has 25% of area rusting; one panel has 20%	No rust; one pinpoint blister on each of two panels	Numerous traces of rust in scratches; several tiny blisters on one	panel	No rust	Rust in scratches for about 50% of lengths	No rust	Traces of rust in scratches for about 50% of lengths	No rust	Slight traces of rust in scratches for about 25% of length	No rust	No rust	No rust	No rust; trace of white corrosion products in scratches
		Section of Panel <sup>(3)</sup>	T	ТX		ß	ВХ	Т	TX	£	ВХ	T	ТХ		<b>£</b> 3	вх	L	ТX	ű	BX	T	X T.	2	BX
	Dg	Thickness, mil(2)	0.5					0.5				0.5					0.5				0.5			
	Coati	Type	Zn					Mu-Zn				Cd					Zn-Sn				Zn ( $Cr$ )			

### 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.

CUMULATIVE RESULTS OF OUTDOOR-EXPOSURE TESTS AFTER 16 MONTHS' EXPOSURE(1)	Description of Corrosion Uniform gray-white film of corrosion products with imumerable pin- point to pinhead spots of heavier white corrosion products; une panel has trace of pinpoint rust on upper edge demeral appearance same as T; two panels have no rust, third panel has 2% of area rusted, and fourth panel has 5% of area rusted has 2% of area rusted, and fourth panel has 5% of area rusted one panel has no rust, two panels each have 1% rust, and fourth panel has 20% rust 0%, 12%, 15%, and 25%, respectively, of the surfaces of four panels rusting; the rusting has spread mostly from the scratches No rust Slight scattered traces of rust in scratches Slight scattered traces of rust in scratches Slight scattered traces of rust in scratches	No rust; all panels have varying amounts of pinpoint to pinhead spots of white corrosion products 1%, 8%, 40%, and 40%, respectively, of the surfaces of four panels have moderate to heavy rust No rust 1%, 10%, 25%, and 30%, respectively, of the surfaces of four panels have moderate to heavy rust
TABLE A-8.	Section of Panel(3) T T T BX BX BX BX BX	T X B X B
	Coating Thickness, mil(2) 0.1 0.1	
AFTE 5592 .	Zn (Cr)	

	TABLE A-8. (Continued)			Lescription of Corrosion	white corrogion reaction one panel; all panels have uniform grav-	microscopic to pinhead spots of white connection with innumerable	Faint brown stains along lower edges of all four manifests	and white corrosion products same as T		and tust, white corrosion products in scratches	6%, 8%, 10%, and 45%	covered with pinpoint to 2 millimeter and surfaces of four panels	50%, 70%, 90%, and 90% variable fust spots	rusting	12%, 85%, 80%, and qne	rusting rusting of four panels	75%, 95%, 95%, and 95%, respectively, of the surfaces of form .	Austing	No rust	Slight trace of rust in scratches	No rust	Slight trace of rust in scratches	No rust	Traces of rust in scratches	No rust	Jugnt trace of rust in scratches
			Section of Panel(3)	T	I	Ş	<b>V</b> T	E,	BX		T		TX	ł	B		хх		Т	TX 5	а й	BX	E I	X I	BX	
		tting	Thickness, mil(2)	0.3							0.3							, c	u. 3			, C	c. 0			
AFTR	569	2 5	Type	2n						. An 21	U7-114							P C	3			Zn-Sn				
	/	- 0	which t	t								40														

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TABLE	Description of Corrosion No rust: scattered pinpoint specks of white corrosion products along lower edges of all panels; a few scattered large white spots else- where on all panels	No rust Few traces of rust in scratches; white corrosion products from panels < 5%, 18%, 90%, and 90%, respectively, of coatings on four panels have flaked off, and the bare steel is rusting 2%, 12%, 90%, and 90%, respectively, of coatings on four panels have flaked off, and the bare steel is rusting Rust undercutting all four panels to an unknown extent rust undercutting all four panels have lost adherence on narrow zone along lower edge	No rust Possible traces of rust in scratches; white corrosion products in scratches	No rust No rust; white corrosion products ın scratches
	Section of Panel(3) T TX	BX XB T X XB XX XB	T TX	в Х
	ng nickness, mil(2) 0. 3	0.5	0.5	
	Type Zn (Cr)	۲ ۱۱	ч2	
	- 1			

TABLE A-8. (Continued)

TABLE A-8. (Continued)	Pecceine	Two panels have no rust; two have 1% and 8%, respectively, of their surfaces covered with pinpoint to moderately heavy rust 6%, 25%, 30%, and 30%, respectively, of the surfacer of 6	flaking off the panel, with 30% rust 10%, 15%, 15%, and 15%, respectively, of the areas of four panels show light rust beneath the coatings which have lost adherence and	50%, 70%, 70%, and 75%, respectively, of the areas of four panels show light rust beneath the coatings which have lost adherence and are flaking	Numerous traces of rust in scratches; several tiny blisters on one Numerous traces of rust in scratches; several tiny blisters on one No rust	Rust in scratches for about 50% of lengths No rust	Traces of rust in scratches for about 50% of lengths No rust Slight traces of rust in scratches for about 25% of lengths
	Section of Panel(3)	T TX	B AR	Ч.	T B B	A <sup>T</sup> Y	BX
AFTR 5692 Cup	t <u>Type mil(2)</u> Mn-Zn of		lız	Cd 0.5		<sup>7</sup> n-Sn 0, 5	

Description of Corrosion	rust rust rust rust; trace of white corrosion products in scratches		and 0.5) are in terms of mils. One mil = 0.001 inch. ces the sky. ces the ground. ces the ground.
Section of Panel(3)	T TX B BX No	y 17, 1951.	ess values (0. 1, 0. 3, rtion of panel which f rtion of panel which f rtion of panel which f tion of panel which f
Coating Thickness, pe mil(2)	(Cr) 0.5	Test started on Ma	The coating-thicknur T = Unmarked point TX = Scratched point BX = Scratched point BX = Scratched point

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Coati	ng		
Туре	Thickness, mil(2)	Section of panel(3)	Description of Corresion
Zn	0.1		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
		тX	Three panels have 2%, 8%, and 12%, respectively, of their surfaces showing scattered pinpoint to moderate rust; general appearance same as T
		В	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	т	No rust
		тх	Elight scattered traces of rist in scratches
		3	Norut
		BX	Slight scattered traces of rust in actatches
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
		В	No ruit
		BX	3%, 12%, 35%, and 35%, respectively, of the surfaces of four panels have moderate to heavy rust
Zn	0.3	т	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
		тх	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	Т	50%, 75%, 88%, 90%, respectively, of surfaces of four panels covered with thickly clustered pinpoint to 2-millimeter rust spots

### TABLE A-9. CUMULATIVE RESULTS OF OUTDOOR EXPOSURE TESTS AFTER 15 MONTHS' EXPOSURE<sup>(1)</sup>

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Co	ating		
Tues	Thickness,	Section	Description of Correction
<u></u>	maxer		
		ΤX	100% of suffaces of all four patient fushing
		В	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 run
		т <b>х</b>	Slight made of rust in scratches
		В	No rust
		BX	Slight trace of rust in scratches
Zn-Sa	0,3	т	No rust
		тх	Traces of rust in scratches
		В	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 else- where on all panels
		В	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
	and the second second	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)

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TABLE	A-9,	(Contiaue	ed)

<u> </u>	ting		
Туре	Thicknes, mil <sup>(2)</sup>	Section of Panel <sup>(3)</sup>	Description of Corresion
Zn	0.5	т	No suat
		тх	Possible traces of rust in scratches; white corrosion products in scratches
		8	No rust
		BX	No rust; white corresion products in scratches
Ma-Za	0 <b>. 5</b>	T	15%, 15%, 85%, and 100%, respectively, of the coatings of four panels either flaked off or being undercut by rust
		тх	85%, 90%, 100%, and 100%, respectively, of the coatings of four panels either flaked off or being undercut by rust
		В	90%, 95%, 95%, and 95%, respectively, of the coatings of four panels either flaked off or being undercut by rust
		вх	100% of the coatings of all four panels either flaked off or being undercut by rust
Cd	0.5	т	No rust; one pinpoint blister on each of two panels
		тх	Numerous traces of rust in scratches; several tiny blisters on one panel
		В	No rust
		BX	Rust in scratches for about 50% of lengths
Zn-Sn	0.5	т	No ruit
		тх	Traces of rust in scratches for about 50% of lengths
		В	No ruit
		BX	Slight traces of rust in scratches for about 25% of lengths
Z⊓(Cr)	0.5	Т	No rust
		ТХ	No rust
		В	No rust
		ВХ	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. AFTR 5692 Supple 4

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Coa	tirg		
Туре	Thickness, mil <sup>(2)</sup>	Section of Panel <sup>(3)</sup>	Description of Corrosion
Zn	0. 1	Т	All panels have a uniform gray-white film of corrosion products with in- numerable 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
		тх	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
		8	3%, 5%, 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
		тх	Slight scattered traces of rust in scratches
		В	No rust
		BX	Slight scattered traces of rust in scratches
Zn(Cr)	0.1	т	No rust; all panels have varying amounts of pinpoint to pinhead spots of white corrosion products
		тx	3%, 12%, 50%, and 50%, respectively, of the surfaces of four panels have moderate to heavy rust
		В	No rust
		BX	5%, 12%, 35%, and 35%, respectively, of the surfaces of four panels have moderate to heavy rust
Zn	Ũ. 3	T	Small area of pinpoint rust en one panel; all panels have uniform gray- white corrosion products ever entire surface, with innumerable microscopic to pinhead spots of white corrosion products
		тх	Faint brown stains along lower edges of all four panels; gray-white and white corrosion products; general appearance same as T
		B	Νο ευστ
		BX	No rust; white corrosion products in scratches

# TABLE A-10. CUMULATIVE RESULTS OF OUTDOOR-EXPOSURE TESTS AFTER 20 MONTHS' EXPOSURE<sup>(1)</sup>

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TABLE A-10. (Continued)

Thickness, Section MI <sup>(2)</sup> of Fanel <sup>(3)</sup> Description of Corrosion           Mn*Zn         0.3         T         975, 995, 1955, respectively, of the surfaces of four panels covered with thickly clustered 1 = to 3 = mm rust spots           TX         100% of surfaces of sll four panels covered with thickly clustered 1 = to 3 = mm rust spots           S         100% of surfaces of sll four panels have moderately heavy rust breaking through coating or undercutting coating, NOTE: The 0, 3 = min rust spots           BX         100% of surfaces of sll four panels have moderately heavy rust breaking through coating or undercutting coating, NOTE: The 0, 3 = min manages = those = moderately heavy rust breaking through coating or undercutting coating.           Cd         0.3         T         No rust           TX         Slight trace of rust in scratches         B           BX         Slight trace of rust in scratches         B           Zn=Sn         0.3         T         No rust           BX         Slight trace of rust in scratches         B           Zn=Sn         0.3         T         No rust           BX         Slight trace of rust in scratches         B           No rust         BX         Slight trace of rust in scratches           B         No rust         BX         Slight trace of rust in scratches           B         No rust         BX	Coating				
Mn-Zn       0.3       T       995, 995, 105, respectively, of the surfaces of four panels covered with thickly clustered 1- to 3-mm rust spots         TX       100% of surfaces of sli four panels covered with thickly clustered 1- to 3-mm rust spots         B       100% of surfaces of sli four panels covered with thickly clustered 1- to 3-mm rust spots         B       100% of surfaces of sli four panels have moderately heavy rust breaking through costing or undercutting costing.         NO TE:       D         NO Te:       TN         Slight trace of rust in scratches         B       No rust         DX       Slight trace of rust in scratches         Zn-Sn       0.3       T         No rust       TX         TX       Slight trace of rust in scratches         B       No rust         DX       Slight trace of rust in scratches         B       No rust         DX       Slight trace of rust in scratches         Zn-Sn       0.3       T         No rust       BX       Slight trace of rust in scratches         Zn(Cf)       0.3       T         No rust       BX       Slight trace of rust in scratches         Zn(Cf)       0.3       T         No rust       BX       Slight trace of rust in scratches </th <th>Туре</th> <th>Thickness, mil<sup>(2)</sup></th> <th>Section of Panel<sup>(3)</sup></th> <th>Description of Corrosion</th>	Туре	Thickness, mil <sup>(2)</sup>	Section of Panel <sup>(3)</sup>	Description of Corrosion	
TX       100% of surfaces of sil four panels covered with thickly clustered 1- to 3-mm ruit spots         8       100% of surfaces of sil four panels have moderately heavy rust breaking through coating or undercutting coating         BX       100% of surfaces of sil four panels have moderately heavy rust breaking through coating or undercutting coating.         NOTE:       The 0, 3-mil manganes-sine-coated panels were removed from the test rack on January 18, 1963         Cd       0,3       T         No rust       TX         Slight trace of rust in scratches       B         No rust       TX         TX       Traces of rust in scratches         B       No rust         BX       Slight trace of rust in scratches         B       No rust         BX       Slight trace of rust in scratches         B       No rust         BX       Slight trace of rust in scratches         B       No rust         BX       Slight trace of rust in scratches         B       No rust         BX       Slight trace of rust in scratches         B       No rust         BX       Slight trace of rust in scratches         B       No rust         BX       Slight trace of rust in scratches         B       No rust<	Ma <b>-Z</b> a	0.3	T	92%. 95%, 25%, and 100%, respectively, of the surfaces of 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 mill manganese sinc "coated panels were removed from the test rack on January 18, 1963         Cd       0,3       T       No rust         TX       Slight trace of rust in scratches         B       No rust         SX       Slight trace of rust in scratches         Zn*Sn       0,3       T         No rust       TX         TX       Traces of rust in scratches         B       No rust         SX       Slight trace of rust in scratches         B       No rust         SX       Slight trace of rust in scratches         B       No rust         SX       Slight trace of rust in scratches         B       No rust         SX       Slight trace of rust in scratches         Zn(Cr)       0,3       T         No rust       SX         SX       Slight trace of rust in scratches         Zn(Cr)       0,3       T         No rust       SX         SX       Slight trace of rust in scratches         D <td< td=""><td></td><td></td><td>TX</td><td>100% of surfaces of all four panels covered with thickly clustered 1- to 3-mm rust spots</td></td<>			TX	100% of surfaces of all four panels covered with thickly clustered 1- to 3-mm rust spots	
BX       100% of surfaces of all four panels have moderately heavy rust breaking through coating or undercutting coating.         NOTE: The 0,3 mill mangarese zinc "coated panels were removed from the test rack on January 18, 1963         Cd       0,3       T         No rust       TX       Slight trace of rust in scratches         B       No rust         DX       Slight trace of rust in scratches         Zn*Sn       0,3       T         No rust       TX         Slight trace of rust in scratches         Zn*Sn       0,3         TX       Slight trace of rust in scratches         Zn*Sn       0,3         TX       Traces of rust in scratches         B       No rust         BX       Slight trace of rust in scratches         Zn(Cr)       0,3       T         No rust       BX         Slight trace of rust in scratches       In scratches         Zn(Cr)       0,3       T         No rust       BX         SX       Slight trace of rust in scratches         In orust       BX         A few traces of rust in scratches!         BN n rust       BX         BX       A few traces of rust in scratches!         BX       A			B	100% of surfaces of all four panels have moderately heavy rust breaking through coating or undercutting coating	
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         TX       Traces of rust in scratches         B       No rust         BX       Slight trace of rust in scratches         B       No rust         BX       Slight trace of rust in scratches         B       No rust         BX       Slight trace of rust in scratches         Zn(Cr)       0,3       T         No rust       No rust         BX       No rust         BX       A few traces of rust in scratches; white corrosion products along low edges of all anels; 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         BX       A few traces of rust in scratches; white corrosion products in scratches         Mn       0,5       T         BX       A few traces of rust in scratches; white corrosion products in scratches         Mn       0,5       T			BX	100% of surfaces of all four panels have moderately heavy nust 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	
TXSlight trace of rust in scratchesBNo rustBXSlight trace of rust in scratchesZn-Sn0,3TTXTraces of rust in scratchesBNo rustTXTraces of rust in scratchesBNo rustBXSlight trace of rust in scratchesCn(Cr)0,3TTXNo rust is caster of pinpoint specks of white corrosion products along lows edges of all anels; a few scattered large white spots elsewhere on all panelsBNo rustBXA few traces of rust in scratches; white corrosion products in scratchesMn0,5TTX15%, 75%, 97%, and 97%, respectively, of coatings on four panels have fraked off and the exposed steel is rustingB10%, 10%, 15%, and 40%, respectively, of four panels have fraked off and the exposed steel is rustingB10%, 10%, 15%, and 40%, respectively, of four panels have rust (mostli along edges) undercutting the coating or where coating has already fraked off	Cd	0,3	т	No tust	
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         B       No rust         BX       Slight trace of rust in scratches         Zn(Cr)       0,3       T       No rust; scatte id pinpoint specks of white corrosion products along lows edges of all anels, 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 four panels have rust (most) flaked off and the exposed steel is rusting         B       10%, 10%, 15%, 10%, 15%, and 40%, respectively, of four panels have rust (most) flaked off and the exposed steel is rusting			тх	Slight trace of rust in scratches	
BX       Slight trace of rust in scratches         Zn-Sn       0,3       T         No rust       TX         TX       Traces of rust in scratches         B       No rust         BX       Slight trace of rust in scratches         Zn(Cr)       0,3       T         No rust       BX         Slight trace of rust in scratches         Zn(Cr)       0,3       T         No rust       No rust; scatte rd pinpoint specks of white corrosion products along low: edges of all anels; 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 fiaked off and the exposed steel is rusting         TX       25%, 50%, 95%, and 95%, respectively, of four panels have rust (most laked off and the exposed steel is rusting         B       10%, 10%, 15%, and 40%, respectively, of four panels have rust (most laked off and the exposed steel is rusting         B       10%, 10%, 15%, and 40%, respectively, of four panels have rust (most laked off and the exposed steel is rusting			в	No rust	
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; scatter id pinpoint specks of white corrosion products along lows edges of all anels; 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 four panels have rurt (mostl along edges) undercutting the coating or where coating has already flaked off			BX	Slight trace of rust in scratches	
TX       Traces of rust in scratches         B       No rust         BX       Slight trace of rust in scratches         Zn(Cr)       0.3       T         TX       No rust; scatte id pinpoint specks of white corrosion products along lows edges of all anels; 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 (mostl along edges) undercutting the costing or where coating has already flaked off	Zn-Sn	0.3	т	No rust	
B       No rust         BX       Silight trace of rust in scratches         Zn(Cr)       0,3       T       No rust; scatte of pinpoint specks of white corrosion products along low edges of all anels; 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 fiaked off and the exposed steel is rusting         TX       25%, 50%, 95%, and 95%, respectively, of four panels have rust (mostl along edges) undercutting the coating or where coating has already fiaked off			тх	Traces of rust in scratches	
BX       Slight trace of rust in scratches         Zn(Cr)       0,3       T TX         No rust; scatte of pinpoint specks of white corrosion products along low edges of all anels; 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 (mostl along edges) undercutting the costing or where coating has already flaked off			B	No rust	
<ul> <li>Zn(Cr) 0,3</li> <li>T X</li> <li>No rust; scattered pinpoint specks of white corrosion products along low edges of all anels; a few scattered large white spots elsewhere on all panels</li> <li>B No rust</li> <li>BX A few traces of rust in scratches; white corrosion products in scratches</li> <li>Mn 0,5</li> <li>T 15%, 75%, 97%, and 97%, respectively, of coatings on four panels have flaked off and the exposed steel is rusting</li> <li>TX 25%, 50%, 95%, and 95%, respectively, of coatings on four panels have flaked off and the exposed steel is rusting</li> <li>B 10%, 10%, 15%, and 40%, respectively, of four panels have rust (most along edges) undercutting the coating or where coating has already flaked off</li> </ul>			BX	Slight trace of rust in scratches	
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%, 15%, and 40%, respectively, of four panels have rust (mostlialong edges) undercutting the coating or where coating has already flaked off	Zn(Cr)	0,3	$\left\{ {{T_{\mathbf{X}}} \atop{{\mathbf{T}}{\mathbf{X}}}} \right\}$	No rust; scatte ad pinpoint specks of white corrosion products along lower edges of all anels; a few scattered large white spots elsewhere on all panels	
BXA few traces of rust in scratches; white corrosion products in scratchesMn0.5T15%, 75%, 97%, and 97%, respectively, of coatings on four panels have flaked off and the exposed steel is rustingTX25%, 50%, 95%, and 95%, respectively, of coatings on four panels have flaked off and the exposed steel is rustingB10%, 10%, 15%, and 40%, respectively, of four panels have rust (mostl along edges) undercutting the coating or where coating has already flaked off			В	No rust	
<ul> <li>Mn 0.5 T 15%, 75%, 97%, and 97%, respectively, of coatings on four panels have flaked off and the exposed steel is rusting</li> <li>TX 25%, 50%, 95%, and 95%, respectively, of coatings on four panels have flaked off and the exposed steel is rusting</li> <li>B 10%, 10%, 15%, and 40%, respectively, of four panels have rust (most along edges) undercutting the coating or where coating has already flaked off</li> </ul>			BX	A few traces of rust in scratches; white corrosion products in scratches	
<ul> <li>TX 25%, 50%, 95%, and 95%, respectively, of coatings on four panels have flaked off and the exposed steel is rusting</li> <li>B 10%, 10%, 15%, and 40%, respectively, of four panels have rust (mostl along edges) undercutting the coating or where coating has already flaked off</li> </ul>	Mn	0,5	т	15%, 75%, 97%, and 97%, 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 rurt (mostl along edges) undercutting the coating or where coating has already flaked off			тх	25%, 50%, 95%, and 95%, respectively, of coatings on four panels have flaked off and the exposed steel is rusting	
			В	10%, 10%, 15%, and 40%, respectively, of four panels have russ (mostly along edges) undercutting the costing or where coating has already flaked off	

TABLE	<u> ) () .</u>	(Continued)
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<u>C</u>	ating		
Туре	Thickness, mil <sup>(2)</sup>	Section of Panel <sup>(S)</sup>	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	т	No rust
		тх	Possible traces of rust in scratches; white corrosion products in scratches
		Б	No rust
		BX	No rust; white corrosion products in scratches
Mn-Zn	0, 5	т	16%, 25%, 85%, and 100%, respectively, of the coatings of four panels either have flaked off or are being undercut by rust
		тх	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	т	No rust; one pinpoint blister on each of two panels
		тх	Numerous traces of rust in scratches; several tiny blisters on one panel
		В	No rust
		BX	Rust in scratches for about 50% of lengths
Zn -Sn	0,5	т	No rust
		тх	Laces 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	т	No rust
		тх	No rust
		8	No rust
		BX	No rust; traces of white corrosion products in scratches

Footnotes appear on the following page,

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### 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 PLATLIG AND CLEANING PROCEDURES USED IN PREPARING PANELS FOR THE OUTDOOR-EXPOSURE TEST

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### 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/1
NaCN	37.5 g/l
NaOH	90 g/1

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/1 Temperature: 90 F Current: 10 amperes Anodes: Steel Bath was continuously filtered.

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<sup>\*</sup>McDermid, Inc., Waterbury, Connecticut.

In this and all other plating, the current is that per 4"x6" panel plus its "robber-type" sack, The Udylits Corporation, Detroit 11, Michigan.

### Plating Times:

0.1 mil	4.7 minutes
0,3 mil	16 minutes
0,5 mil	25 minutes

### Manganese Plating

$MnSO_4 \cdot H_2O$	<b>40</b> g/1
(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	135 g/1
Na2503.7H20	0.5 g/1

Temperature: 100 F

Current: 30 amperes

Anodes: Carbon rods in porous Alundum cups

Anolyte: (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> 135 g/1

pH: 7,5

Plating Times:

0.1 mil	3.5 minutes
0.3 mil	ll 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 $g/1$
NECN 5	g/1
Na OH 5	g/1
Temperature: 80 F	
Current: 30 amperes	
Anodes: Stainless steel	
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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 fro n a special acid-type zinc solution developed here for other applications. Since the manganese-zinc costing did not perform well in exposure tests, release of information on the zinc deposition is not needed.

Plating Times:

	Time, minutes		
Total Thickness	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<sup>‡</sup>. Its composition is as follows:

Tin (as sodium stannate)**	30 g/1
Zinc (as zinc cyanide)	2.5 g/1
NaOH (free)	4 to 6 g/1
Total cyanide (as NaCN)	25 to 28 g/1
Free NaCN	17.5 g/1
Temperature: 140 F	
Anodes: Cast 20% zinc-80% tin alloy	
Current: 15 amperes	

<sup>\*</sup>J. Electrochem, Soc., 94, 73 (1948).

<sup>&</sup>quot;High putity 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 twothirds 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<sup>‡</sup> process was used to produce a chromate conversion coating on 12 of the zinc-coated panels,

$H_2SO_4$ (Conc.)	30 m1/1
Na <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>	200 g/1

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

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<sup>&</sup>quot;New Jenney Zinc Co., U. S. Patent 2,035,380.

