Designation: G 101 – 01

Standard Guide for Estimating the Atmospheric Corrosion Resistance of Low-Alloy Steels[1]

This standard is issued under the fixed designation G 101; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide presents two methods for estimating the atmospheric corrosion resistance of low-alloy weathering steels, such as those described in Specifications A 242/A 242M, A 588/A 588M, A 606 Type 4, A 709/A 709M grades 50W, HPS 70W, and 100W, A 852/A 852M, and A 871/A 871M. One method gives an estimate of the long-term thickness loss of a steel at a specific site based on results of short-term tests. The other gives an estimate of relative corrosion resistance based on chemical composition.

2. Referenced Documents

2.1 *ASTM Standards:*

A 242/A 242M Specification for High-Strength Low-Alloy Structural Steel[2]

A 588/A 588M Specification for High-Strength Low-Alloy Structural Steel with 50 Ksi (345 MPa) Minimum Yield Point to 4 in. (100 mm) Thick[2]

A 606 Specification for Steel, Sheet and Strip, High Strength, Low-Alloy, Hot-Rolled and Cold Rolled, With Improved Atmospheric Corrosion Resistance[3]

A 709/A 709M Specification for Carbon and High-Strength Low-Alloy Structural Steel Shapes, Plates, and Bars and Quenched-and-Tempered Alloy Structural Steel Plates for Bridges

A 852/A 852M Specification for Quenched and Tempered Low-Alloy Structural Steel Plate with 70 ksi (485 MPa) Minimum Yield Strength to 4 in (100 mm) Thick[2]

A 871/A 871M Specification for High Strength Low-Alloy Structural Steel Plate With Atmospheric Corrosion Resistance[2]

G 1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens[4]

G 16 Guide for Applying Statistics to Analysis of Corrosion Data[4]

G 50 Practice for Conducting Atmospheric Corrosion Tests on Metals[4]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *low-alloy steels*—Iron-carbon alloys containing greater than 1.0 % but less than 5.0 %, by mass, total alloying elements.

NOTE 1—Most "low-alloy weathering steels" contain additions of both chromium and copper, and may also contain additions of silicon, nickel, phosphorus, or other alloying elements which enhance atmospheric corrosion resistance.

4. Summary of Guide

4.1 In this guide, two general methods are presented for estimating the atmospheric corrosion resistance of low-alloy weathering steels. These are not alternative methods; each method is intended for a specific purpose, as outlined in 5.2 and 5.3.

4.1.1 The first method utilizes linear regression analysis of short-term atmospheric corrosion data to enable prediction of long-term performance by an extrapolation method.

4.1.2 The second method utilizes predictive equations based on the steel composition to calculate indices of atmospheric corrosion resistance.

5. Significance and Use

5.1 In the past, ASTM specifications for low-alloy weathering steels, such as Specifications A 242/A 242M, A 588/A 588M, A 606 Type 4, A 709/A 709M Grade 50W, HPS 70W, and 100W, A 852/A 852M, and A 871/A 871M stated that the atmospheric corrosion resistance of these steels is "approximately two times that of carbon structural steel with copper." A footnote in the specifications stated that "two times carbon structural steel with copper is equivalent to four times carbon structural steel without copper (Cu 0.02 maximum)." Because such statements relating the corrosion resistance of weathering

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[2] *Annual Book of ASTM Standards*, Vol 01.04.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

[4] *Annual Book of ASTM Standards*, Vol 03.02.

steels to that of other steels are imprecise and, more importantly, lack significance to the user **(1 and 2)**[5], the present guide was prepared to describe more meaningful methods of estimating the atmospheric corrosion resistance of weathering steels.

5.2 The first method of this guide is intended for use in estimating the expected long-term atmospheric corrosion losses of specific grades of low-alloy steels in various environments, utilizing existing short-term atmospheric corrosion data for these grades of steel.

5.3 The second method of this guide is intended for use in estimating the relative atmospheric corrosion resistance of a specific heat of low-alloy steel, based on its chemical composition.

5.4 It is important to recognize that the methods presented here are based on calculations made from test data for flat, boldly exposed steel specimens. Atmospheric corrosion rates can be much higher when the weathering steel remains wet for prolonged periods of time, or is heavily contaminated with salt or other corrosive chemicals. Therefore, caution must be exercised in the application of these methods for prediction of long-term performance of actual structures.

6. Procedure

6.1 Atmospheric corrosion data for the methods presented here should be collected in accordance with Practice G 50. Specimen preparation, cleaning, and evaluation should conform to Practice G 1.

6.2 *Linear Regression Extrapolation Method*:

6.2.1 This method essentially involves the extrapolation of logarithmic plots of corrosion losses versus time. Such plots of atmospheric corrosion data generally fit well to straight lines, and can be represented by equations in slope-intercept form, **(3-5):**

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

where:

C = corrosion loss,
t = time, and
A and B = constants. A is the corrosion loss at t = 1, and B is the slope of a log C versus log + plot.

C may be expressed as mass loss per unit area, or as a calculated thickness loss or penetration based on mass loss.

6.2.2 The method is best implemented by linear regression analysis, using the method of least squares detailed in Guide G 16. At least three data points are required. Once the constants of the equation are determined by the linear regression analysis, the projected corrosion loss can be calculated for any given time. A sample calculation is shown in Appendix X1.

NOTE 2—Eq 1 can also be written as follows:

$$C = At^B \quad (2)$$

Differentiation of Eq 2 with respect to time gives the corrosion rate (R) at any given time:

$$R = ABt^{(B-1)} \quad (3)$$

Also, the time to a given corrosion loss can be calculated as follows:

$$t = (C/A)^{1/B} \quad (4)$$

6.2.3 Examples of projected atmospheric corrosion losses over a period of fifty years for low-alloy weathering steels in various environments are presented in Appendix X1.

NOTE 3—It has been reported **(6 and 7)** that for some environments, use of log-log linear regression extrapolations may result in predictions which are somewhat lower or somewhat higher than actual losses. Specifically, in environments of very low corrosivity, the log-log predictions may be higher than actual losses **(6)**, whereas in environments of very high corrosivity the opposite may be true **(7)**. For these cases, use of numerical optimization or composite modeling methods **(7 and 8)** may provide more accurate predictions. Nevertheless, the simpler log-log linear regression method described above provides adequate estimates for most purposes.

6.3 *Predictive Methods Based on Steel Composition*—Two approaches are provided for prediction of relative corrosion resistance from composition. The first is based on the data of Larrabee and Coburn (6.3.1). Its advantage is that it is comparatively simple to apply. This approach is suitable when the alloying elements are limited to Cu, Ni, Cr, Si, and P, and

[5] The boldface numbers in parentheses refer to the list of references at the end of this guide.

TABLE 1 Constants and Coefficients for Calculating the Rate Constants A and B from Composition

	A (μm)			B (T in months)		
n	275	227	248	275	227	248
site	Bethlehem, PA	Columbus, OH	Pittsburgh, PA	Bethlehem, PA	Columbus, OH	Pittsburgh, PA
Constant	15.157	16.143	14.862	0.511	0.539	0.604
Carbon	6.310	[A]	3.350	–0.102	–0.103	–0.046
Manganese	[A]	–2.170	–2.370	–0.097	–0.019	0.042
Phosphorus	–1.770	–10.250	–5.120	–0.592	–0.333	–0.546
Sulfur	–27.200	–15.970	[A]	2.408	0.908	1.004
Silicon	6.50	2.96	1.38	–0.20	–0.16	–0.13
Nickel	1.970	–1.380	1.180	–0.080	–0.029	–0.088
Chromium	[A]	2.560	2.370	–0.103	–0.095	–0.174
Copper	[A]	0.990	–1.970	–0.072	–0.067	–0.068
Aluminum	[A]	1.580	5.520	[A]	[A]	–0.087
Vanadium	[A]	6.110	[A]	[A]	–0.193	[A]
Cobalt	1.580	–1.770	–2.560	–0.063	–0.053	0.044
Arsenic	3.150	–6.110	–7.690	–0.157	[A]	0.097
Molybdenum	[A]	[A]	–2.960	–0.078	–0.038	[A]
Tin	–3.740	–7.490	–9.860	–0.151	–0.038	[A]
Tungsten	[A]	–5.520	[A]	–0.148	[A]	[A]

[A] Coefficient has greater than 50 % probability of chance occurrence.

TABLE 2 Corrosion Indices for Pure Iron and Various Low-Alloy Steels

Element w/o	Range Maximum	Pure Fe	Typical A36	A36 + 0.2% Cu	Min. A588	Alloy 1	Typical A588	Alloy 2	Max. A588	Alloy 3	Alloy 4
C	1.50	0.000	0.160	0.160	0.060	0.075	0.100	0.060	0.190	0.091	0.060
Mn	1.50	0.000	1.010	1.010	0.800	0.690	1.180	1.090	1.250	0.580	1.000
P	0.30	0.000	0.012	0.012	0.005	0.030	0.012	0.007	0.040	0.004	0.010
S	0.30	0.000	0.013	0.013	0.001	0.004	0.011	0.002	0.050	0.001	0.002
Si	1.50	0.000	0.220	0.220	0.300	0.280	0.360	0.290	0.650	0.200	0.250
Ni	1.10	0.000	0.019	0.019	0.050	1.440	0.310	0.970	0.400	2.970	0.750
Cr	1.10	0.000	0.027	0.027	0.400	0.040	0.530	0.018	0.650	0.025	0.500
Cu	1.50	0.000	0.018	0.200	0.250	0.014	0.300	0.940	0.400	0.350	1.000
Al	1.50	0.000	0.051	0.051	0.010	0.000	0.020	0.000	0.000	0.000	0.030
V	0.50	0.000	0.003	0.003	0.020	0.000	0.040	0.000	0.100	0.000	0.060
Co	1.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
As	0.50	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
Mo	0.50	0.000	0.004	0.004	0.000	0.300	0.005	0.004	0.000	0.006	0.500
Sn	0.50	0.000	0.003	0.003	0.000	0.000	0.002	0.000	0.000	0.000	0.000
W	0.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Bethlehem	0.51	0.37	0.36	0.30	0.23	0.23	0.19	0.20	0.14	0.13
B	Columbus	0.54	0.47	0.46	0.41	0.41	0.37	0.37	0.31	0.38	0.31
	Pittsburgh	0.60	0.60	0.59	0.50	0.44	0.47	0.45	0.42	0.31	0.38
	Bethlehem	15.16	17.34	17.30	17.52	20.40	18.42	19.12	20.03	22.80	18.61
A	Columbus	16.14	14.44	14.62	16.58	13.01	15.84	14.18	16.30	11.75	15.85
	Pittsburgh	14.86	13.56	13.20	14.06	14.60	13.83	12.17	14.26	16.91	11.59
Years to 10-mil loss for pure iron	Bethlehem	20.80									
	Columbus	13.82									
	Pittsburgh	9.18									
20.8-yr mils	Bethlehem	10.00	5.23	4.85	3.62	2.81	2.53	2.18	2.35	1.93	1.48
13.82-yr mils	Columbus	10.00	6.34	6.03	5.32	4.18	4.12	3.77	3.09	3.15	2.99
9.18-yr mils	Pittsburgh	10.00	9.14	8.40	5.86	4.56	4.84	4.05	3.96	2.82	2.67
	Bethlehem	0.00	4.77	5.15	6.38	7.19	7.47	7.82	7.65	8.07	8.52
Differences	Columbus	0.00	3.66	3.97	4.68	5.82	5.88	6.23	6.91	6.85	7.01
	Pittsburgh	0.00	0.86	1.60	4.14	5.44	5.16	5.95	6.04	7.18	7.33
Index 6.3.2		0.00	3.09	3.57	5.07	6.15	6.17	6.66	6.86	7.37	7.62
Index 6.3.1		0.00	1.09	4.48	5.53	6.39	6.67	–7.42	7.74	9.25	–8.86

in amounts within the range of the original data. Corrosion indices by either of the two approaches can be easily determined by use of the tool provided on the ASTM website at http://www.astm.org/COMMIT/G01_G101Calculator.xls.

6.3.1 *Predictive Method Based on the Data of Larabee and Coburn*—Equations for predicting corrosion loss of low-alloy steels after 15.5 years of exposure to various atmospheres, based on the chemical composition of the steel, were published by Legault and Leckie **(9).** The equations are based on extensive data published by Larrabee and Coburn **(10).**

6.3.1.1 For use in this guide, the Legault-Leckie equation for an industrial atmosphere (Kearny, N.J.) was modified to allow calculation of an atmospheric corrosion resistance index based on chemical composition. The modification consisted of deletion of the constant and changing the signs of all the terms in the equation. The modified equation for calculation of the atmospheric corrosion resistance index (I) is given below. The higher the index, the more corrosion resistant is the steel.

$$I = 26.01\,(\%\,Cu) + 3.88\,(\%\,Ni) + 1.20\,(\%\,Cr) + 1.49\,(\%\,Si) + 17.28\,(\%\,P) - 7.29\,(\%\,Cu)\,(\%\,Ni) - 9.10\,(\%\,Ni)\,(\%\,P) - 33.39\,(\%\,Cu)^2$$

NOTE 4—Similar indices can be calculated for the Legault-Leckie equations for marine and semi-rural atmospheres. However, it has been found that the *ranking* of the indices of various steel compositions is the same for all these equations. Therefore, only one equation is required to rank the relative corrosion resistance of different steels.

6.3.1.2 The predictive equation should be used only for steel compositions within the range of the original test materials in the Larrabee-Coburn data set **(7).** These limits are as follows:

Cu 0.51 % max
Ni 1.1 % max
Cr 1.3 % max
Si 0.64 % max
P 0.12 % max

6.3.1.3 Examples of averages and ranges of atmospheric corrosion resistance indices calculated by the Larrabee-Coburn method for 72 heats of each of two weathering steels are shown in Table X2.1.

6.3.2 *Predictive Method Based on the Data of Townsend*—Equations for predicting the corrosion loss of low alloy steels based on a statistical analysis of the effects of chemical composition on the corrosion losses of hundreds of steels exposed at three industrial locations were published by Townsend **(11)**.

6.3.2.1 In this method, the coefficients A and B, as defined for Eq 1, are calculated as linear combinations of the effects of each alloying element, according to Eq 5 and 6.

$$A = a_o + \Sigma a_i x_i \quad (5)$$

$$B = b_o + \Sigma b_i x_i \quad (6)$$

where:

A *and* B = constants in the exponential corrosion loss function as defined for Eq 1,
a_o *and* b_o = constants for three industrial locations as given in Table 1,
a_i *and* b_i = constants for each alloying element as given in Table 1 for three industrial locations, and
x_i = compositions of the individual alloying elements.

The A and B values calculated from Eq 4 and 5 can be used to compute corrosion losses, corrosion rates, and times to a given loss at any of the three sites by use of Eq 2-4, respectively.

6.3.2.2 For purposes of calculating a corrosion index from the Townsend data, the following procedure shall be followed.

(1) For each of the three test sites, A and B values for pure, unalloyed iron at are calculated by use of the regression constants given in Table 1, and Eq 5 and 6.

(2) The times for pure iron to reach a 254-µm loss at the three sites are then calculated by use of Eq 4.

(3) For a given low alloy steel, A and B values at each site are calculated from the regression constants and coefficients in Table 1, and Eq 5 and 6.

(4) The losses of the low alloy steel at each site are calculated from Eq 1 at the times required for pure iron to lose 254 µm at the same site as determined in *(1)*.

(5) The respective differences between the 254-µm loss for pure iron and the calculated loss for the low alloy steel at each site as determined in *(4)* are averaged to give a corrosion index.

(6) Examples of corrosion indices calculated by the Townsend method are shown in Table 2 for pure iron and a variety of low-alloy steel compositions. The upper limit of the composition ranges of each element in the Townsend data are also given in Table 2.

6.3.3 The minimum acceptable atmospheric corrosion index should be a matter of negotiation between the buyer and the seller.

7. Report

7.1 When reporting estimates of atmospheric corrosion resistance, the method of calculation should always be specified. Also, in the Linear Regression Extrapolation Method (6.2) of this guide, the data used should be referenced with respect to type of specimens, condition and location of exposure, and duration of exposure.

8. Keywords

8.1 atmospheric corrosion resistance; compositional effects; corrosion indices; high-strength; low-alloy steel; industrial environments; marine environments; rural environments; weathering steels

APPENDIXES

(Nonmandatory Information)

X1. PROJECTED ATMOSPHERIC CORROSION PENETRATIONS FOR WEATHERING STEELS

X1.1 Projected atmospheric corrosion losses in fifty years for flat, boldly exposed specimens of Specifications A 588/A 588M and A 242/A 242M Type 1 weathering steels in rural, industrial, and marine environments are shown in Figs. X1.1-X1.3. (The "loss" shown in the figures is the average thickness loss per surface, calculated from the mass loss per unit area. The uniformity of the thickness loss varies with the type of environment.) These figures were developed from data **(12)** for specimens exposed for time periods up to 8 or 16 years in various countries. The specific exposure locations are given in Tables X1.1-X1.3, and the compositions of the steels are given in Table X1.4. In this test program, specimens were exposed in four orientations: 30° to the horizontal facing north and facing south, and vertical facing north and facing south. (The back surface of each specimen was protected with a durable paint system.) For the lines plotted in Figs. X1.1-X1.3, data for the test orientations showing the greatest corrosion losses were used.

TABLE X1.1 Rural Exposure Sites for Test Data in Fig. X1.1

Country	Identification	Exposure Site	Latitude
South Africa	S. Afr	Pretoria—8 km E	25°45'S
Japan	Japan	Lake Yamanaka	35°25'N
United States	US	Potter County, PA	42°N
United Kingdom	UK	Avon Dam	50°17'N
Belgium	Belg	Eupen	50°38'N
Sweden	Swed	Ryda Kungsgård	60°36'N

TABLE X1.2 Industrial Exposure Sites for Test Data in Fig. X1.2

Country	Identification	Exposure Site	Latitude
South Africa	S. Afr	Pretoria—8 km W	25°45'S
Japan	Japan	Kawasaki	35°32'N
United States	US	Kearny, NJ	40°30'N
France	Fr	St. Denis	48°56'N
Belgium	Belg	Liege	50°39'N
Germany	Ger	Essen Frintrop	51°28'N
United Kingdom	UK	Stratford	52°12'N
Sweden	Swed	Stockholm	59°20'N

X1.2 It must be emphasized that the data shown in Figs. X1.1-X1.3 apply only to *flat, boldly exposed* specimens. Presence of crevices or other design details which can trap and hold moisture, or exposure under partially sheltered conditions, may increase the rate of corrosion substantially.

X1.3 *Example Calculation:*
Steel: ASTM A 588/588M