INFORMATICS JOURNALS
The Journal of Electrochemical Society of India, *Volume 74, Issue (3&4), April – June 2025; pp. 97–104*
ISSN (Print) : 0013-466X
ISSN (Online) : xxxx-xxxx
DOI: 10.18311/JESCI/2025/51692

Modelling and Prediction of Electrochemical Corrosion in Natural Environments

Cui Liu[1], Xiangxu Qu[1], Bin Xue[1] and J. H. Qiu[2*]

[1]School of Mechanical and Electrical Engineering, Qingdao Binhai University, Qingdao - 266555, China

[2]WebCorr Corrosion Consulting Services, 1 Scotts Road #24-10, Shaw Centre, Singapore - 228208, Singapore

Abstract

This paper discusses the latest developments in corrosion modelling and prediction software for applications in natural environments such as the atmosphere, soils, and seawater. Critical parameters affecting electrochemical corrosion of common engineering metals and alloys are discussed. Application examples of relevant software for modelling and prediction of corrosion in the atmosphere, soils, and seawater are presented.

Keywords: Atmosphere, Corrosion, Modelling, Seawater, Soils

1. Introduction

Many structures, such as wind and solar power installations, offshore platforms, underground pipelines, plant equipment and machinery are exposed to natural environments – atmosphere, soils and seawater where corrosion poses a major risk to the safety and durability of the system[1]. Corrosion of common engineering metals and alloys in natural environments has one thing in common: the corrosion process is electrochemical in nature. Electrochemical corrosion, aqueous corrosion, and low temperature corrosion are sometimes used interchangeably to differentiate from gaseous corrosion at high temperature. Critical parameters affecting the rate of corrosion in natural environments are temperature, dissolved oxygen content, pH, and other chemical species present in the natural environments[1]. Corrosion processes in natural environments can be described by the following equations:

Metal oxidation (anodic reaction): $M \rightarrow M^{z+} + ze^-$ 1

Reduction of dissolved oxygen (cathodic reaction): $2H_2O + O_2 \rightarrow 4OH^-$ 2

In natural environments, the rate-determining step in the corrosion process is often the oxygen reduction reaction[1]. The corrosion rate (corrosion current density, i_{corr}) is related to the cathodic polarisation η_c, the rate of cathodic reaction i_c, and the oxygen diffusion limiting current density i_L:

$$\eta_c = \beta_c \log \frac{i_c}{i_{corr}} + \frac{2.3RT}{zF} \log\left[1 - \frac{i_c}{i_L}\right] \quad 3$$

where,
η_c: Cathodic polarisation
β_c: Cathodic Tafel constant
i_c: Cathodic current density
R: Gas constant
T: Temperature
z: Valence
F: Faraday constant
i_L: O_2 diffusion limiting current density

The diffusion limiting current density, i_L, is influenced by the diffusion coefficient, D, dissolved oxygen concentration in the bulk solution, C_B, and the thickness of the stagnant layers of electrolyte next to the electrode surface, δ, and the transference number, τ:

*Email: j.h.qiu@corrosionclinic.com

$$i_L = \frac{DzF}{\delta\tau} C_B \qquad 4$$

Corrosion of metals and alloys in natural environments is electrochemical in nature. Based on the rigorous framework of thermodynamic and electrode kinetics, and validated against long-term field data, corrosion modelling and prediction software can provide facility owners and operators with a powerful means to determine the extent of corrosion damage and the remaining life of the system.

2. Modelling and Prediction of Electrochemical Corrosion in the Atmosphere

Atmosphere-Compass[2] is a device and OS independent software tool for modelling and prediction of atmospheric corrosion of metals and alloys in compliance with ISO 9223[3] and ISO 9224[4]. Designers, architects, OEM engineers, consultants, operation personnel, maintenance and inspection engineers can quickly determine the expected service life of a structure or component exposed to indoor or outdoor atmospheres[2]. The software predicts the corrosion rate, the maximum and average corrosion depth, the rust rating number and the rust area ratio of equipment or structures based on the following inputs:

(1) material type/grade
(2) age of structure
(3) nominal thickness
(4) exposure condition - indoor or outdoor
(5) ISO exposure environments (A - F), or

Table 1a. ISO exposure environment used in the atmosphere-compass

ISO Exposure Environment	Indoor	Outdoor
A	Heated spaces with low relative humidity and insignificant pollution, e.g. offices, schools, museums	Dry or cold zone, atmospheric environment with very low pollution and time of wetness, e.g. certain deserts, Central Arctic/Antarctica.
B	Unheated spaces with varying temperatures and relative humidity. Low frequency of condensation and low pollution, e.g. storage, sports halls.	Temperate zone, atmospheric environment with low pollution (SO_2 < 5 µg/m^3), e.g. rural areas, small towns. Dry or cold zone, atmospheric environment with short time of wetness, e.g. deserts, subarctic areas.
C	Spaces with moderate frequency of condensation and moderate pollution from production processes, e.g. food-processing plants, laundries, breweries, dairies.	Temperate zone, atmospheric environment with medium pollution (SO_2: 5 µg/m^3 to 30 µg/m^3) or some effect of chlorides, e.g. urban areas, coastal areas with low deposition of chlorides. Subtropical and tropical zone, atmosphere with low pollution.
D	Spaces with high frequency of condensation and high pollution from the production process, e.g. industrial processing plants, swimming pools.	Temperate zone, atmospheric environment with high pollution (SO_2: 30 µg/m^3 to 90 µg/m^3) or substantial effect of chlorides, e.g. polluted urban areas, industrial areas, coastal areas without spray of salt water or exposure to strong effect of de-icing salts. Subtropical and tropical zone, atmosphere with medium pollution.
E	Spaces with very high frequency of condensation and/or with high pollution from production processes, e.g. mines, caverns for industrial purposes, unventilated sheds in subtropical and tropical zones.	Temperate and subtropical zone, atmospheric environment with very high pollution (SO_2: 90 µg/m^3 to 250 µg/m^3) and/or significant effect of chlorides, e.g. industrial areas, coastal areas, sheltered positions on the coastline.
F	Spaces with almost permanent condensation or extensive periods of exposure to extreme humidity effects and/or with high pollution from the production process, e.g. unventilated sheds in humid tropical zones with penetration of outdoor pollution, including airborne chlorides and corrosion-stimulating particulate matter.	Subtropical and tropical zone (very high time of wetness), atmospheric environment with very high SO_2 pollution (higher than 250 µg/m^3), including accompanying and production factors and/or strong effect of chlorides, e.g. extreme industrial areas, coastal and offshore areas, occasional contact with salt spray.

(6) site-specific data if available (temperature, relative humidity, sulfur dioxide (SO_2) deposition rate, chloride deposition rate, and distance from the shore)

The outputs of Atmosphere-Compass include the following:

(1) the atmosphere corrosivity category
(2) the atmosphere corrosivity ranking
(3) the degree of rust and stains on the surface measured by the rust rating number (RN) and the rust area ratio (%) as per BS ISO 23721 standard[5].
(4) the maximum or average corrosion depth at the specified age of the equipment or structure
(5) the corrosion rate at the specified age of the equipment or structure
(6) the remaining life of the equipment or structure
(7) a plot of the corrosion depth (μm) vs. service life in years

Figures 1a-1f below show the input options and outputs in Atmosphere-Compass. Users can select ISO exposure environment (A-F in Table 1a) or use site-specific data (Figure 1b). Users can enter the deposition rates of chloride and sulphate at the site location or enter the distance from the shore and the distance from the industrial zone (Figures 1c-1e).

Table 1b shows the common engineering metals and alloys included in the software database

Table 1b. Common engineering metals and alloys included in the atmosphere-compass

Aluminium Al1XXX Al2XXX Al3XXX Al5XXX Al6XXX Al7XXX Copper Steel Zinc HDG Zinc Coating Zn-5Al Coating Zn-55Al Coating Zn-2.5Al-3Mg Coating Zn-3.5Al-3Mg Coating Zn-6Al-3Mg Coating	Type 410 Type 430 Type 444 Type 446 Type 304 Type 304L Type 304LN Type 316 Type 316L Type 316LN Type 317 Type 317L Type 317LMN Type 321 Type 347	904L 254SMO AL-6X AL-6XN Incoloy 825 Inconel 625 Duplex 2205 Duplex 2304 Duplex 2507 Duplex 2707HD

3. Modelling and Prediction of Electrochemical Corrosion in Natural Soils

Soil-Compass[6] is a device and OS independent software tool for the prediction and modelling of soil corrosion for metals and alloys. Designers, architects, engineers, consultants, operation personnel, maintenance and inspection engineers can quickly determine the corrosion depth, the corrosion rates, and the remaining life of the

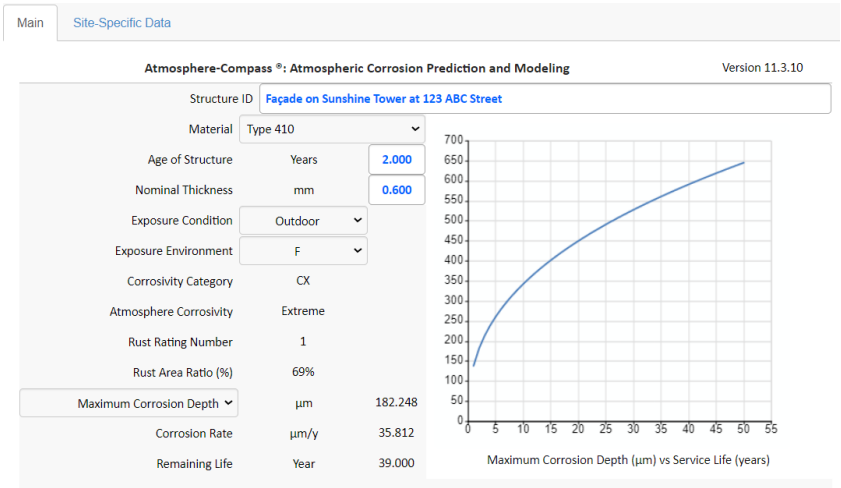


Figure 1a. Atmosphere-Compass uses the ISO exposure environment as inputs.

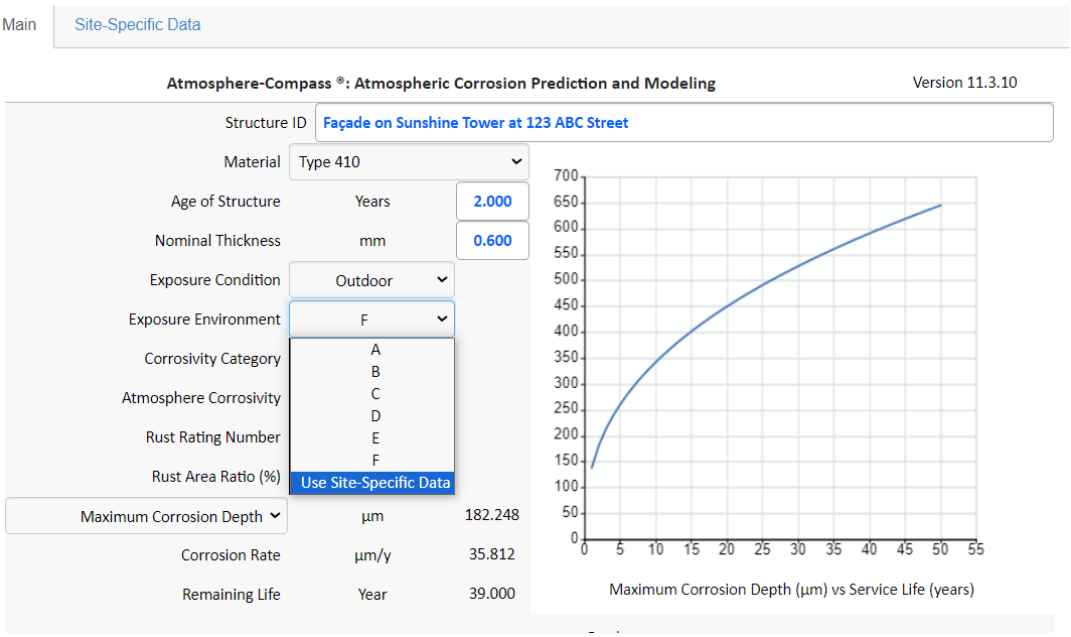


Figure 1b. Atmosphere-Compass uses site-specific data as inputs.

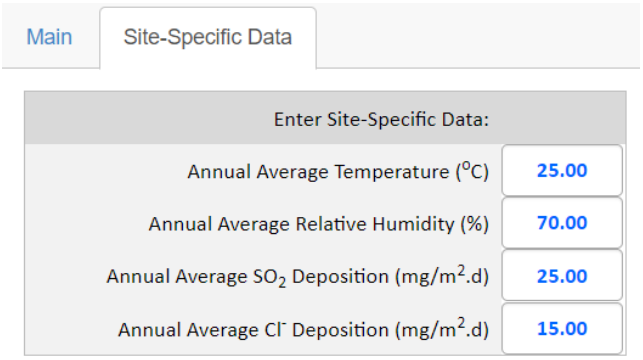


Figure 1c. Site-specific data used as inputs in atmosphere-compass.

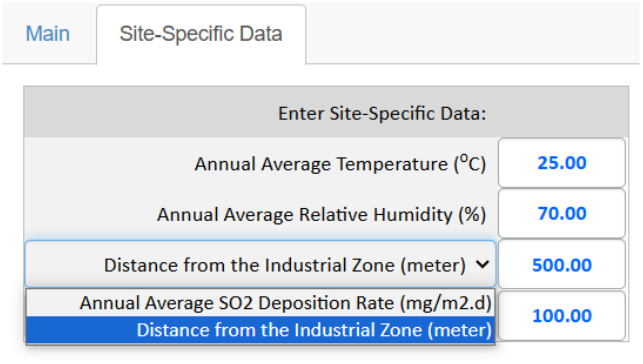


Figure 1d. Site-specific data, distance from the industrial zone used as input.

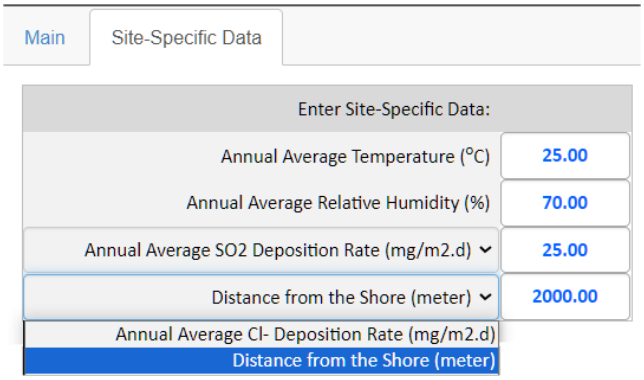


Figure 1e. Site-specific data, distance from the shore used as input.

structure or components in contact with or buried in soils. Soil-Compass also predicts the ANSI/AWWA C105 point rating[7], the soil corrosivity class[8], the likelihood of Microbiologically-Influenced Corrosion (MIC), DC stray current corrosion and AC corrosion in compliance with ISO 18086[9]. Soil-Compass software models the effects of the following critical factors on soil corrosion:

(1) Soil type
(2) Soil temperature
(3) Soil resistivity
(4) Soil pH
(5) Soil moisture content
(6) Soil chloride content

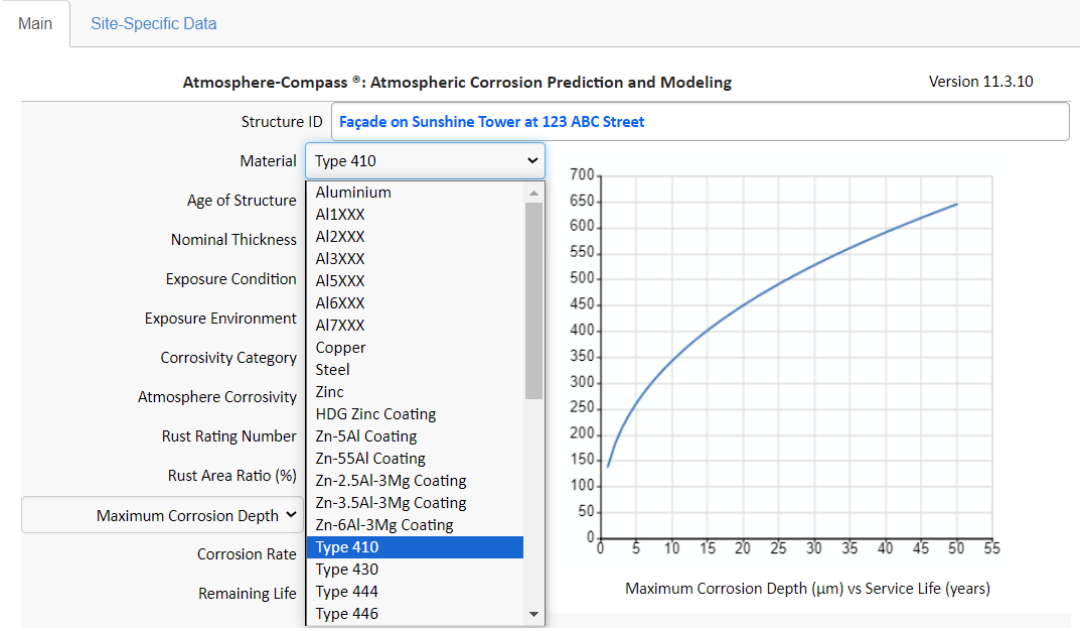


Figure 1f. Common engineering metals and alloys in the atmosphere.

(7) Soil carbonate content
(8) Soil sulfate content
(9) Soil sulfide content
(10) Soil redox potential

The outputs of Soil-Compass include the following:

(1) the ANSI/AWWA C105 point rating about soil corrosivity[7],
(2) the soil corrosivity category as per BS EN 12501 standard[8],
(3) the corrosion depth,
(4) the corrosion rate,
(5) the remaining life or the time-to-perforation,
(6) the mode of failure,
(7) likelihood of Microbiologically-Influenced Corrosion (MIC) in the soil environments
(8) the risk of DC stray current corrosion and AC corrosion[9]

Under the specified exposure conditions shown in Figure 2 below, Soil-Compass predicts that the accumulated maximum corrosion depth at the specified age of 8 years is 1.668 mm, the corrosion rate at the specified age is 0.104 mm/y, and the remaining life of the structure is 17.8 years. The predictive engine used in Soil-Compass for the modelling and prediction of soil corrosion of metals and alloys complies with applicable international standards ISO 18086, BS EN 12501, and relevant industry best practices. Table 2 shows the common engineering metals and alloys included in the software database.

4. Modelling and Prediction of Electrochemical Corrosion in Seawater

Seawater-Compass[9] is a device and OS independent software tool for the modelling and life prediction of seawater corrosion of metals and alloys, including carbon steels, aluminium alloys, brass, copper-nickel alloys, nickel alloys, stainless steels, duplex stainless steels, and titanium alloys.

Input parameters in Seawater-Compass are:

(1) the material
(2) remaining thickness
(3) seawater temperature
(4) seawater salinity
(5) dissolved oxygen (measured or saturated)
(6) seawater velocity

The outputs in Seawater-Compass are:

(1) corrosion current density
(2) corrosion rate



Figure 2. Inputs and outputs in Soil-Compass.

Table 2. Common engineering metals and alloys included in Soil-Compass

Al 1100	Type 410	904L
Al 2017	Type 430	254SMO
Al 2024	Type 444	AL-6X
Al 5052	Type 446	AL-6XN
Al 6053	Type 304	Inconel 625
Cast Iron	Type 304L	Incoloy 825
Ductile Iron	Type 304LN	Duplex 2205
Open Hearth Iron	Type 316	Duplex 2304
Wrought Iron	Type 316L	Duplex 2507
Steel	Type 316LN	Duplex 2707HD
Galvanized Steel	Type 317	
Copper	Type 317L	
Lead	Type 317LMN	
Zinc	Type 321	
	Type 347	

(3) remaining service life
(4) major forms of corrosion expected
(5) caution notes on
(a) The high risk of stress corrosion cracking (SCC) when the temperature exceeds the threshold.
(b) the risk of erosion, corrosion, and cavitation when the seawater velocity is high.
(c) The risk of pitting, crevice corrosion, and Microbiologically-Influenced Corrosion (MIC) when the velocity is too low.

In the application example in Figure 3 above, the predicted corrosion rate of carbon steel in seawater of salinity of 35‰ is 0.107 mm/y at the temperature of 10°C, dissolved oxygen of 6.50 ppm, and seawater velocity of 1.50 m/s. Seawater-Compass predicts that

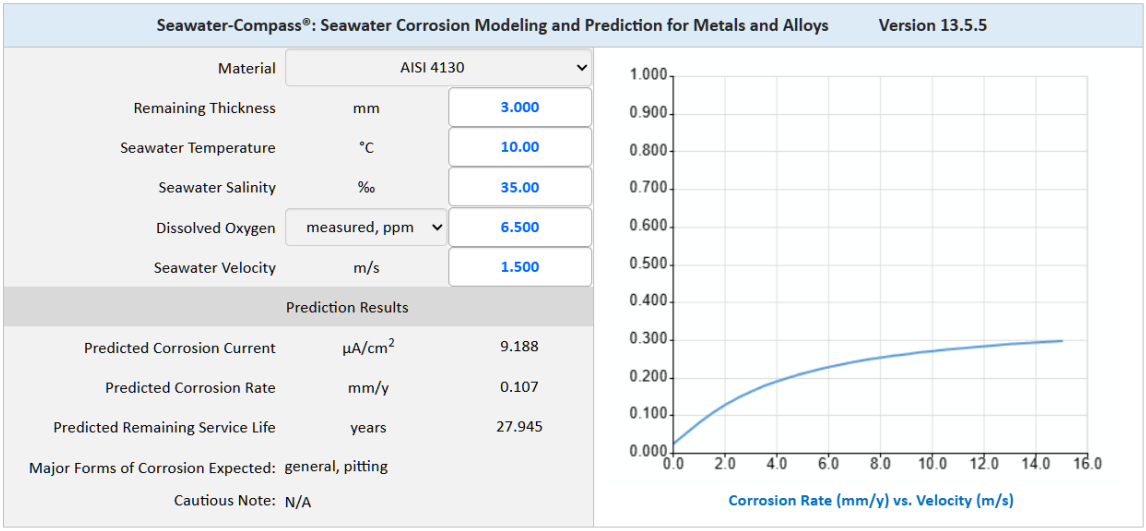


Figure 3. Inputs and outputs in Seawater-Compass.

Table 3. Common engineering metals and alloys included in Seawater-Compass

Aluminium	Carbon Steel	Duplex 2205
Cadmium	AISI 1020	Duplex 2304
Copper	HY-80 Steel	Duplex 2507
Lead	AISI 4130	Duplex 2707 HD
Magnesium	AISI 4340	Brass
Nickel	Type 304	Bronze
Silver	Type 316	Monel 400
Tin	AL6-XN	Naval Brass
Titanium	13-8PH	Admiralty Brass
Zinc	17-4PH	Nickel-Aluminium-Bronze
AA1100	904L	Cu70Ni30 (C71500)
AA2024	Inconel 625	Cu90Ni10 (C70600)
AA2050	Hastelloy C	SMO254
AA2060	Hastelloy C-276	Ti6Al4V
AA2195		Ti-CP-TA2
AA2219		
AA5083		
AA6061		
AA7050		
AA7075		

the major forms of corrosion expected are general attack and pitting under the prevailing operating conditions.

The applicability of Seawater-Compass is not limited to seawater. By changing the salinity input value, Seawater-Compass can be used to model and predict corrosion in all natural waters. Table 3 shows the common engineering metals and alloys included in the software database.

5. Conclusion

Corrosion in natural environments such as the atmosphere, soils, and waters is electrochemical in nature. Oxygen reduction in the moisture film or water is often the rate-determining step. Corrosion modelling and prediction software based on a rigorous framework of thermodynamics and electrode kinetics can be used to quantify the degree of corrosion and the rate of corrosion, making service life prediction possible for many structures such as wind and solar power installations, offshore platforms, underground pipelines, plant equipment and machinery.

6. References

1. Revie RW, Uhlig HH. Corrosion and corrosion control: an introduction to corrosion science and engineering. 4th ed. Hoboken, NJ: John Wiley and Sons; 2008.
2. WebCorr Corrosion Consulting Services. Atmosphere-Compass user manual. Singapore: WebCorr Corrosion Consulting Services; 2025.
3. International Organization for Standardization. ISO 9223:2012. Corrosion of metals and alloys - corrosivity of atmospheres - classification, determination and estimation. Geneva: ISO; 2012.
4. International Organization for Standardization. ISO 9224:2012. Corrosion of metals and alloys - corrosivity of atmospheres - guiding values for the corrosivity categories. Geneva: ISO; 2012.

5. British Standards Institution. BS ISO 23721:2022. Corrosion of metals and alloys - rating method by appearance of rust and stains of atmospheric corrosion for stainless steels. London: BSI; 2022.
6. WebCorr Corrosion Consulting Services. Soil-Compass user manual. Singapore: WebCorr Corrosion Consulting Services; 2025.
7. American National Standards Institute/American Water Works Association. ANSI/AWWA C105/A21.5:2005. Polyethene encasement for ductile-iron pipe systems. Denver, CO: AWWA; 2005.
8. British Standards Institution. BS EN 12501:2003. Protection of metallic materials against corrosion. London: BSI; 2003.
9. International Organization for Standardization. ISO 18086:2019. Corrosion of metals and alloys - determination of AC corrosion. Geneva: ISO; 2019.