



Designation: **G101–04 (Reapproved 2010) G101 – 04 (Reapproved 2015)**

Standard Guide for Estimating the Atmospheric Corrosion Resistance of Low- Alloy Steels¹

This standard is issued under the fixed designation G101; 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 [A242/A242M](#), [A588/A588M](#), [A606](#) Type 4, [A709/A709M](#) grades 50W, HPS 70W, and 100W, [A852/A852M](#), and [A871/A871M](#). 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.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

2. Referenced Documents

2.1 ASTM Standards:²

[A242/A242M](#) Specification for High-Strength Low-Alloy Structural Steel

[A588/A588M](#) Specification for High-Strength Low-Alloy Structural Steel, up to 50 ksi [345 MPa] Minimum Yield Point, with Atmospheric Corrosion Resistance

[A606](#) Specification for Steel, Sheet and Strip, High-Strength, Low-Alloy, Hot-Rolled and Cold-Rolled, with Improved Atmospheric Corrosion Resistance

[A709/A709M](#) Specification for Structural Steel for Bridges

[A852/A852M](#) Specification for Quenched and Tempered Low-Alloy Structural Steel Plate with 70 ksi [485 MPa] Minimum Yield Strength to 4 in. [100 mm] Thick (Withdrawn 2010)³

[A871/A871M](#) Specification for High-Strength Low-Alloy Structural Steel Plate With Atmospheric Corrosion Resistance

[G1](#) Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens

[G16](#) Guide for Applying Statistics to Analysis of Corrosion Data

[G50](#) Practice for Conducting Atmospheric Corrosion Tests on Metals

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

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

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ The last approved version of this historical standard is referenced on www.astm.org.

3.1.1.1 Discussion—

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 [A242/A242M](#), [A588/A588M](#), [A606](#) Type 4, [A709/A709M](#) Grade 50W, HPS 70W, and 100W, [A852/A852M](#), and [A871/A871M](#) 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 steels to that of other steels are imprecise and, more importantly, lack significance to the user (**1 and 2**)⁴, 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 [G50](#). Specimen preparation, cleaning, and evaluation should conform to Practice [G1](#).

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 t 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 [G16](#). 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 1—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 2—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.

⁴ The boldface numbers in parentheses refer to a list of references at the end of this standard.

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 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, NJ) 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.

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

NOTE 3—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.

$$A = a_o + \sum a_i x_i \tag{5}$$

$$B = b_o + \sum b_i x_i \tag{6}$$

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

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

n site	A (μm)			B (T in months)		
	275 Bethlehem, PA	227 Columbus, OH	248 Pittsburgh, PA	275 Bethlehem, PA	227 Columbus, OH	248 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.

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 are calculated by use of the regression constants given in Table 1, and Eq 5 and 6.

(1) For each of the three test sites, A and B values for pure, unalloyed iron 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- μ m 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 μ m at the same site as determined in (1).

(5) The respective differences between the 254- μ m 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.

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

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

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
B	Bethlehem	0.51	0.37	0.36	0.30	0.23	0.23	0.19	0.20	0.14	0.13
	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
A	Bethlehem	15.16	17.34	17.30	17.52	20.40	18.42	19.12	20.03	22.80	18.61
	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 13.82-yr mils 9.18-yr mils	Bethlehem	10.00	5.23	4.85	3.62	2.81	2.53	2.18	2.35	1.93	1.48
	Columbus	10.00	6.34	6.03	5.32	4.18	4.12	3.77	3.09	3.15	2.99
	Pittsburgh	10.00	9.14	8.40	5.86	4.56	4.84	4.05	3.96	2.82	2.67
Differences	Bethlehem	0.00	4.77	5.15	6.38	7.19	7.47	7.82	7.65	8.07	8.52
	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

^A Several of the alloys given in Table 2 exceed the minimum limits on composition for Method 6.3.1. (as given in 6.3.1.2) or Method 6.3.2 (as given in Column 2 of this table). Note how this leads to anomalous results (for example, negative values for alloys high in copper) for corrosion indices calculated by Method 6.3.1, but not for those calculated by Method 6.3.1.2. See (12) for further examples and comparison.

(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; low-alloy steel; 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 **A588/A588M** and **A242/A242M** 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 (13) 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.

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 **A588/A588M**

Type of Environment: Semi-industrial

Test Location: Monroeville, PA

Data:

Time (t), Yrs.	Avg. Thickness Loss per Surface (C), ⁴
	μm
1.5	33
3.5	49
7.5	70
15.5	97

⁴ Calculated from mass loss.

Calculations:

log t	log C	(log C) (log t)	(log t) ²
0.176	1.518	0.267	0.031
0.544	1.690	0.919	0.296
0.875	1.845	1.614	0.766
1.190	1.987	2.364	1.412
Σ 2.785	7.040	5.164	2.505

Equation (from 6.2.1):

$$\log C = \log A + B \log t$$

From Guide G16:

$$B = \frac{n \sum [(\log C) (\log t)] - (\sum \log t) (\sum \log C)}{n \sum (\log t)^2 - (\sum \log t)^2}$$

where:

n = Number of data points = 4

$$B = \frac{(4)(5.164) - (2.785)(7.040)}{(4)(2.505) - (2.785)^2}$$

$$B = 0.463$$

$$\log A = 1/n (\sum \log C - B \sum \log t)$$

$$\log A = 1/4 [(7.040) - (0.463)(2.785)]$$

$$\log A = 1.437$$

$$A = 27.35$$

Final Equation:

$$\log C = 1.437 + 0.463 \log t$$

Estimated Loss in 50 Years:

$$\log C = 1.437 + 0.463 \log 50$$

$$= 2.224$$

$$C = 167 \mu\text{m}$$

If desired, upper confidence limits (UCL) for the estimated loss can be calculated in accordance with Guide G16. Results for this example at 50 years and 100 years are shown.

$$C_{(50)} = 167 \mu\text{m} \quad C_{(100)} = 231 \mu\text{m}$$

$$95\% \text{ UCL} = 174 \mu\text{m} \quad 95\% \text{ UCL} = 241 \mu\text{m}$$

$$99\% \text{ UCL} = 183 \mu\text{m} \quad 99\% \text{ UCL} = 256 \mu\text{m}$$

Corrosion Rate at 50 Years:

$$R = ABt^{B-1}$$

$$= (27.35)(0.463)(50)^{(0.463-1)}$$

$$= 1.55 \mu\text{m/year}$$

Time to Loss of 250 μm:

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

$$= (250/27.35)^{1/0.463}$$

$$= 119 \text{ years}$$