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Corrosion of metals and alloys — Corrosivity of atmospheres — Guiding values for the corrosivity categories

Corrosion des métaux et alliages — Corrosivité des atmosphères — Valeurs de référence relatives aux classes de corrosivité

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 9224 was prepared by Technical Committee ISO/TC 156, *Corrosion of metals and alloys*.

This second edition cancels and replaces the first edition (ISO 9224:1992), which has been technically revised.

Introduction

The “corrosivity category” established in ISO 9223 is a general term suitable for engineering purposes, which describes the corrosion properties of atmospheres based on current knowledge of atmospheric corrosion.

Guiding values of corrosion attack can be used to predict the extent of corrosion attack in long-term exposures based on measurements of corrosion attack in the first-year exposure to the outdoor atmosphere in question. These values can also be used to determine conservative estimates of corrosion attack based on environmental information or corrosivity category estimates as shown in ISO 9223.

Corrosion attack estimates obtained by using the methods in this International Standard can be used to predict the useful life of metallic components and, in some cases, of metallic coatings exposed to outdoor atmospheres covered by ISO 9223. The corrosion attack results can also be used to determine whether or not protective measures, such as coatings, are required to achieve desired product lives. Other uses include the selection of construction materials for outdoor atmospheric service.

Guiding values of corrosion can be used as information for the selection of a protection method against atmospheric corrosion according to ISO 11303.

The guiding values in this International Standard are based on a large number of exposures in many locations throughout the world. However, the procedure used in this International Standard cannot possibly cover all the situations in natural environments and service conditions which can occur. In particular, situations that result in significant changes in the environment can cause major increases or decreases in corrosion rates. Users of this International Standard are cautioned to consult with qualified experts in the field of outdoor atmospheric corrosion in cases where localized corrosion can be more important than general attack. The specific issues of galvanic (bi-metallic) corrosion, pitting corrosion, crevice corrosion, environmental cracking and corrosion product wedging are not addressed in this International Standard.

Corrosion of metals and alloys — Corrosivity of atmospheres — Guiding values for the corrosivity categories

1 Scope

This International Standard specifies guiding values of corrosion attack for metals and alloys exposed to natural outdoor atmospheres for exposures greater than one year. This International Standard is intended to be used in conjunction with ISO 9223.

Guiding corrosion values for standard structural materials can be used for engineering calculations. The guiding corrosion values specify the technical content of each of the individual corrosivity categories for these standard metals.

Annex A provides examples of calculated maximum corrosion attack after extended exposure (up to 20 years) for six standardized corrosivity categories.

Annex B provides presumed average initial and steady-state corrosion rates of standard metals in intervals relative to six standardized corrosivity categories.

Annex C provides the calculation procedure for corrosion attack of steels in regard to their composition.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 8044, *Corrosion of metals and alloys — Basic terms and definitions*

ISO 9223, *Corrosion of metals and alloys — Corrosivity of atmospheres — Classification, determination and estimation*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8044 and the following apply.

3.1
guiding corrosion value
corrosion rates, mass loss, penetration or other corrosion characteristics expressing the expected corrosive action of the atmospheric environment of a given corrosivity category towards standard metals

3.2
corrosion rate after extended exposure
corrosion rate after exposures longer than one year

3.3
average corrosion rate
r_{av}
yearly corrosion rate calculated as an average value for the first 10 years of atmospheric exposure of a metal

3.4
steady-state corrosion rate
r_{lin}
yearly corrosion rate derived from a long-term atmospheric exposure of a metal, not including the initial period

NOTE For the purposes of this International Standard, the corrosion rate after 10 years of exposure is considered constant.

4 Principle

The corrosion rate of metals and alloys exposed to natural outdoor atmospheres is not constant with exposure time. For most metals and alloys, it decreases with exposure time because of the accumulation of corrosion products on the surface of the metal exposed. The progress of attack on engineering metals and alloys is usually observed to be linear when the total damage is plotted against exposure time on logarithmic coordinates. This relationship indicates that the total attack, D, expressed either as mass loss per unit area or penetration depth, may be given as:

$$D = r_{corr} \, t^{b} \tag{1}$$

where

t is the exposure time, expressed in years;

r_{corr} is the corrosion rate experienced in the first year, expressed in grams per square metre per year [g/(m^2·a)] or micrometres per year (µm/a), in accordance with ISO 9223;

b is the metal-environment-specific time exponent, usually less than 1.

5 Prediction of corrosion attack after extended exposure

This procedure should be used in cases where the extent of corrosion attack in the first year is available or can be estimated by the procedures in ISO 9223, and the desire is to predict the extent of attack after an extended exposure.

The attack prediction is calculated by substituting the values in Equation (1).

An appropriate b value is selected or calculated according to Clause 7. In cases where long-term metal loss data are available, use the b value from this data. In cases where the detailed composition of the metal is not known, select the B1 value from Table 2 for the metal or alloy in question. This is the b value to be used in Equation (1).

The B1 values were taken as the average time exponents from regression analyses of the flat panel long-term results of the ISO CORRAG atmospheric exposure programme[1].

NOTE It is necessary to distinguish between metal-environment-specific time exponent, b, in Equation (1), estimated from exposure data, and B1 and B2 values assumed or calculated from the ISO CORRAG programme as generalized b values.

Table 3 contains values of the function t^b for time values up to 100 years with the B1 exponents to simplify the calculations. However, it is possible for Equation (1) not to apply to exposures beyond 20 years (see Clause 7 below for a discussion of long-term exposures).

In cases where it is important to estimate a conservative upper limit of corrosion attack after an extended exposure, the b value used in Equation (1) should be increased to account for uncertainties in the data. One way to do this is to add two standard deviations to the average value to obtain a value at the upper 95 % confidence level. For the four metals shown in Table 2, the standard deviations of the b values[1] are:

— Carbon steel: 0,026 0

— Zinc: 0,030 0

— Copper: 0,029 5

— Aluminium: 0,039 5

NOTE Estimation of a conservative upper limit of corrosion attack after an extended exposure is based on uncertainties in b. This estimation does not take into account uncertainties in r_{corr}, which are defined in ISO 9223.

The B2 values in Table 2 include the two standard deviation additions and may be used where an upper limit of corrosion attack is desired when using the flat panel data from the ISO CORRAG programme. Table 3 also provides calculated values for the function, t^b, up to 100 years using B2 values for b (see Clause 7 for exposures beyond 20 years).

Annex A provides maximum corrosion attack for the standard metals covered in ISO 9223 for exposures up to 20 years for the six corrosion categories. These calculations are made using the time exponents given in Table 2.

6 Specific criteria for calculation of corrosion rates of structural metals

6.1 Steels

The protectiveness of rust layers on steels in atmospheric exposures is very strongly affected by the alloying elements in the steel. Weathering steels, in particular, have specific alloying additions to promote the formation of a protective rust layer that develops during the exposure. Other carbon and low-alloy steels vary significantly in their performance in atmospheric exposures depending on their specific alloy content. The calculation procedure for corrosion rates of steels in regard to their composition is given in Annex C.

The B1 and B2 values in Table 2 are estimated for carbon steel with the composition mentioned in Table 1[2].

Table 1 — Composition of steel for which the B1 and B2 values are estimated

Element	**Composition** mass fraction %
Carbon	0,056
Silicon	0,060
Sulfur	0,012
Phosphorus	0,013
Chromium	0,02
Molybdenum	0,01
Nickel	0,04
Copper	0,03
Niobium	0,01
Titanium	0,01
Vanadium	0,01
Aluminium	0,02
Tin	0,005
Nitrogen	0,004
Manganese	0,39

Crevices and sheltered areas not exposed to rain impingement have been observed to experience significantly higher corrosion damage than predicted by Equation (1) in extended exposures. In addition, designs using weathering steels or unprotected carbon steels should anticipate that rain run-off leaves rust deposits on surfaces exposed to this run-off and permanent staining can occur to concrete, stone, masonry and other porous materials.

Steels that have been hardened to produce tensile strengths above about 1 000 MPa can suffer environmentally assisted cracking as a result of atmospheric corrosion.

6.2 Zinc materials

Zinc alloys also vary significantly in their atmospheric performance. The B1 values in Table 2 are obtained from commercially pure zinc alloys, but other zinc alloys have shown higher b values in atmospheric exposures[3]. Electroplated zinc coatings, mechanically plated zinc coatings, and hot-dipped zinc coatings all have unique behaviours, and using Equation (1) with the B1 or B2 values might not accurately predict their performance. Zinc materials are particularly susceptible to attack from sulfur dioxide, and environments with high levels of this gas (sulfur dioxide range P_3) probably corrode at higher rates than predicted by Equation (1). In these cases, it is prudent to assume a corrosion rate that is linear with time, that is the b value is 1,0.

NOTE For more information on the use of zinc coatings for corrosion protection, see ISO 14713-1.

6.3 Copper alloys

Copper alloys, such as brasses (i.e. copper-zinc alloys), bronzes (i.e. copper-tin alloys), nickel silvers (i.e. copper alloys with zinc and nickel contents) and cupronickels, have atmospheric corrosion rates similar to, or somewhat less than, pure copper[4][5]. The B1 and B2 values in Table 2 are adequate for all of these materials. Brasses with zinc contents above about 20 % can experience dezincification in aggressive atmospheres. Two-phase brasses are most susceptible to this type of attack. It should also be noted that strain-hardened copper alloys can experience environmental cracking in natural atmospheres if their degree of strain hardening is high enough.

6.4 Aluminium alloys

Aluminium alloys experience both uniform and localized corrosion in natural atmospheres. As a result, the attack calculated by the above-mentioned methods can seriously underestimate maximum penetrations that occur. In addition, high strength, age hardening alloys that contain significant copper or copper-zinc levels can experience exfoliation corrosion. Aluminium products having a layer of galvanic protective alloy clad on the high strength alloy generally have much improved corrosion resistance in atmospheric exposures. Specific tempers have also been developed for high strength, age hardening alloys containing significant copper-zinc levels in order to prevent exfoliation or stress corrosion cracking. Alloys with good long-term corrosion behaviour used for structural, marine and building applications are covered in specific aluminium standards.

7 Long-term exposures

Equation (1) has been observed to be valid for exposures of up to 20 years' duration for the metals covered by this International Standard. However, Equation (1) is based on the fact that the corrosion product layers increase in thickness and degree of protection during the exposure. At some point in time beyond 20 years, the layer stabilizes and, at this point, the corrosion rate becomes linear with time, because the rate of metal loss becomes equal to the rate of loss from the corrosion product layer. Unfortunately, there are no experimental data that show when this might occur and there is no method of predicting this time. The use of Equation (1) beyond 20 years is probably justified in most cases, especially if the exposure is not much greater than 20 years.

However, an approach that yields the maximum estimate of attack is to assume that the corrosion rate becomes linear at 20 years of exposure. In this case, the corrosion rate may be calculated using Equation (2):

$$\mathrm{d}D/\mathrm{d}t = b\, r_{\mathrm{corr}}\, (t)^{b-1} \qquad (2)$$

Then the total attack would be:

$$D(t > 20) = r_{corr} [20^b + b (20^{b-1}) (t - 20)] \quad (3)$$

Table 4 gives values for the term $b(20^{b-1})$ for the b values shown in Table 2. Equation (3) provides larger corrosion attack estimates than Equation (1) for exposures beyond 20 years, but, in cases where a maximum attack estimate is required, Equation (3) is justified.

Table 2 — Time exponent values for predicting and estimating corrosion attack

Metal	B1	B2
Carbon steel	0,523	0,575
Zinc	0,813	0,873
Copper	0,667	0,726
Aluminium	0,728	0,807

Table 3 — Metal-environment-specific time exponents for standard metals

	Steel		Zinc		Copper		Aluminium	
	B1	B2	B1	B2	B1	B2	B1	B2
b values	0,523	0,575	0,813	0,873	0,667	0,726	0,728	0,807
t (years)								
1	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
2	1,437	1,490	1,757	1,831	1,588	1,654	1,656	1,750
3	1,776	1,881	2,443	2,609	2,081	2,220	2,225	2,427
4	2,065	2,219	3,087	3,354	2,521	2,736	2,743	3,061
5	2,320	2,523	3,701	4,076	2,926	3,217	3,227	3,665
6	2,553	2,802	4,292	4,779	3,304	3,672	3,685	4,246
7	2,767	3,061	4,865	5,467	3,662	4,107	4,123	4,808
8	2,967	3,306	5,423	6,143	4,003	4,525	4,544	5,355
9	3,156	3,537	5,968	6,809	4,330	4,929	4,951	5,889
10	3,334	3,758	6,501	7,464	4,645	5,321	5,346	6,412
11	3,505	3,970	7,025	8,112	4,950	5,702	5,730	6,925
12	3,668	4,174	7,540	8,752	5,246	6,074	6,104	7,428
13	3,825	4,370	8,047	9,386	5,534	6,438	6,471	7,924
14	3,976	4,561	8,547	10,013	5,814	6,793	6,829	8,413
15	4,122	4,745	9,040	10,635	6,088	7,142	7,181	8,894
16	4,263	4,925	9,527	11,251	6,355	7,485	7,527	9,370
17	4,401	5,099	10,008	11,863	6,618	7,822	7,866	9,839
18	4,534	5,270	10,484	12,470	6,875	8,153	8,200	10,304
19	4,664	5,436	10,955	13,072	7,127	8,480	8,530	10,764
20	4,791	5,599	11,422	13,671	7,375	8,801	8,854	11,218

Table 3 (*continued*)

	Steel		Zinc		Copper		Aluminium	
	B1	**B2**	**B1**	**B2**	**B1**	**B2**	**B1**	**B2**
25	5,384	6,365	13,694	16,611	8,559	10,349	10,416	13,432
30	5,923	7,069	15,882	19,477	9,666	11,814	11,814	15,561
35	6,420	7,724	18,002	22,283	10,713	13,213	13,307	17,622
40	6,885	8,340	20,067	25,038	11,710	14,558	14,666	19,627
45	7,322	8,925	22,083	27,749	12,668	15,857	15,979	21,585
50	7,737	9,482	24,058	30,423	13,590	17,118	17,252	23,500
60	8,511	10,530	27,902	35,672	15,347	19,541	19,701	27,225
70	9,225	11,506	31,627	40,810	17,009	21,855	22,041	30,831
80	9,893	12,424	35,254	45,856	18,593	24,079	24,291	34,339
90	10,521	13,295	38,797	50,822	20,113	26,229	26,466	37,764
100	11,117	14,125	42,267	55,719	21,577	28,314	28,576	41,115

Table 4 — Values of $b(20^{b-1})$

Metal		b	20^b	$b(20^{b-1})$
Carbon steel	B1	0,523	4,791	0,125
	B2	0,575	5,559	0,161
Zinc	B1	0,813	11,422	0,464
	B2	0,873	13,671	0,597
Copper	B1	0,667	7,375	0,246
	B2	0,726	8,803	0,320
Aluminium	B1	0,728	8,854	0,321
	B2	0,807	11,218	0,453

Annex A
(informative)

Example of maximum corrosion attack after extended exposures for corrosivity categories

ISO 9223 provides corrosion attack ranges for four standard metals after one year's exposure to atmospheres with six corrosivity categories. This annex provides an extension of these attack values to various exposure times to demonstrate the effects of longer-term exposures. The B1 time exponent was used in this case because it represents the most probable values. Table A.1 provides mass loss per unit area values, in grams per square metre (g/m^2), while Table A.2 gives the results in penetration units, in micrometres (µm). Aluminium is excluded from Table A.2 because aluminium alloys corrode by a pitting mechanism. Long-term outdoor exposure shows that the depth of pits grows relatively quickly in the first two years, but undergoes little further growth in the subsequent years.

Table A.1 — Maximum corrosion attack for extended exposures for the different corrosivity categories

Corrosion attack values in grams per square metre

Metal	Corrosivity category	Exposure time years					
		1	2	5	10	15	20
Carbon steel	C1	10	14	23	33	41	48
	C2	200	287	464	668	824	958
	C3	400	575	928	1 334	1 649	1 916
	C4	650	934	1 508	2 167	2 679	3 114
	C5	1 500	2 155	3 480	5 001	6 183	7 186
	CX	5 500	7 904	12 760	18 337	22 671	26 390
Zinc	C1	0,7	1,2	2,6	4,6	6,3	8,0
	C2	5	9	18	32	45	57
	C3	15	26	56	97	136	171
	C4	30	53	111	195	271	343
	C5	60	105	222	390	542	625
	CX	180	316	666	1 170	1 627	2 056
Copper	C1	0,9	1,4	2,6	4,2	5,5	6,6
	C2	5	8	20	23	30	37
	C3	12	19	35	56	73	88
	C4	25	40	73	116	152	184
	C5	50	79	146	232	304	368
	CX	90	143	263	418	548	664
Aluminium	C1	Negligible					
	C2	0,6	1,0	1,9	3,2	4,4	5,3
	C3	2	3	6	11	14	18
	C4	5	8	16	28	36	44
	C5	10	17	32	54	72	88
	CX	Data concerning general corrosion can be misleading.					
NOTE The values for aluminium given in Table 2 show a linear growing uniform corrosion. In practice, the mass loss grows relatively quickly in the first two years. Due to the formation of the oxide layer, the surface is passivated and the uniform corrosion rates decrease to lower values.							

Table A.2 — Maximum corrosion attack for extended exposures for the different corrosivity categories

Corrosion attack values in micrometres

Metal	Corrosivity category	Exposure time years					
		1	2	5	10	15	20
Carbon steel	C1	1,3	1,9	3,0	4,3	5,4	6,2
	C2	25	36	58	83	103	120
	C3	50	72	116	167	206	240
	C4	80	115	186	267	330	383
	C5	200	287	464	667	824	958
	CX	700	1 006	1 624	2 334	2 885	3 354
Zinc	C1	0,1	0,2	0,4	0,6	0,9	1,1
	C2	0,7	1,2	2,6	4,5	6,3	8,0
	C3	2,1	3,7	7,8	13,6	19,0	24,0
	C4	4,2	7,4	15,5	27,3	38,0	48,0
	C5	8,4	14,3	31,1	54,6	75,9	95,9
	CX	25	44	93	162	226	286
Copper	C1	0,1	0,2	0,3	0,5	0,6	0,7
	C2	0,6	1,0	1,8	2,8	3,6	4,4
	C3	1,3	2,1	3,8	6,0	7,9	9,6
	C4	2,8	4,4	8,2	13,0	17,0	20,6
	C5	5,6	8,9	16,4	26,0	34,1	41,3
	CX	10	16	29	46	61	74

Annex B
(informative)

Average initial corrosion rates and average steady corrosion rates in intervals relative to classified corrosivity categories

For some engineering applications, more general guiding corrosion values defined in intervals of average corrosion rates for corrosivity categories may be used. Average corrosion rates of up to 10 years are considered to correspond to the initial period of exposure. Average corrosion rates for periods longer than 10 years are considered steady-state corrosion rates. The uncertainty level for guiding corrosion values defined as averages for initial and steady-state periods is high.

Table B.1 — Guiding corrosion values for corrosion rates, r_{av}, r_{lin}, of carbon steel, zinc and copper in atmospheres of classified corrosivity categories

Values in micrometres per year

Metal	Average corrosion rate, r_{av}, during the first 10 years for the following corrosivity categories					
	C1	C2	C3	C4	C5	CX
Carbon steel	$r_{av} \leq 0,4$	$0,4 < r_{av} \leq 8,3$	$8,3 < r_{av} \leq 17$	$17 < r_{av} \leq 27$	$27 < r_{av} \leq 67$	$67 < r_{av} \leq 233$
Zinc	$r_{av} \leq 0,07$	$0,07 < r_{av} \leq 0,5$	$0,5 < r_{av} \leq 1,4$	$1,4 < r_{av} \leq 2,7$	$2,7 < r_{av} \leq 5,5$	$5,5 < r_{av} \leq 16$
Copper	$r_{av} \leq 0,05$	$0,05 < r_{av} \leq 0,3$	$0,3 < r_{av} \leq 0,6$	$0,6 < r_{av} \leq 1,3$	$1,3 < r_{av} \leq 2,6$	$2,6 < r_{av} \leq 4,6$
Metal	**Steady-state corrosion rate, r_{lin}, estimated as the average corrosion rate during the first 30 years for the following corrosivity categories**					
	C1	**C2**	**C3**	**C4**	**C5**	**CX**
Carbon steel	$r_{lin} \leq 0,3$	$0,3 < r_{lin} \leq 4,9$	$4,9 < r_{lin} \leq 10$	$10 < r_{lin} \leq 16$	$16 < r_{lin} \leq 39$	$39 < r_{lin} \leq 138$
Zinc	$r_{lin} \leq 0,05$	$0,05 < r_{lin} \leq 0,4$	$0,4 < r_{lin} \leq 1,1$	$1,1 < r_{lin} \leq 2,2$	$2,2 < r_{lin} \leq 4,4$	$4,4 < r_{lin} \leq 13$
Copper	$r_{lin} \leq 0,03$	$0,03 < r_{lin} \leq 0,2$	$0,2 < r_{lin} \leq 0,4$	$0,4 < r_{lin} \leq 0,9$	$0,9 < r_{lin} \leq 1,8$	$1,8 < r_{lin} \leq 3,2$

Calculated ranges of average corrosion rates are based on a calculation procedure in accordance with this International Standard and they are derived from the first-year corrosion rates for six corrosivity categories in accordance with ISO 9223. These values represent generalized information on guiding corrosion values for six corrosivity categories.

Annex C
(informative)

Prediction of corrosion attack of steels with regard to steel composition

In cases where the steel composition is known or can be estimated based on either specifications or average lot compositions, Equation (C.1) may be used to predict the b value for use in Equation (1).

$$b_a = 0{,}569 + \Sigma\, b_i\, w_i \qquad \text{(C.1)}$$

where

b_a is the alloy-specific value of b in non-marine exposures;

b_i is the multiplier for the ith alloying element;

w_i is the mass fraction of the ith alloying element.

Equation (C.1) is based on data from ASTM G101[6]. The 0,569 value is the average b value for pure iron in three non-marine exposures[7][8]. The standard deviation of this value is 0,029. The b values for alloying elements that contribute significantly to the development of rust layers on steel are given in Table C.1. Other alloying elements can have minor effects on the protectiveness of rust layers, but they have not been found to be universally effective and are therefore not included in this method.

Table C.1 — Alloying element multipliers for Equation (C.1)

Element	Multiplier b_i
C	−0,084
P	−0,490
S	+1,440
Si	−0,163
Ni	−0,066
Cr	−0,124
Cu	−0,069

In marine atmospheres, chloride deposition reduces the protectiveness of rust layers. The extent of chloride deposition varies significantly depending on distance from surf and its activity, wind direction and velocity, surface orientation and size of object, the presence of obstacles that affect air circulation and many other factors. An approximate level of chloride deposition may be obtained using the chloride candle technique described in ISO 9225. Using this technique, the following relationship was found between the increase in b value, Δb, and the chloride deposition rate, S_d:

$$\Delta b = 0{,}084\,5\, S_d^{0{,}26} \qquad \text{(C.2)}$$

where

Δb is the increase in b value;

S_d is the chloride ion deposition rate, expressed in milligrams per square metre per day [mg/(m^2·d)].

The data used to develop Equation (C.2) were taken from publications in which 19 steels were exposed at nine marine sites with various degrees of chloride deposition[9][10][11]. The Δb values calculated with Equation (C.2) had a coefficient of variation (standard deviation divided by the value) of 27 %.

The two standard deviation additions shown in Clause 5 shall be included in the calculation of b values if a conservative upper limit of corrosion damage is desired.

Bibliography

[1] DEAN, S.W. and REISER, D.B., "Analysis of Long Term Atmospheric Results From ISO CORRAG Program", *Outdoor Atmospheric Corrosion*. ASTM STP 1421, TOWNSEND, H.E. Ed., ASTM International, West Conshohocken, PA, USA, 2002, pp. 3-18

[2] KNOTKOVA, D., BOSCHEK, P., and KREISLOVA, K., "Results of ISO CORRAG Program: Processing of One-Year Data in Respect to Corrosivity Classification", *Atmospheric Corrosion*. ASTM STP 1239, KIRK, W.W. and LAWSON, H.H. Eds., ASTM International, West Conshohocken, PA, USA, 1995, pp. 38-55

[3] KNOTKOVA, D. and VLCKOVA, J., "Atmospheric Corrosion of Bolted Lap Joints Made of Weathering Steels", *Atmospheric Corrosion*. ASTM 1239, KIRK, W.W. and LAWSON, H.H. Eds., ASTM International, West Conshohocken, PA, USA, 1995, pp. 114-136

[4] CASTILLO, A.P. and POPPLEWELL, J.M., "General, Localized and Stress Corrosion Cracking of a Series of Copper Alloys in Natural Environments", *Atmospheric Corrosion of Metals*, STP 767, S.W. DEAN, Jr. and RHEA, E.C., Eds., ASTM International, West Conshohocken, PA, USA, 1982, pp. 60-84

[5] COSTAS, L.P., "Atmospheric Corrosion of Copper Alloys Exposed for 15 to 20 Years", *Atmospheric Corrosion of Metals*, STP 767, S.W. DEAN, Jr. and RHEA, E.C. Eds., ASTM International, West Conshohocken, PA, USA, 1982, pp. 106-115

[6] ASTM G101, *Standard Guide for Estimating the Atmospheric Corrosion Resistance of Low-Alloy Steels*

[7] TOWNSEND, H.E., "The Effects of Alloying Elements on the Corrosion Resistance of Steel in Industrial Environments", *Proceedings of the Fourteenth International Corrosion Congress*. Corrosion Institute of South Africa, September 1999

[8] TOWNSEND, H.E., "Estimating the Atmospheric Corrosion Resistance of Weathering Steels", *Outdoor Atmospheric Corrosion*. STP 1421, TOWNSEND, H.E. Ed., ASTM International, West Conshohocken, PA, USA, 2002, pp. 292-300

[9] TOWNSEND, H.E., "Effects of Silicon and Nickel Contents on the Atmospheric Corrosion Resistance of ASTM A500 Weathering Steel", *Atmospheric Corrosion*. ASTM 1239, KIRK, W.W. and LAWSON, H.H. Eds., ASTM International, West Conshohocken, PA, USA, 1995, pp. 85-100

[10] COBURN, S.K., KOMP, M.E., and LORE, S.G., "Atmospheric Corrosion Rates of Weathering Steels Test Sites in the Eastern United States – Affect of Environment and Test Panel Orientation". *Atmospheric Corrosion*. ASTM 1239, KIRK, W.W. and LAWSON, H.H. Eds., ASTM International, West Conshohocken, PA, USA, 1995, pp. 101-113

[11] MORCILLO, M., SIMANCAS, J., and FELIU, S., "Long-Term Atmospheric Corrosion in Spain: Results after 13–16 Years of Exposure and Comparison with Worldwide Data", *Atmospheric Corrosion*. ASTM STP 1239, KIRK, W.W., and LAWSON, H.H. Eds., ASTM International, West Conshohocken, PA, USA, 1995, pp. 195-214

[12] ISO 14713-1, *Zinc coatings — Guidelines and recommendations for the protection against corrosion of iron and steel in structures — Part 1: General principles of design and corrosion resistance*

[13] KNOTKOVA, D., KREISLOVA, K., DEAN, S.W., "ISO CORRAG International Atmospheric Exposure Program Summary of Results", *ASTM Data Series 71*. ASTM International, PA, USA, 2010

[14] ISO 11303, *Corrosion of metals and alloys — Guidance for selection of protection method against atmospheric corrosion*

[15] ISO 9225, *Corrosion of metals and alloys — Corrosivity of atmospheres — Measurement of environmental parameters affecting corrosivity of atmospheres*

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