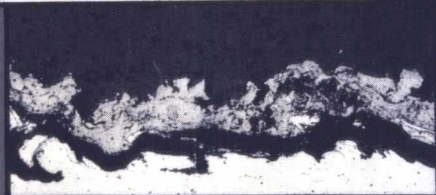
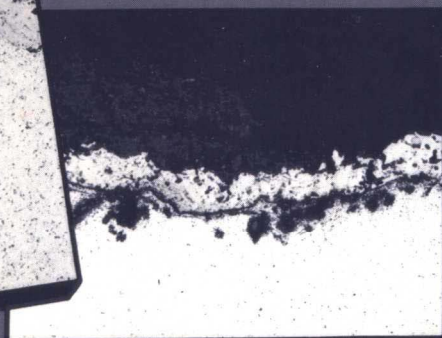
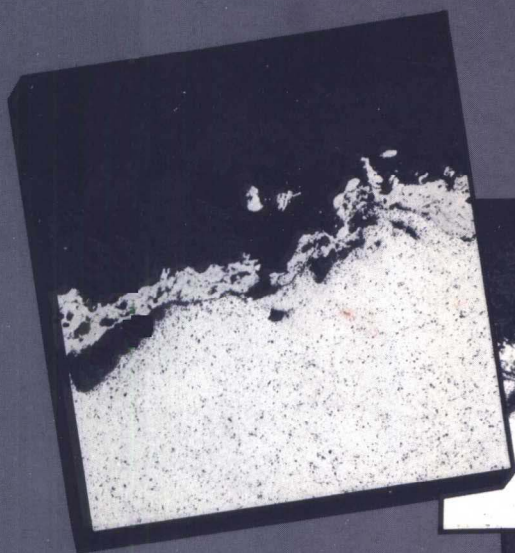


# Degradation of Metals in the Atmosphere

DEAN/LEE  
editors



ASTM STP 965

# DEGRADATION OF METALS IN THE ATMOSPHERE

A symposium sponsored by ASTM Committee G-1  
on Corrosion of Metals  
Philadelphia, PA, 12-13 May 1986

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## FOREWORD

The Symposium on Degradation of Metals in the Atmosphere was presented at Philadelphia, PA, on 12-13 May 1986. The symposium was sponsored by ASTM Committee G-1 on Corrosion of Metals. Sheldon W. Dean, Air Products and Chemicals, Inc., and T. S. Lee, National Association of Corrosion Engineers, served as chairmen of the symposium and are editors of the resulting publication.

## A Note of Appreciation to Reviewers

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

*ASTM Committee on Publications*

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# Introduction

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ASTM has provided leadership in generating information on atmospheric corrosion since 1906 when the first ASTM exposure program was initiated. Much of the early test work was aimed at evaluating the effective life of protective coatings so that meaningful specifications could be written. In 1964, Committee G-1 on the Corrosion of Metals was formed, and its scope included "the promotion and stimulation of research" and "collection of engineering data relating to the corrosion of metals." Subcommittee G01.04 on Atmospheric Corrosion has pursued these goals through a series of symposia that have resulted in Special Technical Publications (STPs).

The first of these symposia was held in Boston, MA, 25-30 June 1967 and resulted in ASTM STP 435 [1]. The next symposium was held in Philadelphia, PA, 24-29 June 1973, and the papers were published in STP 558 [2], together with the papers of two other symposia. The Golden Anniversary Symposium commemorating 50 years Atmospheric Exposure Testing at the State College Rural Test Site was held at Pennsylvania State University, State College, PA, 18-19 May 1976, and the papers were published in STP 646 [3]. The Symposium on Atmospheric Corrosion of Metals was held in Denver, CO, 19-20 May 1980 and resulted in STP 767 [4]. The approach of using symposia has allowed wide participation and more comprehensive coverage of the subject. Contributions from sources outside the United States have also given these publications an international scope.

The Symposium on Degradation of Metals in the Atmosphere was organized as a continuation of the atmospheric corrosion series. The following goals were identified for the symposium:

- to highlight the performance of new alloys and metallic combinations, including metallic coatings,
- to report on the behavior of metals and alloys used in atmospheric service,
- to provide updated information on the effects of sulfur oxides and other accelerators of atmospheric corrosion,
- to report on studies showing correlation between atmospheric exposure results and laboratory tests designed to simulate atmospheric service, and
- to discuss the development and use of standards to control and minimize the atmospheric corrosion of metals.

The atmosphere has undergone significant changes in the past two decades in the United States. The efforts to reduce air pollution levels have resulted in significant reductions in ground level sulfur dioxide concentration, together with reduced lead content in particulates near highways. However, the use of tall stacks on coal fired electric power generating facilities has created widespread concerns about acid precipitation. Increased usage of deicing salts to maintain ice and snow-free thoroughfares have also increased the prevalence of chlorides in nonmarine environments. The development of atmospheric monitoring systems and the widespread availability of computers have made possible extensive modeling and correlation studies. All of these developments have made the study of atmospheric corrosion a dynamic and challenging field in spite of eight decades of work.

The symposium that was held 12-14 May 1986 in Philadelphia featured 30 speakers on a wide variety of topics. All the major engineering metals were covered, including weathering and structural steel, stainless steels, zinc galvanized steel, aluminum and copper alloys. Several

other papers on atmospheric effects, corrosion monitoring, clad metals, and computer modeling rounded out the program.

In 1976, the first plenary meeting of the International Organization for Standardization (ISO) Technical Committee 156 in Corrosion of Metals and Alloys met and identified atmospheric corrosion as a priority area for standards development. Two working groups were formed to address aspects of atmospheric corrosion. Working Group 3 (ISO/TC 156/WG3) was concerned with corrosion test methods, while Working Group 4 (ISO/TC 156/WG4) was concerned with classification of atmospheric corrosivity. Working Group 4 is now sponsoring an atmospheric exposure program that is described in this STP.

In view of the wide coverage and international participation in this symposium, this STP provides a cross section of the state of the art in atmospheric corrosion testing in the mid 1980s. Taken with the other ASTM STPs, it provides a comprehensive view of the subject. However, the field is continuing to develop and more symposia will be needed in the future.

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## **Materials Performance**



# Sixteen-Year Atmospheric Corrosion Performance of Weathering Steels in Marine, Rural, and Industrial Environments

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**REFERENCE:** Shastry, C. R., Friel, J. J., and Townsend, H. E., "Sixteen-Year Atmospheric Corrosion Performance of Weathering Steels in Marine, Rural, and Industrial Environments," *Degradation of Metals in the Atmosphere*, ASTM STP 965, S. W. Dean and T. S. Lee, Eds., American Society of Testing and Materials, Philadelphia, 1988, pp. 5-15.

**ABSTRACT:** Weathering steels ASTM A 242-Type 1 and ASTM A 588-Grade B and steels with 0.21 and 0.021% copper are tested for atmospheric corrosion resistance in marine, rural, and industrial environments. The 16-year atmospheric exposure test results obey well the kinetic equations of the form  $C = At^B$ , where  $C$  is the corrosion loss,  $t$  is time, and  $A$  and  $B$  are constants. The corrosion resistance of steels is compared on the basis of times required to achieve a 250  $\mu\text{m}$  thickness loss calculated using the rate equations. In these environments, weathering steel ASTM A 242 is at least 16 times more corrosion resistant than the 0.021% copper steel and at least four times more corrosion resistant than the 0.21% copper steel. Similarly, weathering steel ASTM A 588 is about eight times more durable than the 0.021% copper steel and at least two times more durable than the 0.21% copper steel.

**KEY WORDS:** corrosion, corrosion tests, atmospheric corrosion, industrial environment, marine environment, rural environment, steels, weathering steel, kinetics, regression analysis

Atmospheric corrosion can lead to the deterioration of steel structures. Although the effects of corrosion can be reduced by painting, it is often more advantageous to make use of maintenance-free weathering steels. The term weathering steel applies to a class of low-alloy steels that contain small amounts of such alloying elements as Cu, Cr, Ni, P and Si, which promote the formation of a protective rust layer that acts as a self-healing barrier against further corrosion. The attractive and protective rust layers that develop on these steels during outdoor exposure, coupled with no need for maintenance, have provided the necessary impetus for the widespread use of weathering steels over the years in a variety of structural applications including buildings and bridges.

The weathering steels are covered by ASTM Specification (A 588-77a, Grade B) for high-strength low-alloy structural steel with 345 MPa (50,000 psi) minimum yield strength to 102 mm thick and by Specification (A 242-75, Type 1) for high strength low-alloy structural steel. Bethlehem produces both of these grades under the trade names Mayari R-50 and Mayari R, respectively. The main difference between the two grades is in their P content, which in the case of A 242 is about 0.10%, whereas for the A 588 steel it is held below 0.04% for improved tough-

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ness and weldability. The complete analysis of the two Bethlehem grades is given in Table 1 along with the corresponding ASTM specifications. The revised A 588 Specification (A 588-82, Grade B) has a higher upper limit for Si than the earlier (A 588-77a, Grade B) version (0.50% versus 0.30%). This change was made in order to further enhance the corrosion resistance of this steel based on published information on the effect of Si [1]. It is expected that the atmospheric corrosion performance of the new grade (A 588-82, Grade B) will be better than that of the earlier (A 588-77a, Grade B).

Atmospheric corrosion performance of weathering steels is usually measured in terms of thickness loss over a period of time. In an earlier paper [2], the eight-year atmospheric corrosion performance of A 588 weathering steel in industrial, rural, and marine environments was described. It was shown that the atmospheric corrosion performance of A 588-77a, Grade B exceeds the ASTM specification that the weathering steel be two times more durable than carbon structural steel with copper (0.20 minimum-percent Cu), and four times more durable than carbon structural steel without copper (0.02 maximum-percent Cu).

We have now obtained 16-year atmospheric exposure test results which lend further support to the above conclusion. Additionally, we have also obtained long-term atmospheric exposure test results for the A 242-75, Type 1 weathering steel, which indicate an outstanding corrosion performance by this steel in all three types of test environments. This paper presents the results of 16-year outdoor corrosion tests on the two weathering steels (A 588-77a, Grade B and A 242-75 Type 1) in three different environments and compares their performance with that of carbon structural steels both with and without copper.

### Materials and Test Procedures

The composition of steels tested is given in Table 1. Plant-produced 38-mm thick weathering steel plates are hot-rolled in our laboratories to 2.5-mm thickness, and from these sheets, panels measuring approximately 150 mm  $\times$  100 mm  $\times$  2.5 mm (6 in.  $\times$  4 in.  $\times$  0.1 in.) are cut, grit-blasted, stamped with identification, degreased, and weighed before atmospheric exposure.

The steel containing 0.21% copper is similarly prepared from 5 mm plate. The steel with 0.021% copper is procured in the form of cold-rolled and annealed 2.8-mm (0.11 in.) carbon steel sheet. The latter steel is similar to that used by Coburn et al. [3] in an ASTM study to determine the severity of various atmospheric test sites.

The test panels are exposed 30° from the horizontal, with skyward surfaces facing south at three test sites (described below) representing a broad range of environmental conditions:

1. Kure Beach, NC: This is an internationally known marine test site located about 250 m from the open Atlantic Ocean, and is operated by the LaQue Center for Corrosion Technology.
2. Saylorsburg, PA: This site is located in the Pocono Mountains about 50 km north of Bethlehem. The site is operated by Bethlehem Steel.
3. Bethlehem, PA: This is an industrial site in the proximity (3 km) of Bethlehem Steel's integrated steel making facility.

A comparison of these sites over the years 1968 to 1984 is given in Fig. 1. This figure shows the corrosion loss of 1.2-mm, thick-rolled pure zinc panels (Zn  $\geq$  99.85%, Pb = 0.09%, Al < 0.005%, Cu < 0.005%, Cd < 0.01%, Mg < 0.005%, Sn < 0.005%, Fe = 0.02%) exposed as controls at the same time as the test specimens. The zinc corrosion rate averaged 1.64  $\mu$ m/year at the Saylorsburg site, 1.91  $\mu$ m/year at Bethlehem, and 2.12  $\mu$ m/year at Kure Beach.

Exposed duplicate specimens were removed after one, two, six, eight, and 16 years of exposure, cleaned in a molten sodium hydroxide (NaOH)-sodium hydride (NaH) mixture to remove corrosion products, and reweighed to determine metal loss according to ASTM Recommended Practice G 1-81. Details of the sodium hydride cleaning process are given in Du Pont publication SP 29-370 [4]. Briefly, our procedure consists of immersing preheated weathered steel panels in a carrier bath of fused NaOH containing about 2% NaH at a temperature of 643 K  $\pm$  10.

TABLE 1—Composition of steels in the atmospheric corrosion tests.

Steel	Composition, % by Weight								
	C	Mn	P	S	Si	Ni	Cr	Cu	V
ASTM Specification A 242-75, Type 1	0.15 max	1.00 max	0.15 max	0.05 max	...	...	...	0.20 min	...
A 242 Test Material	0.09	0.65	0.11	0.032	0.29	0.66	0.52	0.27	...
ASTM Specification: A 588-82, Grade B	0.20 max	0.75-1.35	0.04 max	0.05 max	0.15-0.50	0.50 max	0.40-0.70	0.20-0.40	0.01-0.10
ASTM Specification A 588-77a, Grade B	0.20 max	0.75-1.25	0.04 max	0.05 max	0.15-0.30	0.50 max	0.40-0.70	0.20-0.40	0.01-0.10
A 588 Test Material	0.13	1.02	0.008	0.018	0.22	0.27	0.64	0.21	0.062
0.21 Cu Test Material	0.02	0.35	0.005	0.013	0.01	0.02	0.02	0.21	...
0.021 Cu Test Material	0.07	0.35	0.009	0.020	<0.001	0.01	0.02	0.021	...

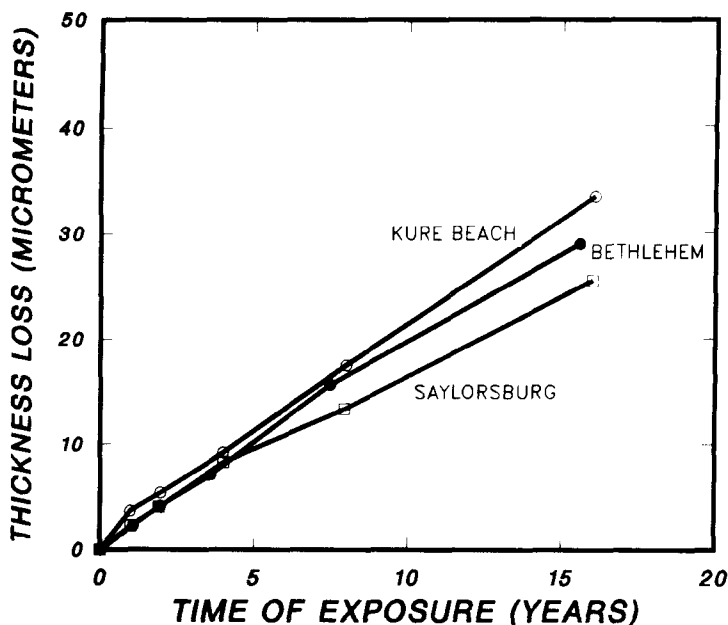


FIG. 1—Corrosion of pure zinc from 1968 to 1984 at each site.

Sodium hydride, the active descaling agent, is generated in the bath by reacting metallic Na and H in generators that are partially immersed in the fused hydroxide bath. The time of immersion is approximately 20 min. Following immersion, the panels are removed from the bath, allowed to drain for a short time, and then quenched in water, scrubbed, and allowed to dry before weighing.

### Results and Discussion

Results of the corrosion tests are plotted as a linear function of time in Figs. 2 to 4. Each point in these figures represents the average of the corrosion loss values from duplicate specimens. The individual values for the duplicate specimens differ in general by less than 5% of the average value. On the basis of these data, the steels can be qualitatively ranked in terms of their corrosion resistance as follows: A 242 weathering steel > A 588 weathering steel > 0.21 Cu steel > 0.021 Cu steel. When replotted on logarithmic scales, Figs. 5 to 7, the same data fit well to straight lines. These straight line relationships can be represented by equations of the form shown below:

$$\log C = \log A + B \log t \quad (1)$$

where

$C$  = corrosion loss in micrometers,

$t$  = time in years, and

$A$  and  $B$  = constants.

The constants of the equation are obtained by linear regression analysis of these data, and are shown in Table 2 along with the associated correlation coefficients,  $R$ . The  $R$  values listed in the



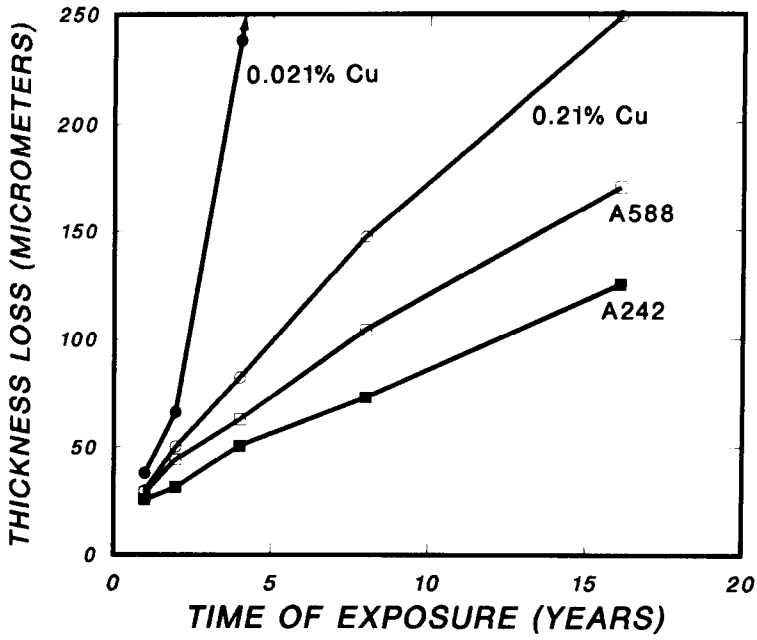


FIG. 2—Corrosion performance of steels at Kure Beach, NC.

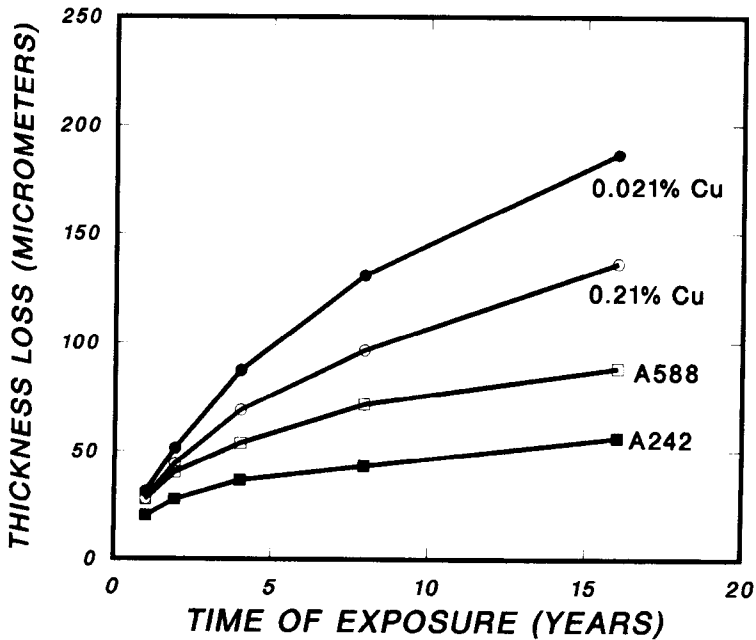


FIG. 3—Corrosion performance of steels at Saylorsburg, PA.