Corrosion Behaviour of Metal-Coated Panels at Eight Canadian Locations - Summary of a Fourteen-Year Program

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CORROSION BEHAVIOUR OF METAL - COATED PANELS AT EIGHT CANADIAN LOCATIONS - SUMMARY OF A FOURTEEN - YEAR PROGRAM

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PREFACE

An outdoor metals exposure program was undertaken by the former Associate Committee on Corrosion Research and Prevention to provide information on the corrosion behaviour of different architectural metals and metal coatings at eight locations across Canada. The first metal coatings were set out during 1955 and included specimens of cadmium electroplated steel, hot-dip galvanized steel and zinc electroplated steel. In 1956 specimens of continuous galvanized steel and hot-dip aluminized steel were exposed. Sealed and unsealed specimens of metallized coatings of aluminum and zinc were set out during 1958 to complete the coating materials exposed for observation. This report describes their performance at the different outdoor sites until the program was terminated in 1969.

The initial group of metals exposed included three types of steel, three stainless steels, two magnesium alloys, a rolled zinc, three aluminum alloys and riveted galvanic couples of aluminum 3S alloy coupled to zinc, copper, and mild steel. The ten-year results of these Group 1 metals have been described in NRCC 11630. A second group of metals that included specimens of lead alloys, monel, copper and muntz metal have recently completed 10 years of exposure and a report describing their behaviour is in preparation.

This cooperative undertaking has involved a number of metal suppliers, users and research organizations. The Division is indebted not only to those companies who have assisted in making this study possible, but also to those who have contributed in the provision and servicing of certain of the exposure sites.

Ottawa
October 1971

N. B. Hutcheon,
Director.

CORROSION BEHAVIOUR OF METAL-COATED PANELS AT EIGHT CANADIAN LOCATIONS -- SUMMARY OF A FOURTEEN-YEAR PROGRAM

ABSTRACT

An exposure program was initiated to test the atmospheric corrosion behaviour of different metal coatings on steel. The metal coatings exposed included specimens of cadmium electroplated steel, hot-dip galvanized steel, continuous galvanized steel, hot-dip aluminized steel, electroplated steel and sealed and unsealed specimens of metallized coatings of zinc and aluminum on steel. The specimens were set out at eight test sites across Canada and their behaviour was examined at regular intervals during the exposure period. This publication describes the performance of the different metal coatings at the various outdoor sites until the program was terminated in 1969.

LA CORROSION DE PANNEAUX REVETUS DE METAL EXPOSES EN HUIT ENDROITS AU CANADA -- RESUME D'UN PROGRAMME DE 14 ANS

RESUME

On a entrepris des expériences sur la corrosion de divers revêtements métalliques de l'acier exposés à l'atmosphère. Les échantillons comprenaient de l'acier revêtu de cadmium, de l'acier galvanisé à chaud, de l'acier galvanisé continu, de l'acier revêtu d'aluminium à chaud, de l'acier revêtu par galvanoplastie et des spécimens étanches et non étanches de revêtements métalliques de zinc et d'aluminium sur de l'acier. On a exposé les échantillons en huit endroits au Canada et on a examiné leur comportement à des intervalles réguliers au cours de la période d'exposition. Le présent article décrit le rendement des différents revêtements métalliques exposés à l'atmosphère jusqu'à la fin du programme en 1969.

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INTRODUCTION

Atmospheric exposure testing of a number of types of metallic coating was initiated in 1955 as a phase of a program undertaken by the Associate Committee on Corrosion Research and Prevention of the National Research Council of Canada. Details of the program were planned by Subcommittee C of the Associate Committee and exposures were made at the eight test sites of the Division of Building Research of the National Research Council. In 1960, when ACCRP was disbanded, DBR assumed responsibility for the program.

Original plans called for continuation of the program until failure of the materials under test occurred. However, owing to a change in emphasis in DBR atmospheric corrosion research, a decision was made to terminate the exposures in 1969. The purpose of this report is to summarize the status of the test materials as of September, 1969.

TEST MATERIALS

All panels supplied to the program measured 4 in. by 6 in. They were identified as to type, lot number, specimen number, and/or exposure location by edge-notching or punched-hole code. Details concerning the types of coating and exposure dates are as follows:

1. Cadmium electroplated steel. Designated A-6. Exposed 1955. Panels individually electroplated. Coating thickness - 0.1 to 0.6 mil, with most gauge readings 0.2 to 0.5 mil. Supplied by Canadian Hanson Van Winkle Company Limited.

2. Hot-dip galvanized steel. Designated B-6. Exposed 1955. Panels sheared from commercial sheet. Coating thickness - 1.8 to 2.6 mils (gauge); 2.2 to 2.4 mils (stripping test). Supplied by The Steel Company of Canada Limited.

3. Zinc electroplated steel. Designated B-7. Exposed 1956. Panels sheared from commercial strip. Coating thickness - not measured; nominally 1.0 mil. Supplied by the Steel Company of Canada Limited.

4. Continuous galvanized steel. Designated B-9. Exposed 1956. Panels sheared from commercial strip. Coating thickness - not measured; nominally 1.0 mil. Supplied by the Steel Company of Canada Limited.

5. Hot-dip aluminized steel (corrosion resistant type). Designated E-1. Exposed 1956. Panels sheared from commercial sheet. Coating thickness - 1.4 to 2.7 mils, average 2.0 mils. Supplied by Armco Steel Corporation.

6. Zinc metallized mild steel - not sealed. No letter designation. Exposed 1958. Panels individually metallized by wire process. Coating thickness - 5 to 7 mils. Coating weight applied - 29.1 to 32.7 g/panel. Supplied by Cominco Limited.

7. Zinc metallized mild steel - sealed. No letter designation. Exposed 1958. Panels individually metallized by wire process. Sealed with one coat of a proprietary vinyl copolymer with 10 per cent non-leafing aluminum flake. Zinc coating thickness - as (6) above. Supplied by Cominco Limited.

8. Aluminum metallized mild steel - not sealed. No letter designation. Exposed 1958. Panels individually metallized by wire process. Coating thickness - 5 to 6 mils. Coating weight applied - 10.0 to 10.8 g/panel. Supplied by Alcan Research and Development Limited.

9. Aluminum metallized mild steel - sealed. No letter designation. Exposed 1958. Panels individually metallized by wire process. Sealed with one coat of a proprietary polyvinyl butyral wash-primer, one coat of a proprietary vinyl copolymer with 10 per cent non-leafing aluminum flake. Aluminum coating thickness - as (8) above. Supplied by Alcan Research and Development Limited.

DESCRIPTION OF TEST SITES

A complete description of the atmospheric test sites used in this study has been published (1). The following is a brief summary of each along with their site numbers.

1. Ottawa - This site is located on the property of the Montreal Road Laboratories of the National Research Council of Canada. It is on the eastern outskirts of the city and is classified semi-rural.

2. Saskatoon - This is a rural site located on the campus of the University of Saskatchewan on the outskirts of Saskatoon.

3. Montreal - This is an industrial site on the roof of a two-storey stores building of the Canadian National Railways, in the Point St. Charles district.

4. Halifax - This is a marine-industrial site located on the roof of a federal public building in downtown Halifax, two city blocks from the harbour. This site provided the severest exposure condition, with relatively high levels of sulphur dioxide and particulate matter.

5. York Redoubt - This is a rural marine site located on the Atlantic Coast. It is at an elevation of 100 feet and is about 300 feet from the ocean, about seven miles from the city of Halifax.

6. Norman Wells - This is a far northern site located in the Mackenzie River Valley about 90 miles south of the Arctic Circle.

7. Esquimalt (Rocky Point) - This is a marine site on the Pacific coast of the southeastern extremity of Vancouver Island, about 15 miles from the City of Victoria. It is at an elevation of 50 feet and is about 1500 feet from the ocean.

8. Trail - This is a semi-rural site located at Birchbank in the Columbia River Valley about 6 miles north of the City of Trail. It is the outdoor test station of Cominco Limited.

The relative level of the atmospheric sulphur dioxide was measured by the lead perioxide method, at each site during most of the program. The relative activities are indicated in Table I. Shown are average values for the ten-year period 1955-1965.

EXPERIMENTAL PROCEDURE

Panels were exposed at an angle of 30° to the horizontal, facing south, at all locations. They were inspected in the field periodically and observations regarding appearance noted on a standard panel inspection form. Where applicable, panels were withdrawn from test at varying stages of coating failure for closer examination in the laboratory. All remaining panels were removed from test on termination of the program in September, 1969, and inspected in the laboratory.

EXPERIMENTAL RESULTS

Program results are tabulated in Tables II-VIII. Shown are condition of the panels as of September, 1969 (or earlier where prior complete coating failure occurred), and times to 5, 25, 75 and 100 per cent rusting (where applicable).

The times to varying amounts of rusting are generally extrapolations from the inspection sheets. All information shown applies to the skyward surfaces of the panels. Attack on the groundward surfaces was less, as shown in the tables. In no case did onset of base metal corrosion (or total coating failure) on the groundward surfaces precede that on the skyward.

The performances of the types of coating that experienced degrees of failure are shown graphically as "per cent rust" vs "exposure time" in Figures 1 to 4. It will be noted that only the A-6, B-6, B-7 and B-9 panels are included and that, with each, some sites were still rust-free when the test was terminated.

Not evident from the tabulated and plotted information is the fact that base metal rusting of the B-6 and B-9 panels started at cut edges (and punched holes) and spread inwards with time. With the A-6 and B-7 panels, which were electroplated after cutting, rusting started at points of thinnest coating (which were not necessarily located at edges) and spread from those.

DISCUSSION

This particular phase of the over-all ACCRP (NRC) program has dealt with a number of commercially available coatings that are applied to steel for controlling atmospheric corrosion. It was not the intent of the program to determine the superiority of one product over another. Rather, the intent was to develop information pertinent to the capabilities of each of the materials as a "means" towards intelligent choice and usage in specific applications. It must be recognized that factors other than performance also warrant consideration. These include coating costs, process limitations with respect to coating thickness and size of objects to be coated, product availability, formability, joinability, anticipated service life of the article, compatibility with complimentary protective systems, and others.

In spite of the fact that the program was terminated before the onset of failure of many of the coatings under test, it has generated considerable performance data of interest. Comments concerning specific materials are as follows:

1. Sealed aluminum and zinc metallized mild steel. The wash-primer/vinyl sealing system used is most effective at all test locations. Virtually no sealant breakdown occurred during 11 years of exposure.

2. Aluminum metallized mild steel. Coatings are intact and free from defects at all sites except No. 4 (Halifax). At this site, the black soot deposit is underlain with many nodes containing white corrosion product. There are no signs of base metal rust in the nodes. Node formation began sometime prior to the 4-year inspection. The nodes do not appear to have increased in size or frequency since.

3. Hot-dip aluminized steel (E-1). Coatings are intact and free from surface defects at all sites except No. 4 (Halifax). At this site, there is considerable surface roughness which is underlain with white corrosion product. There are no signs of red rust in the product. A yellowish-gold stain is present, in areas adjacent to cut edges and punched holes, on panels from the other sites. This stain developed early in the program and has not increased in intensity or size with time.

4. Zinc metallized mild steel. Coatings are intact and free from defects at all sites except Nos. 3 (Montreal) and 4 (Halifax). At the Montreal location, there is a trace of rust in areas adjacent to the support insulators on some panels. There are no other signs of coating failure. At Halifax, the coating is very rough and there are traces of rust adjacent to the edges and insulators and at a few pinholes dispersed over the panel surfaces. This type of coating breakdown was first noted after 3-4 years of exposure, but has not progressed markedly since. The zinc, on corroding, has shed or prevented a heavy soot build-up which is peculiar to most panels at this site. A cyclic building-up and sloughing-off of soot during the program is probably responsible for the surface roughness at the time of test termination.

5. Zinc electroplated steel (B-7). Coatings have completely failed at Sites 3 (Montreal) and 4 (Halifax); first signs of failure are evident at Site 8 (Trail); elsewhere coatings are intact and free from defects. If one considers a criterion of 50 per cent rust as failure, the service lives of coatings at Montreal and Halifax are as might be estimated from a knowledge of corrosion rates for zinc developed during the first ten years of exposure of these panels (0.130 and 0.532 m.p.y. respectively (2)) and the applied coating thickness (1.5 mils average).

6. Hot-dip galvanized steel (B-6). Coatings have completely failed at Sites 3 (Montreal) and 4 (Halifax); base metal rusting has begun at Site 8 (Trail); alloy stain is present at Sites 1 (Ottawa), 5 (York Redoubt) and 8; elsewhere the coatings are intact and free from defects. This coating differs from the other zinc coatings under test in that it has a composite structure. Iron-zinc intermetallics are present as a distinct layer adjacent to the basis steel; a pure zinc layer overlays these. With this type of coating, once the zinc layer has been consumed, the iron-zinc alloys

corrode to produce yellowish-orange coloured products. This accounts for the "alloy stain" terminology above. Alloy stain is an appearance defect and is not indicative of base metal attack.

Coating thickness on the B-6 panels is 2+ mils. They were exposed on the same dates as the thinner B-7 panels, and contrary to expectations, showed earlier failure at Montreal and similar life at Halifax. The accelerating effect of sacrificial corrosion adjacent to cut edges probably accounts for this.

7. Continuous galvanized steel (B-9). Coatings have completely failed at Site 3 (Montreal) and 4 (Halifax); first rusting has begun at Sites 8 (Trail), 1 (Ottawa) and 5 (York Redoubt) -- traces of rust at the edges only are present at the latter two; elsewhere the coatings are intact and free from defects. Performance, as compared to series B-6 and B-7, was better than expected. The improvement could be due to deviation from the reported nominal coating thickness of one mil and/or a different exposure date (1956 rather than 1955). Documentation in the technical literature (3, 4) suggests that climatic conditions prevalent at the time of initial exposure can exert marked effects on the initial corrosion rate of zinc and that these can persist for long periods of time. Thus, rates can vary from exposure period to exposure period, even though they overlap time-wise.

8. Cadmium electroplated steel (A-6). Coatings have failed at all sites except No. 2 (Saskatoon), 6 (Norman Wells), and 7 (Esquimalt). The thinness of the coatings is responsible for their relatively short service lives.

Based on the results, a general comment can be made on the effects of atmospheric SO_2 on corrosion. They show that atmospheric SO_2 is a major factor contributing to site corrosivity, at least with respect to corrosion of zinc and cadmium coatings. Thus, a listing of the eight test sites in decreasing order of corrosivity would correspond to a site listing in decreasing order of SO_2 activity values. Other factors known to contribute to corrosivity, such as atmospheric chlorides and time of wetness, were not measured at all of the sites.

CONCLUSIONS

The following conclusions can be made, based on the program results:

1. The sealed aluminum and zinc metallized coatings constitute viable, heavy-duty protective systems under even very aggressive atmospheric conditions. The wash-primer/vinyl sealant was virtually unaffected at all test locations after 11 years of exposure. The results suggest that thinner metallized coatings plus the sealant are capable of offering long, acceptable service lives at most Canadian locations.

2. The aluminum and zinc metallized coatings, in the thicknesses tested, are capable of providing protection for 12 years plus at the Halifax site and for very long periods of time at all other sites. Sealed coatings should probably be considered (in both cases) for exposure under conditions similar to those existing at the Halifax test site.

3. The hot-dip aluminized coating performed very well at all sites. The staining at cut edges which became evident early in the program did not progress to any serious extent with time. There were no signs of base metal corrosion of consequence at any site, including Halifax (where roughness underlain with white corrosion product developed).

4. The electroplated and hot-dip applied zinc coatings performed in a predictable manner (based on coating thicknesses and a knowledge of site corrosivity) at the more aggressive sites where failures occurred Indications are that (within this group) equivalent thicknesses should give approximately equivalent service lives. It is recommended that paint be considered in conjunction with these types of zinc coatings in industrial atmospheres, where conditions similar to those at Montreal and Halifax prevail. Elsewhere, even the relatively thin coating, as applied to the B-9 continuous galvanized steel, is capable of providing a long, useful service life.

5. Thin cadmium coatings, as applied to the A-6 panels, have relatively short service lives at all but the non-aggressive rural locations. Similar coatings are applied in practice to fasteners, small stampings and miscellaneous small articles.

ACKNOWLEDGEMENT

Personnel from a number of organizations including Alcan Research and Development Ltd., Armco Steel Corporation, Canadian Hanson and Van Winkle Company Limited, Cominco Ltd., Metallizing Engineering Company Inc., and the Steel Company of Canada Limited, prepared or supplied specimens to this program and participated in panel inspections. Their contributions are hereby gratefully acknowledged.

Thanks are also due to staff of DBR in Ottawa and the regional stations at Vancouver, Halifax, Saskatoon and Norman Wells for the operation of the sites in those areas. Special thanks are also due to Cominco Ltd. and the Canadian National Railway for making exposure areas available and servicing the sites at Trail and Montreal respectively. Similar assistance given by the Departments of National Defence, Transport and Public Works is also gratefully acknowledged.

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TABLE I

AVERAGE SULPHUR DIOXIDE ACTIVITY
IN THE ATMOSPHERE AT EACH SITE FROM 1955-1965

Site No.	Location	mg SO_3/dm^2 day
1	Ottawa	0.52
2	Saskatoon	0.13
3	Montreal	1.61
4	Halifax	5.13
5	York Redoubt	0.25
6	Norman Wells	0.01
7	Esquimalt	0.06
8	Trail	0.72

TABLE II

CADMIUM ELECTROPLATED STEEL: A-6

Site No.	Condition as of Sept. 1969 (168 mo)	Time to % Rust Indicated - mo 5%	25%	75%	100%
1	100% Rust	33	41	58	95
2	Dull metallic. 0 rust.	--	--	--	--
3	100% Rust	15	24	36	50
4	100% Rust	3.5	5	7	13
5	100% Rust	48	58	82	115
6	Dull metallic. 0 Rust.	--	--	--	--
7	Trace rust (edges-insulators, punched holes). Balance dull metallic.	--	--	--	--
8	100% Rust	25	31	49	65

TABLE III

HOT-DIP GALVANIZED STEEL: B-6

Site No.	Condition as of Sept. 1969 (168 mo)	Time to % Rust Indicated - mo 5%	25%	75%	100%
1	<5% Rust (edges), 40-50% alloy stain (pin holes rust), 50-60% metallic.	--	--	--	--
2	Grey metallic. 0 Rust.	--	--	--	--
3	100% Rust	72	81	99	130
4	100% Rust	12	20	28	44
5	Trace rust (edges); 5-10% alloy stain (pin holes rust); 90-95% metallic.	--	--	--	--
6	Grey metallic. 0 Rust	--	--	--	--
7	Grey metallic. 0 Rust	--	--	--	--
8	10-15% rust (edges); 75-80% alloy stain (pin holes rust); 10% metallic.	108	--	--	--

TABLE IV

ZINC ELECTROPLATED STEEL: B-7

Site No.	Condition as of Sept. 1969 (168 mo)	Time to % Rust Indicated - mo 5%	25%	75%	100%
1	100% grey-matte. 0 rust	--	--	--	--
2	100% grey-matte. 0 rust	--	--	--	--
3	95-100% Rust. Balance metallic.	96	108	129	168
4	100% Rust	9	17	29	40
5	100% grey-matte. 0 rust	--	--	--	--
6	100% grey-matte. 0 rust	--	--	--	--
7	100% blue-grey metallic. 0 rust	--	--	--	--
8	<5% rust (punched holes). Balance grey-matte. Signs of penetration to base metal in spots.	--	--	--	--

TABLE V

CONTINUOUS GALVANIZED STEEL: B-9

Site No.	Condition as of Sept. 1969 (156 mo)	Time to % Rust Indicated - mo 5%	25%	75%	100%
1	95-100% grey-matte. <5% base metal exposed (edges). Trace rust (edges). Spangle.	--	--	--	--
2	100% grey-matte. Spangle	--	--	--	--
3	100% Rust	80	85	91	106
4	100% Rust	17	25	31	36
5	100% grey-matte. Trace base metal exposed (edges). Trace rust (edges). Spangle	--	--	--	--
6	100% metallic. Spangle	--	--	--	--
7	100% grey-matte. Spangle	--	--	--	--
8	90-95% grey-matte. 5-10% rust (edges).	156	--	--	--

TABLE VI

HOT-DIP ALUMINIZED STEEL: E-1

Site No.	Condition as of Sept. 1969 (156 mo)
1	Dull metallic. Yellowish-gold stain punched holes and edges.
2	Shiny metallic. Yellowish-gold stain punched holes and edges.
3	Dull metallic. Adherent grey-black deposit. Some stain as above at punched holes and edges.
4	Heavy black (soot) deposit. Considerable surface roughness.
5	Dull metallic. Yellowish-gold stain punched holes and edges.
6	Shiny metallic.
7	Dull metallic. Yellowish-gold stain punched holes and edges.
8	Shiny metallic. Yellowish-gold stain punched holes and edges.

TABLE VII

ZINC METALLIZED MILD STEEL

Site No.	Condition as of Sept. 1969 (132 mo)	
	Not Sealed	Sealed
1	Blue-grey	As original
2	Blue-grey	As original
3	Blue-grey. Trace rust at few insulators.	As original
4	Blue-grey. Some black spots (soot). Trace rust (edges). Few pin holes rust. Surface very rough	Surface soot covered. No roughness.
5	Blue-grey	Dulled slightly from original.
6	Blue-grey	As original
7	Blue-grey	As original
8	Blue-grey	Dulled slightly from original.

TABLE VIII

ALUMINUM METALLIZED MILD STEEL

Site No.	Condition as of Sept. 1969 (132 mo)	
	Not Sealed	Sealed
1	White metallic. Some dirt deposit.	Dulled slightly from original.
2	White metallic	As original.
3	White metallic. Some dirt deposit.	Dulled from original.
4	Surface black (soot). Many nodes with underlying white corrosion product. No base metal rust.	Surface dirty (soot). No corrosion.
5	White metallic	Dulled slightly from original.
6	White metallic. Some dirt.	As original.
7	Metallic	As original.
8	White metallic	Dulled from original.

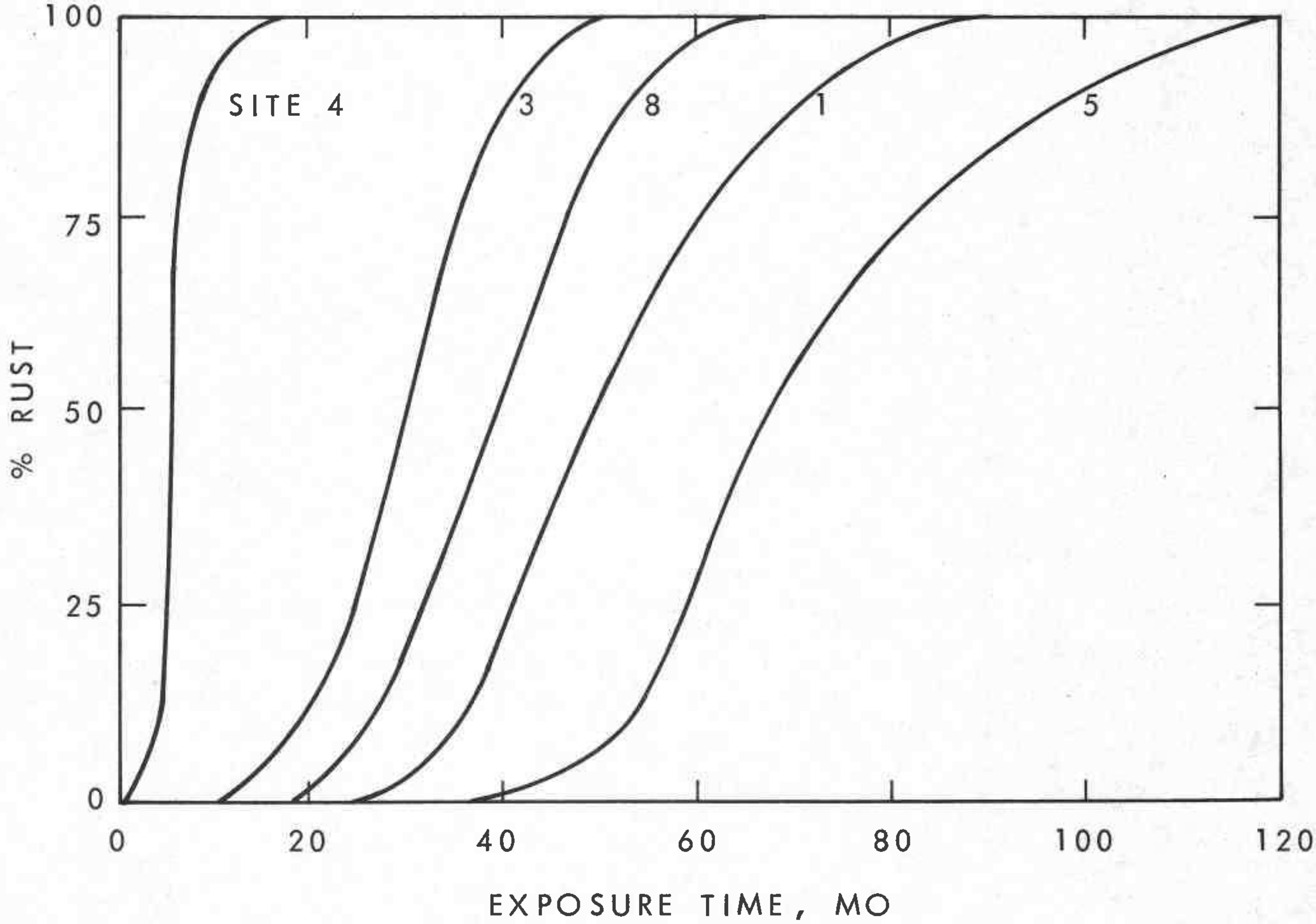

FIGURE 1

PERFORMANCE OF CADMIUM ELECTROPLATED STEEL : A-6

BR 4812 - 1

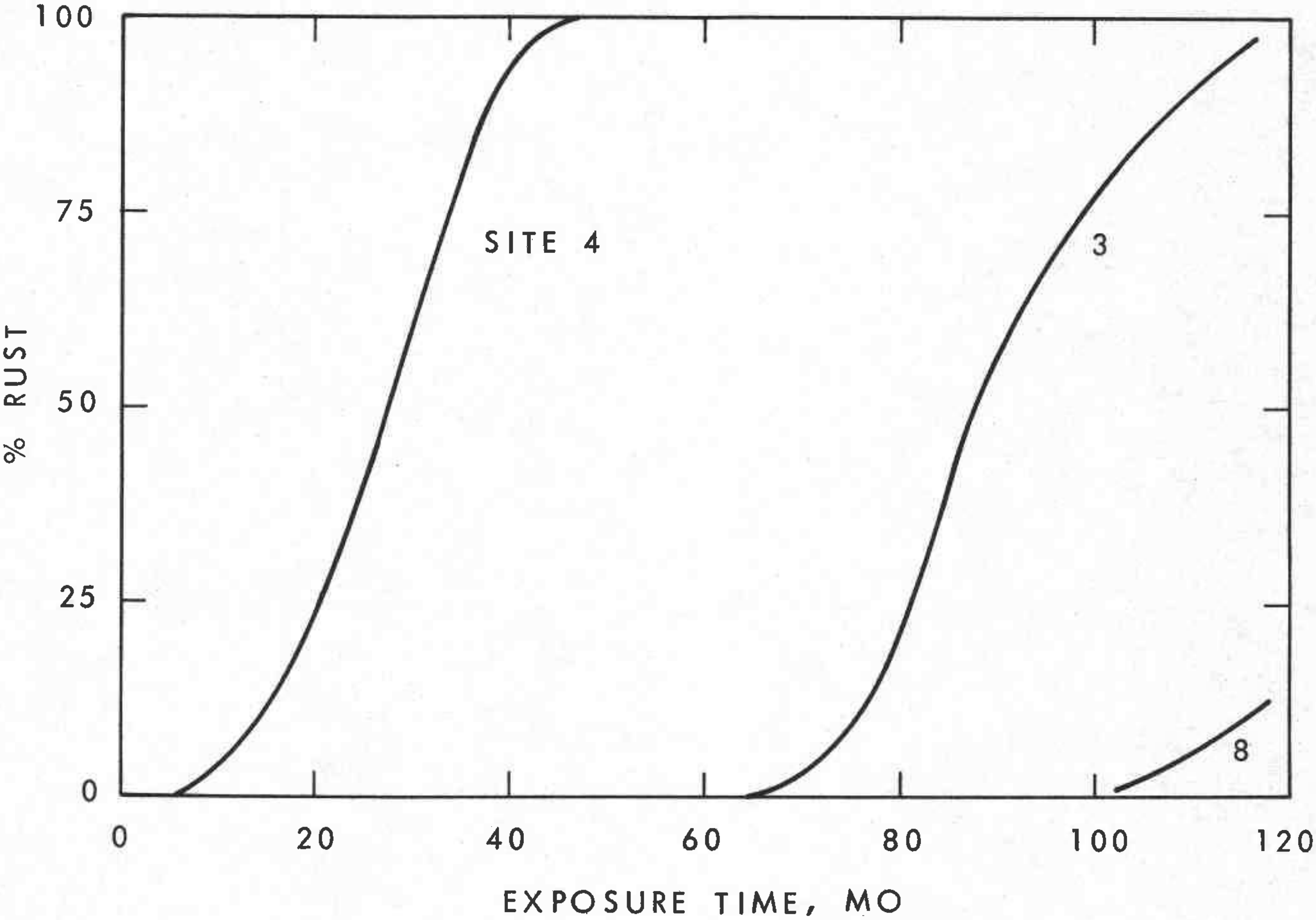

FIGURE 2

PERFORMANCE OF HOT-DIP GALVANIZED STEEL : B - 6

BR 4812-2

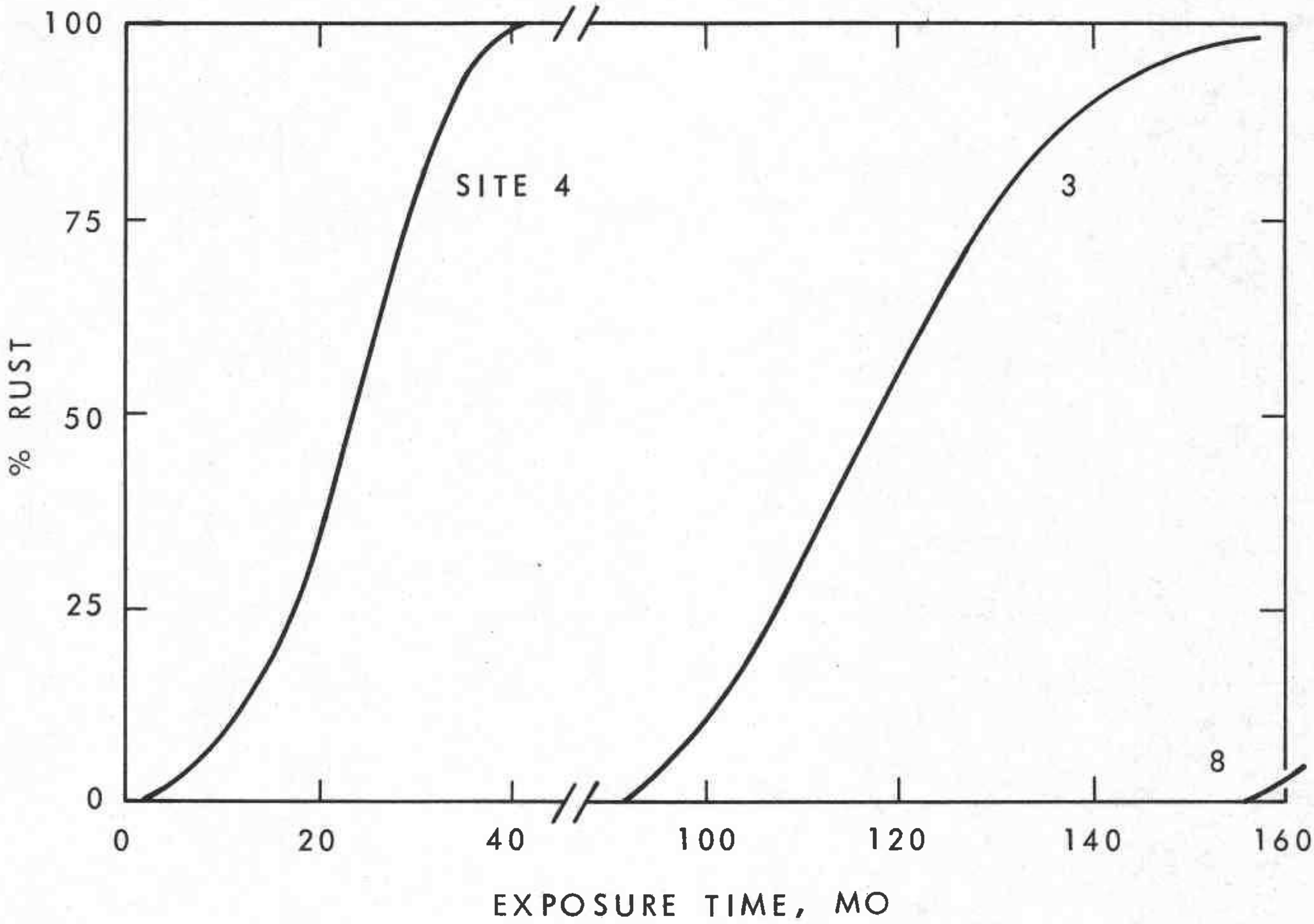

FIGURE 3

PERFORMANCE OF ZINC ELECTROPLATED STEEL : B-7

BR4812-3

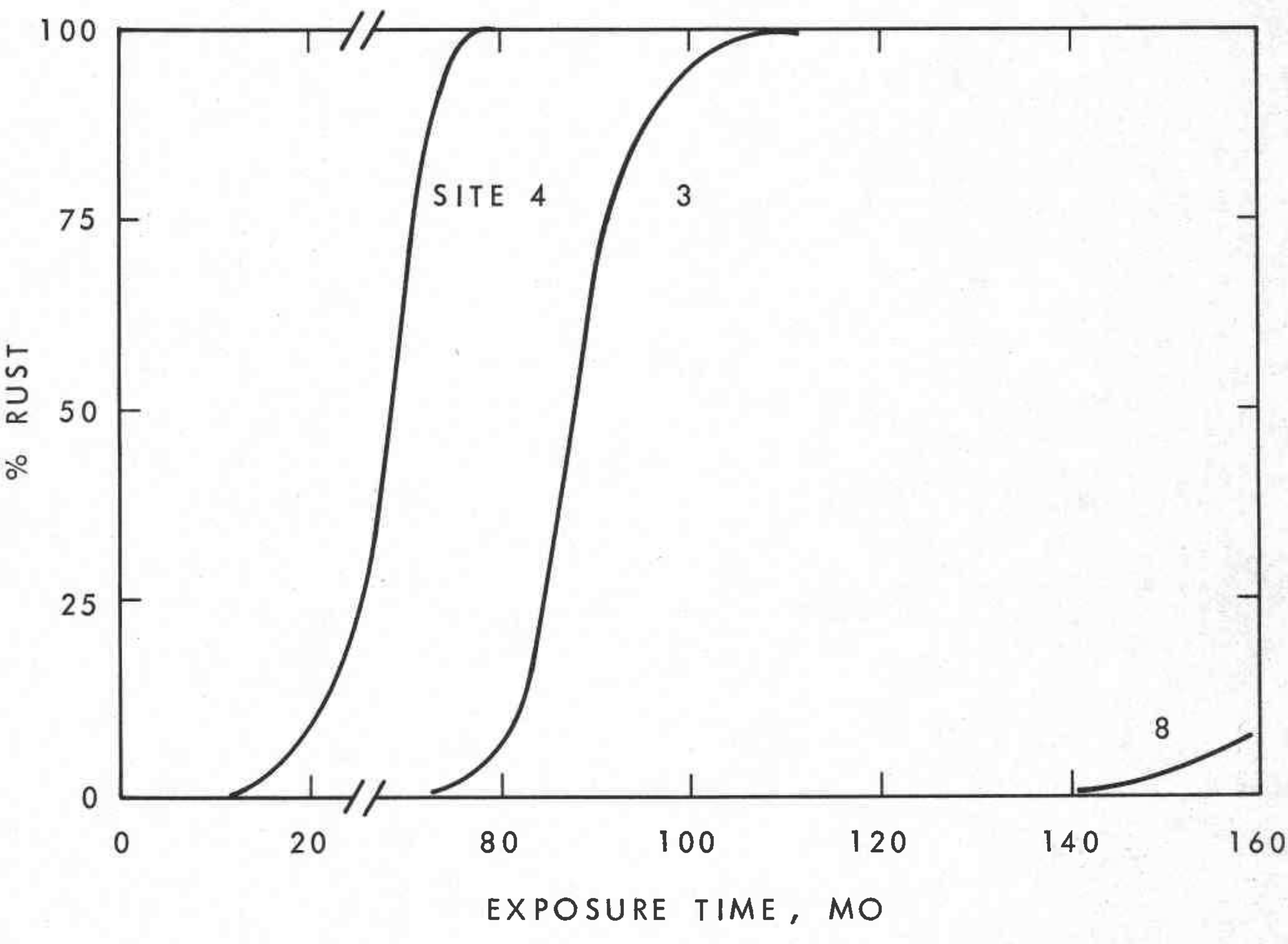

FIGURE 4

PERFORMANCE OF CONTINUOUS GALVANIZED STEEL: B-9

BR4812-4