Estimation of Atmospheric Corrosion of High-Strength, Low-Alloy Steels

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This data analysis was undertaken to investigate the weatherability of steels whose compositions do not fall in the range of ASTM Standard G101, Estimating the Atmospheric Corrosion Resistance of Low-Alloy Steels (1). This standard was developed to estimate the corrosion resistance of low-alloy weathering steels from chemical composition data and from actual atmospheric exposure tests. This standard is limited to steels within the composition range outlined in TABLE 1.

There are many high-strength, low-alloy steels that are used at the present time or that are under development with chemical composition ranges extending beyond the chemical compositions of steels covered by the ASTM Standard G101. These steels may contain more nickel and more copper or elements not included in the G101 Standard. Ability to estimate the weatherability of these steels is of current interest.

The G101 corrosion index, which is used to predict whether a steel is weatherable, is based on the work of Legault and Leckie (2), who utilized part of an extensive database published by Larrabee and Coburn (3). This database (3) contains steels with concentrations of elements shown in TABLE 1. The ten steels with the highest corrosion loss were omitted from the database by Legault and Leckie in their analysis. They basically used a linear equation to describe the effect of elements on the corrosion of steels. To compensate for nonlinearity, negative square terms for the concentration of Cu and some other elements were introduced, leading to an equation that predicts an increase in corrosion rate, for example, when Cu concentration exceeds 0.25 pct. It is well known that the effect of Cu of atmospheric corrosion resistance of steels is most beneficial at low Cu concentrations (3, 4), but experiments show that the increase of Cu over 0.25 pct leads to a further decrease in corrosion losses. The positive effect of copper on corrosion resistance of steels continues to higher concentrations, as shown in FIGURES 1A and 1B (3, 4).

Experimental atmospheric corrosion data indicate that an increase in the concentrations of alloying elements in high-strength, low-alloy steels is most effective at lower concentrations, and further increases are much less effective. Therefore, a power-law relationship between the corrosion rate and concentration of elements is more appropriate than a linear relation. Of course, the effects of different elements on atmospheric corrosion resistance of steels are different, and this fact should be taken into consideration.

To develop power-law-based equations relating the atmospheric corrosion rate with the concentration of elements in steels, two corrosion databases for 15.5 years of exposure in the marine environment at Kure Beach, NC (Larrabee and Coburn database (3) for 270 steels and LaQue database (3) for 23 steels) were used. The limits for element concentrations for these databases are presented in TABLES 1 and 2.

The following equations were developed to fit the corrosion loss data using least-squares analysis assuming a separate power-law relationship for each element. For steels from the Larrabee and Coburn (3) database:

Loss of thickness (µm) in 15.5 years = 144.73 (1.31 Cu + 0.47 Ni + 0.36 Cr + 0.99 Si + 1.33 P)-0.5552

For steels from the LaQue (5) database:

Loss of thickness (µm) in 15.5 years = 885.16 (-48.3 C + 10.0 Mn + 28.5 Si + 61.1 S + 52.4 P + 7.5 Ni + 4.3 Cu + 5.6 Cr + 16.2 Mo)-0.644

The Legault-Leckie equation (2) for a marine environment (Kure Beach, NC) established using the Larrabee and Coburn (3) database, but eliminating the ten highest corrosion rate steels, is

Loss of thickness (µm) in 15.5 years = 25.4 (15.49 - 16.30 Cu - 4.34 Ni - 4.79 Cr - 12.41 Si - 32.01 P + 2.93 CuNi + 2.46 CuCr + 4.36 CuSi + 2.74 NiSi + 12.82 NiP + 1.75 SiP + 16.60 Cu2 + 1.20 Cr2 + 4.25 Si2)

ASTM Standard G101 defines the atmospheric corrosion resistance index as a sum of the element concentrations with their respective coefficients. FIGURE 2 depicts the corrosion loss of all 270 steels from the Larrabee and Coburn (3) database vs the atmospheric corrosion index from EQUATION 1. It is evident that EQUATION 1 gives good corrosion loss prediction and correctly predicts the dramatic increase in corrosion loss when the alloying elements; concentration is very low. The same database is plotted in FIGURE 3 using the Legault-Leckie atmospheric corrosion resistance index from EQUATION 3. While the equation predicts well the corrosion losses at medium alloying element concentrations, it is obvious that the fit is not good for high corrosion losses.

FIGURE 4 shows the effect of alloying element concentrations on corrosion losses for the 23 steels from LaQue's database (5). The data fit very well to a power-law equation, EQUATION 2. As shown in FIGURE 5, EQUATION 1 which was established using the Larrabee and Coburn (3) database, describes well the corrosion losses for the 23 LaQue's steels despite the fact that the concentration of alloying elements in these steels is much beyond the concentration of the elements in the 270 steel database used to establish EQUATION 1. The elements of C, Mn, S, and Mo are included in EQUATION 2 but not in EQUATION 1.

FIGURE 6 compares the actual corrosion losses of these 23 steels with the calculated values using the Legault-Leckie equation, EQUATION 3. It is obvious that corrosion loss predictions are very poor, especially at low and high measured corrosion rates.

Thus, the Legault-Leckie equation, as well as similar equations for corrosion losses in the industrial environment used in the ASTMG101 Standard, cannot be used to estimate the corrosion losses for steels with concentrations of alloying elements beyond the limits of TABLE 1. Power-law-based equations such as those presented here estimate corrosion losses much better and are more appropriate for predicting the atmospheric corrosion loss of steels.

References

Estimating the Atmospheric Corrosion Resistance of Low-Alloy Steels, ASTM Standard G101, ASTM, Philadelphia, PA, 1995.

R.A. Legault and H.P. Leckie: Corrosion in Natural Environment, ASTM STP 558, ASTM, Philadelphia, PA, 1974, pp. 334-47.

C.P. Larrabee and S.K. Coburn: 1st Int. Congr. On Corrosion, Butterworth and Co., London, 1962, pp. 276-85.

H.R. Copson: Proc. ASTM, 1960, vol. 60, pp. 650-65.

F.L. LaQue: Proc. ASTM, 1951, vol. 51, pp. 495-582.

Notes

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FIGURE 1A

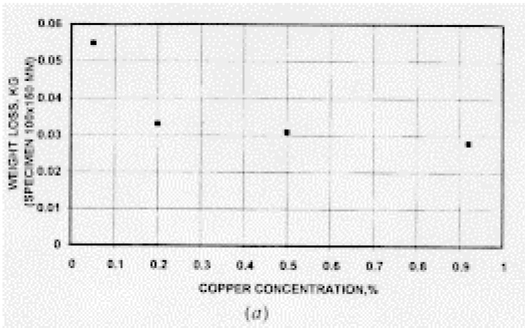

FIGURE 1B

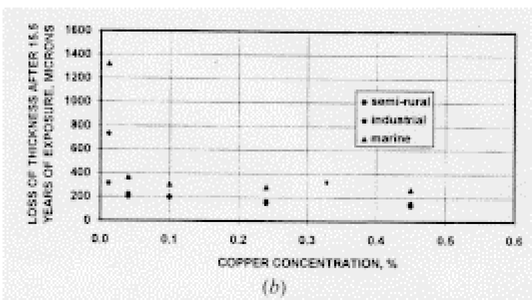

Fig. 1—Effect of copper concentration on atmospheric corrosion of (*a*) Bessemer steel in marine environment (Kure Beach, NC)[4] and (*b*) steels from the Larrabee and Coburn data set[3] in different environments.

FIGURE 2

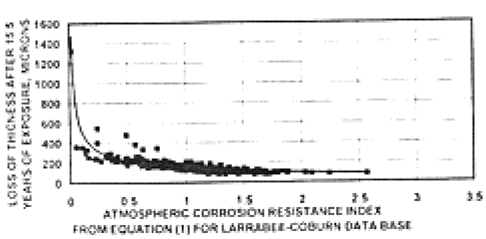

Fig. 2—Plot of atmospheric corrosion thickness losses for 270 steels from the Larrabee and Coburn data set at Kure Beach, NC vs the corrosion index from Eq. [1] (corrosion resistance index as a sum of the element concentrations with their respective coefficients). The line represents Eq. [1]

FIGURE 3

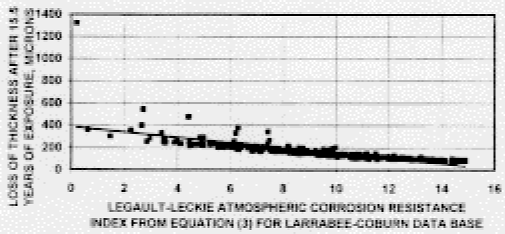

Fig. 3—Plot of atmospheric corrosion thickness losses for 270 steels from the Larrabee and Coburn data set at Kure Beach, NC *vs* the Legault-Leckie corrosion index from Eq. [3]. The line represents Eq. [3].

FIGURE 4

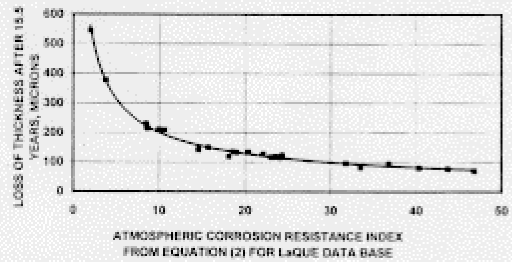

Fig. 4—Plot of atmospheric corrosion thickness losses of 23 steels from the LaQue data set at Kure Beach, NC *vs* the corrosion index from Eq. [2]. The line represents Eq. [2].

FIGURE 5

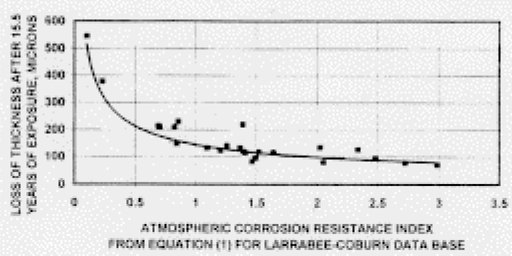

Fig. 5—Plot of atmospheric corrosion thickness losses of 23 steels from the LaQue data set at Kure Beach, NC *vs* the corrosion index from Eq. [1]. The line represents Eq. [1].

FIGURE 6

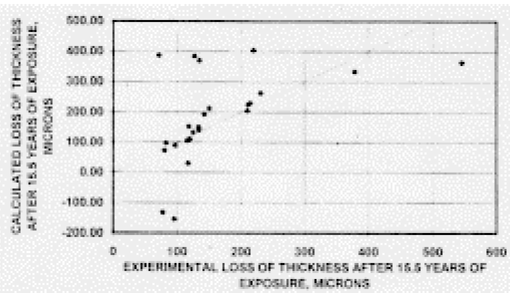

TABLE 1

Table I. Element Limits for Steels from ASTM G101

Element	Concentration (Wt Pct)	
	Lower Limit	Upper Limit
Cu	0.008	0.49
Ni	0.05	1.10
Cr	0.10	1.30
Si	0.10	0.64
P	0.01	0.12

TABLE 2

Table II. Element Limits in LaQue Database[9] (23 Steels)

Element	Concentration (Wt Pct)	
	Lower Limit	Upper Limit
C	0.020	0.190
Mn	0.020	0.890
Si	0.002	1.000
S	0.010	0.050
P	0.005	0.140
Ni	0.004	4.990
Cu	0.030	1.090
Cr	0.000	1.190
Mo	0.000	0.240