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Atmospheric Corrosion Testing of Metals in Canada

by
E. V. GIBBONS

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Atmospheric Corrosion Testing of Metals in Canada*

By E. V. GIBBONS

Introduction

THE HEAVY economic losses that can occur as a result of atmospheric corrosion have resulted in many studies of this problem in different countries. Such an outdoor metals exposure program was begun in Canada during 1950 through the Associate Committee on Corrosion of the National Research Council to provide a better understanding of the behavior of different metals and metal coatings when exposed to different Canadian atmospheres. It was a cooperative venture in that industry members of the Committee provided specimens of the various metals selected to be set out at the sites established and operated by the Division of Building Research.

Metals Exposed

The major architectural and structural metals were chosen for comparison in this study. Among the first metals set out and which have now been exposed more than five years are three types of steel, three stainless steels, two magnesium alloys, a rolled zinc, three aluminum alloys and riveted galvanic couples of the aluminum 3S alloy to mild steel, to zinc and to copper. More recently sheet copper, Muntz metal, and two types of sheet lead have been added. Metal coatings on steel of hot-dipped galvanizing, electroplated zinc, sprayed zinc, sprayed aluminum, aluminized steel, and electroplated cadmium have also been exposed. In addition to these metal coatings, a number of different paint systems have been applied to two types of steel and set out at the sites.

Exposure Sites

The exposure sites of the Council and their facilities have already been described.¹ In view of the behavior of the various metals exposed at these different sites, however, the following is a brief description of their location and atmosphere for which each is considered typical.

(1). Ottawa—rural, high humidity; located on the Montreal Road property of N.R.C.

(2). Saskatoon—rural, low humidity; approximately two miles northeast of the campus of the University of Saskatchewan.

(3). Montreal—industrial; located on the roof of a two-story stores building of the Canadian National Railways, in the Point St. Charles district.

(4). Halifax—marine-industrial; located on the roof of a federal public building in the downtown area of the city, two blocks from the harbor.

About
the
Author

E. VINCENT GIBBONS is head of the Building Materials Section, Division of Building Research of the National Research Council, Ottawa, Ontario. He obtained his engineering training at Queen's University, Kingston. He received his B.Sc. degree in Chemical Engineering 1937 and joined G. F. Sterne and Sons Limited, Brantford, Ontario. From 1941 to 1948 he held the position of Chief Chemist. Mr. Gibbons joined the staff of the Division of Building Research of the NRC in 1948. Since 1950 he has been responsible for the operation of the outdoor exposure sites across Canada of the Council and in carrying out the metals exposure program of an Associate Committee on Corrosion. He is a member of the Chemical Institute of Canada and the Professional Engineers of Ontario.

(5). York Redoubt, N.S.—marine; about seven miles from Halifax. The area used is at an elevation of 100 ft. and is 300 ft. from the ocean.

(6). Norman Wells, N.W.T.—a far northern site; located in the Mackenzie River Valley, approximately 50 miles south of the Arctic Circle.

(7). Rocky Point, B.C.—marine; about fifteen miles from the City of Victoria on Vancouver Island. It is at an elevation of 50 ft. and approximately 1500 ft. from the ocean.

(8). Trail, B.C.—this is a semi-industrial site of the Consolidated Mining and Smelting Company of Canada Limited, which was made available to the committee for corrosion studies. It is located in the Columbia River Valley about six miles north of Trail.

Site Facilities and Related Studies

The sites were provided with tubular racks and stainless steel frames for mounting the specimens. All metal specimens were 4 by 6 inches in size and were held in place by porcelain insulators, at 30 degrees to the horizontal and facing south. Twelve specimens of each type of metal were set out initially at each site. This enabled three specimens of each type to be removed after exposure periods of one, two, five and ten years. The procedure was followed of having the suppliers of the metal prepare the specimens, weigh and identify them by a drilled hole system. This information was checked by the Division prior to shipment to the sites for exposure.

Abstract

The atmospheric corrosion resistance of metals is evaluated after exposure in a number of differing Canadian environments. Test sites included rural, industrial, marine-industrial, marine, far northern and semi-industrial. Metals exposed include three aluminum alloys, aluminum coupled metals, carbon steel, copper-bearing low carbon steel, low alloy copper-nickel-bearing steel, three stainless steels, two magnesium alloys, and rolled zinc. Test exposure periods varied from one to ten years.

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After completing a prescribed period of exposure the particular lot of specimens was returned to the Division to be photographed and sent to the supplier for a detailed examination and assessment.

To assist in obtaining a better understanding of the behavior of the various metals a number of environmental factors were measured at the different sites. As all the sites are near weather stations of the Meteorological Division of the Department of Transport, records were available for each site of the precipitation, temperature, hours of sunshine, wind velocity and direction. Since 1954 the relative level of atmospheric sulfur dioxide has been measured monthly. An indication of the seasonal variation of the level of this pollutant and its variation from site to site is shown in Figure 1. Details concerning the measurement of sulfur dioxide and chlorides in the Halifax area have been described previously.²

Specimens of mild steel and a standard rolling grade zinc have been exposed for several one- and two-year periods at each of the sites. These specimens were made available by an ASTM subcom-

Figure 1—Annual variation in SO₂ level at sites.

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Figure 2—Atmospheric corrosion rates for three aluminum alloys.

Figure 3—Time-corrosion curves for steel alloys.

TABLE 1—Analysis of Metals Tested, Percent

Element	Aluminum Alloys			In Al Couples			Steel Alloys			Stainless Steel			Magnesium Alloys		Rolled Zinc
				Mild Steel	Zinc	Copper									
	3S	57S	65S	Desig. 1010			Carbon	Cu Bearing	Cu-Ni Bearing	302	430	316	AZ80	ZK61	
Cu	0.03	0.02	0.36	....		99.83	0.090	0.205	0.738	....	....	....	0.020	0.001	0.001
Fe	0.40	0.25	0.64	....	0.40		....	....	....	....	....	....	0.003	0.001	0.004
Mg		2.25	1.06	....			....	....	....	....	....	....	....	....	....
Mn	1.06			0.43			0.29	0.32	0.78	1.24	0.43	1.85	0.26	0.004	....
Si	0.10	0.10	0.64	0.019			0.002	0.002	0.021	0.41	0.41	0.38	0.06	....	....
Ti	0.014	0.02	0.05	....			....	....	....				....	....	....
Cr		0.26	0.22	....			....	....	....	18.78	16.62	16.92	....	....	....
C				0.08			0.064	0.069	0.124	0.12	0.11	0.09	....	....	....
B				0.045			....	....	....	....	....	....	....	....	....
P				0.014			0.013	0.014	0.095	0.029	0.030	0.028	....	....	....
Pb				....	1.120		....	....	....	....	....	....	0.003	....	0.08
Cd				....	0.041		....	....	....	....	....	....	....	....	0.002
Zn				....	98.71		....	....	....	....	....	....	0.38	5.9	99.91
Ni				....			....	....	0.680	6.8	0.75	12.82	0.001	0.001	....
S				....			0.035	0.048	0.032	0.018	0.025	0.020	....	....	....
Mo				....			....	....	....	0.23		2.43	....	....	....
Al				....			....	....	....	....	....	....	8.1	0.83	....
Zr				....			....	....	....	....	....	....	0.001	....	....
Sn				....			....	....	....	....	....	....	0.001	....	....
Ca				....			....	....	....	....	....	....	0.001	....	....

mittee determining the relative corrosivity of the atmosphere at ASTM exposure sites. A correlation of the corrosiveness at eight Canadian sites with the eleven sites in the U.S.A. is available.³ In the report describing this calibration study the corrosivity at the Ottawa site with respect to steel is the same as the U.S. site at Pennsylvania State University which was taken as unity but it is more corrosive with respect to zinc (1.3 to 1). The site at Norman Wells was the least corrosive of the nineteen sites reported.

The current studies of a task group of ASTM Committee B-3 on the measurement of atmospheric factors affecting corrosion are of special interest. This work has resulted in the development of instrumentation to detect surface moisture and record the time-of-wetness on exposed metal surfaces in which the

Division of Building Research has played a leading part.⁴ More recently field instruments of this type have been installed to measure time-of-wetness at three Canadian sites and four ASTM sites to obtain a correlation of the metal loss with time-of-wetness, temperature and pollution.

Exposure Results

A progress report has been published which describes the corrosion behavior after one- and two-year periods of exposure of a number of the metals mentioned previously.⁵ A similar report including the results of these metals after five years of exposure is being prepared. Since details of the performance of individual panels and lots are contained in these reports only a brief résumé of the different metals that have completed up to five years of exposure is given here.

The chemical composition of each is shown in Table 1.

Aluminum Alloys

Three aluminum alloys were exposed: 3S-H14, 57S-H34, and 65S-T6. Riveted couples of 3S aluminum sheet and copper, zinc and mild steel were also included.

In general appearance the three alloys were similar at each location. This applies to both the groundward and skyward sides, with few exceptions when examined at the end of the one-, two- and five-year exposure periods. They varied greatly however depending upon the particular sites at which they were exposed. Weathering took the form of surface roughening due to pitting; its extent increased with aggressiveness of the atmosphere. The differences in corrosion rates among the three alloys were

TABLE 2—Stainless Steel Exposed at the Halifax Site

Exposure Period, Years	Weight Loss, gm		
	302	316	430
1.....	0.132	0.074	0.425
2.....	0.229	0.165	0.599
5.....	1.123	0.417	1.144

generally small and up to the end of two years were considered to be similar. By the end of five years of exposure, alloy 57S showed better resistance than the others at the industrial sites with alloy 3S being superior at the mild rural sites. Alloy 65S was intermediate in most cases. Figure 2 shows the corrosion rates, calculated from weight losses, of the three aluminum alloys at the two most corrosive sites—Halifax and Montreal.

The riveted bimetallic couples of copper or mild steel to aluminum 3S alloy caused galvanic corrosion. This was found to be most severe in a marine atmosphere, less severe in industrial atmospheres and negligible at rural sites. Zinc, when coupled to aluminum, tended to protect it in all atmospheres.

Steel

Three steels, a carbon steel, a copper-bearing low carbon, and a low alloy copper-nickel-bearing steel were exposed at each of the sites. The low alloy copper-nickel-bearing steel gave the greatest resistance to atmospheric corrosion at all sites except Norman Wells. The loss due to corrosion at this site is extremely low, however, for all of the metals exposed, as is the weight loss difference between the three steels. There was little difference in weight loss between the carbon steel and the copper-bearing steel. The latter showed a slightly improved resistance at all of the sites after one year of exposure. This behavior continued during the two-and five-year exposure periods. The loss in weight with time of these three steels at each of the sites is shown in Figure 3. These results are somewhat at variance with results reported by others who have had atmospheric corrosion resistance improved by as much as four times for a copper-bearing steel compared to steels with residual copper.⁶ It should be noted in Table 1 that the Cu content of the carbon steel is 0.09 percent, which is relatively high. As was found with the aluminum alloys, there was a decrease in the corrosion rate with time for each of the three steels exposed.

Stainless Steels

Three stainless steels, Types 302 and 316 each with a 2B finish and Type 430 with a 4B finish were set out at each of the sites. Their behavior in appearance and weight loss at each of the sites was similar except for alloy 430 at the Halifax site. Here this alloy had a much higher weight loss than 316 and about the same loss as 302 after five years of exposure. The weight loss after one, two and five years at this site for the three alloys is shown in Table 2. These results

show that Type 316 had the least loss after five years. At all of the remaining sites there was very little loss in weight after five years of exposure for any of the three types. As an example of the effect of environment of the Halifax site on Type 430 the metal loss after five years of exposure was found to be 1.144 gm. At the next most corrosive site this same alloy had a loss of 0.011 gm during the same period of exposure.

Magnesium Alloys

The two magnesium alloys exposed, AZ80 and ZK61, were supplied in a chrome pickled condition. Of the two, ZK61 showed considerably less corrosion resistance at all of the sites for each period of exposure. In comparison with the behavior of the other metals, in which their corrosion rates decreased with time, the weight loss for the two magnesium alloys was approximately proportional to the time of exposure. The marine sites were quite corrosive to the ZK61 alloy. The AZ80 alloy showed considerably improved resistance in these areas with the exception of Halifax where a small improvement was found.

Rolled Zinc

The corrosion rate of the rolled zinc varied considerably between sites; the highest rate was at Halifax followed in order by Montreal, Trail, and York Redoubt. Halifax was also found to be considerably more corrosive to the ASTM zinc specimens than any of the ASTM sites.³ The five-year exposure results have shown that decreases in the rates of corrosion from the one- and two-year results have occurred at the Saskatoon, Halifax, York Redoubt, Norman Wells and Rocky Point sites. They also show increases in rates for the Ottawa and Montreal sites.

The corrosion rate decrease at Halifax may be attributable to the protective action of the relatively heavy deposit that built up on the panels. At the other sites where a decrease in rate has occurred this may be due to the protective action of the corrosion products formed and which remained *in situ*. The increases in rates at Ottawa and Montreal could be due to an increase in aggressiveness of the atmosphere and/or exposure to greater amounts of precipitation. This would tend to wash away corrosion products formed and reduce their protective action. The meteorological records indicate that the annual precipitation at Ottawa and Montreal is greater than at all other sites except for the two in the Halifax area.

Examination of the panels after cleaning indicated that corrosion was substantially uniform and the corrosion appeared to be more severe on the skyward faces than on the groundward.

Conclusions

In all cases the Halifax industrial-marine site was by far the most corrosive of all the sites. Montreal, Trail and York Redoubt were considerably less corrosive and the metal loss at these sites in many instances similar. These sites were fol-

lowed in order by Ottawa, Saskatoon and Rocky Point; Norman Wells was found to have the least corrosive atmosphere. The aggressiveness of the Halifax site is attributable in part to the high level of atmospheric sulfur dioxide which influences the rate of corrosion.

The corrosion performance of the various metals indicated that the penetration rate of the stainless steel alloys was the lowest for the three different exposure periods. Almost no corrosion took place with these alloys except at the Halifax site. The aluminum alloys were the next lowest followed by the rolled zinc. Except for the two Halifax area sites magnesium alloy AZ80 showed better corrosion resistance than the three steel alloys. The copper-nickel-bearing alloy showed considerably better corrosion resistance than the ZK61 magnesium alloy with the carbon steel and the copper-bearing in general just slightly better.

The faying surfaces of the 3S aluminum sheet in the lapped bimetallic, riveted joints were protected by zinc but were adversely affected by copper and mild steel.

The rate of corrosion of the different metals almost invariably decreased with time. There were exceptions to this at some locations for rolled zinc and both magnesium alloys.

Finally the results reported enables a comparison to be made of the performance of the different metals under the exposure conditions described. These results must be used with caution however when predicting the life of the metal as a building component. Different environmental factors of atmosphere, orientation and position with other materials may affect their corrosion characteristics. Therefore studies that will provide ways of measuring the effect of the various factors are encouraged so that their performance in service may be predicted with greater certainty.

Acknowledgment

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