

**Atmospheric Corrosion Behavior of Zinc and Zinc Alloys:
Comparison Between Natural and Accelerated Exposure**

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ABSTRACT

Atmospheric corrosion of galvanized steel is a well-known subject: many experimental results, international research programs, as ISOCORRAG and MICAT, and ISO standards are available. In some applications, as in the case of gabion walls, Zn-Al alloys coatings have been proposed to protect steel wires. These coatings, as a function of thickness and severity of the environment, should guarantee a service life in the range 10 to 120 years. For very aggressive environments, the specific standards propose the use of galvanized steel wires protected by Zn-Al alloys and polymeric top coatings. Aim of this paper is to compare the corrosion rate of pure zinc and Zn-Al alloys, in accelerated exposure tests and in natural atmosphere for medium-long time exposure. Obtained data were matched with the prediction suggested by the standards. The results showed that the corrosion rate of zinc alloys is lower than zinc, in both natural and accelerated exposure. The lack of medium-long term data in natural exposure makes difficult, if not impossible, to forecast the real behavior of zinc alloys, especially in the more severe exposure conditions (C3 to C5 according to ISO 9223).

Key words: atmospheric corrosion, Zn coatings, Zn-Al alloy.

INTRODUCTION

Atmospheric corrosion of steel structure is a well-known topic.¹⁻⁴ Many experimental results have been published in the last decades. International research programs, as ISOCORRAG and MICAT, have been carried out involving the best international research groups.³ All these works lead to the

development of a series of ISO^(*) standards (9223, 9224, 9225 and 9226), firstly issued in the 90s of the past century and recently revised from 2012.⁵ The evaluation of atmospheric corrosiveness in accordance with these regulations is carried out on the basis of the following environmental parameters: time of wetness (TOW), i.e. time in which the relative humidity, RH, is greater than 80% at a T-value greater than 0°C, sulfur dioxide concentration or deposition rate, chlorides deposition rate. Five classes of time of wetness were defined, from τ_1 (TOW < 10 h/a) to τ_5 (TOW > 5500 h/a). Pollution by sulfur dioxide and chlorides are classified in four classes, from P_0 to P_3 for the SO_2 and from S_0 to S_3 for chlorides, respectively.⁵ Six corrosiveness classes are considered: C1, C2, C3, C4, C5 and CX, the latter being the atmospheric class extremely severe.

The same standards, according to the exposure class, propose two methods for estimating the corrosiveness for some metals: carbon steel, zinc, copper and aluminum. The two methods are based on:

- corrosion rate measurement of standard specimens after one year's exposure
- estimation based on environmental information (relative humidity, SO_2 and chlorides pollution) with dose-response function.

In some applications, as in the case of gabion walls, for environments characterized by very low and low corrosiveness category (C1 and C2, according to ISO 9223), it has been proposed to protect carbon steel wires with Zn-Al alloys coatings (Zn-5%Al and Zn-10%Al). These coatings, as a function of their thickness, ranging from 1 to 42 μm and aggressiveness of the environments, should guarantee a service life in the range of 10 to 120 years (according to EN 10223).^{6,7} From medium to very high corrosiveness class (C3 to C5), the same standards provide the use of steel wires coated with Al-Zn alloy. For very aggressive environments (class C5 and CX) the ISO standards propose the use of steel wires coated with both a Zn-Al alloys and a polymeric coating (PVC and polyamide).⁷

In the literature, most of the comparisons between the corrosion behavior of zinc coatings and zinc alloys coatings deal with short-term experimental tests, in natural or accelerated exposure tests (as salt spray fog). Main results of these tests are the formation and the characterization of corrosion products whereas less information are available on the actual corrosion rate.

The goal of this paper is the collection and analysis of corrosion rate data relating to medium-long term exposure tests (between 1 and 10 years) of carbon steel coated with Zn and Zn-Al coatings (Al 5-10%) exposed to natural atmospheres. The comparison of these data has been completed with both the model reported in ISO 9223 standard and with accelerated corrosion tests carried out in a Salt Spray Chamber (SSC).

ATMOSPHERIC CORROSION OF ZINC AND ITS ALLOYS

According to ISO 9223 and ISO 9224, the corroded thickness (D) as a function of time (t) varies with a non-linear law:

$$D = r_{\text{corr}} \cdot t^b \quad (1)$$

where r_{corr} is the first year corrosion rate, determined as a function of corrosiveness class and metal, and the exponent b is a function of the metal, for example it is 0.5 for carbon steel, 0.8 for zinc or 1 for high pollution areas.⁵

In the case of zinc the proposed first year corrosion rate ranges from 0.1 $\mu m/y$ (class C1, dry or cold zones), to 0.1-0.7 $\mu m/y$ (class C2, temperate zones with low pollution, e.g. rural areas), to 0.7-2.1 $\mu m/y$ (class C3, temperate zones with medium level of pollution, e.g. urban areas), to 2.1-4.2 $\mu m/y$ (class C4,

(*) International Standard Organization, Geneve, Switzerland.

temperate zones with high pollution, e.g. industrial or marine areas), up to 4.2-8.4 $\mu\text{m}/\text{y}$ (class C5, temperate or subtropical zones with high pollution or coastal environment).⁵

A wide literature concerning zinc atmospheric corrosion is available: many data may be collected regarding zinc corrosion rate.⁸⁻¹³ Figure 1 compares the corrosion thickness data collected from the literature with the maximum thickness loss estimated using Eq. 1, for the different corrosiveness classes. The corrosion thickness data refer to the exposure in various atmospheric environments (symbols in Figure 1). Comparing real data and prediction, Eq. 1 represents a good model for the study of zinc corrosion in atmospheric environments. A possible explanation is because in most of the field experiments, the assigned corrosiveness class was carried out by the authors based on the results of the first year external exposure, as requested by ISO 9223.

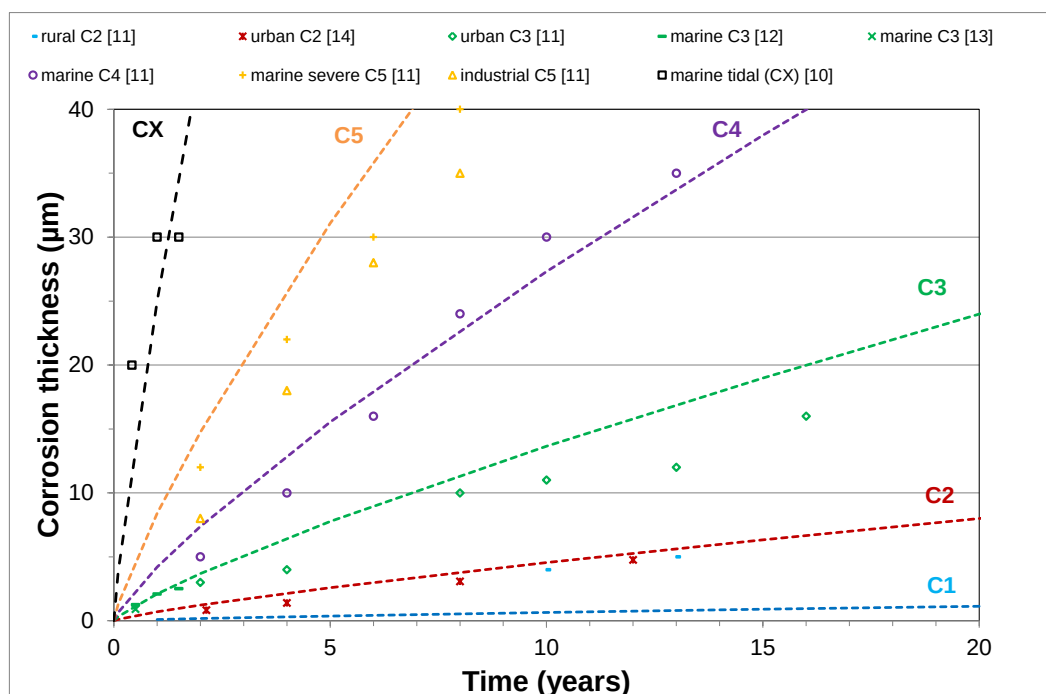


Figure 1: Atmospheric corrosion of zinc: comparison between experimental data (symbols) and estimation obtained by using Eq. 1 (dashed lines).¹⁰⁻¹⁴

The situation is different if zinc alloys are considered, in particular alloys with 5% or 10% of aluminum (called Galfan[†]): few data related to the corroded thickness are available and, in some cases, they are derived from commercial datasheets.¹⁶⁻¹⁸ Figure 2 shows some atmospheric corrosion data. The behavior of pure Zn coatings (solid symbols) has been compared with Zn-Al alloys (empty symbols): the corroded thicknesses for Zn-Al based coatings are lower than those of pure Zn. In some paper, real thickness loss measured in industrial environment (class C3) does not fit exactly the prediction by the ISO standard.

According to the report, the corrosion rate of Zn-Al alloy coatings is lower than corrosion rate of pure zinc coatings by a factor in between 1.5 to 3, even if data supporting this thesis are limited.¹⁶ Data collected from literature, reported in Figure 3, show ratios ranging from 1 to 2 for most of the environments (in particular for classes C1 to C3), and higher ratios, up to 3 and more, for rural environment (class C1).¹⁶⁻¹⁸ In severe exposure conditions (inside swimming pools with high relative humidity and chlorides pollutions), the corrosion rate of zinc and Zn-Al alloy, after 11 years, is similar (3-4 $\mu\text{m}/\text{year}$).²⁰

[†] Trade name