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An study on accelerated corrosion testing of weathering steel

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HIGHLIGHTS

- Atmospheric corrosion of weathering steels is anticipated by wet/dry cyclic tests.
- The most suitable cyclic test depends on the atmosphere to be simulated.
- Cebelcor test (10^{-4} M Na_2SO_4) has simulated reasonably well rural and urban atmospheres.
- Kesternich (0.2 L SO_2) test has simulated industrial atmospheres.
- Prohesion test has simulated moderate marine atmospheres.

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ABSTRACT

This paper assesses the use of wet/dry cyclic laboratory corrosion tests that can provide information on the protective capacity of weathering steels in short times. Two steels were considered, a weathering steel ASTM A 242 Type 1 and a plain carbon steel (as reference), that were exposed in the atmosphere of Madrid (3 years) and in the following laboratory wet/dry cyclic tests: Cebelcor (10^{-4} M Na_2SO_4) (945 h), Kesternich (0.2 L SO_2) (2160 h) and Prohesion (2160 h). Characterisation of rust layers was done by XRD, FTIR, SEM, SKP and EIS. Wet/dry cyclic tests make it possible to shorten the testing time to assess in laboratory the protective capacity of rusts formed on weathering steels in the atmosphere. Some analogies between experimentation in the field and in the laboratory have been established.

1. Introduction

Weathering steels (WS) are high-strength low-alloy steels that have been shown to afford significantly higher atmospheric corrosion resistance than regular carbon steel (CS). This is achieved by adding small amounts of certain elements (e.g. copper, chromium and nickel) to the steel in order to promote the formation of a protective oxide layer (patina) when it is exposed to the atmosphere.

Conventional weathering steels have been a material of choice for many types of structures (bridges, building facades, public lamp posts, sculptures, etc.) for almost half a century. The main advantage of their use is that under normal conditions they may be left unpainted, leading to reduced maintenance and environmental costs [1]. One of the fundamental requirements for the development of a protective patina is the existence of wet/dry cycles during atmospheric exposure [2,3]. The presence of SO_2 in the atmosphere may also help to accelerate patina formation [3,4]. A protective rust layer does not, however, form in marine atmospheres [5].

The atmospheric corrosion rate of weathering steels in the first year of exposure is not usually very different from that of carbon steels. A drop in the corrosion rate related with changes in the rust characteristics is not seen until after some time (several years), which depends among other factors on the climatic conditions to which they are exposed [6–8].

Early progress in the development of weathering steels came through the performance of extensive outdoor exposure tests [9,10] involving a large number of steels in a range of atmospheres: rural, urban, industrial and marine. However, such tests have the disadvantage of being costly and time consuming, providing only a slow response, and in the late 1960's the interest of steel-makers in developing new weathering steels encouraged researchers to use

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Table 1
Chemical composition of the steels used in the study, in wt%.

Steel	Fe	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	Al	Nb	V
Weathering Steel (WS)	Balance	0.12	0.38	0.40	0.089	<0.005	0.65	0.16	<0.050	0.33	0.036	<0.005	<0.01
Carbon Steel (CS)	Balance	0.13	0.09	0.55	<0.020	0.018	0.023	0.023	<0.050	0.015	0.036	<0.005	<0.01

accelerated laboratory tests to investigate the effect of alloy composition on performance [11]. It is well established that a wetting and drying cycle should be an integral part of any laboratory test in which the characteristic properties of weathering steels are revealed [12].

Over the years different accelerated corrosion tests have been developed for weathering steels [13–17], though the results obtained have sometimes failed to match real-life exposure tests [18]. The matter is further complicated by the fact that no accelerated test can be consistent with the different kinds of atmospheric exposure: for instance, the relative merits of steels in marine atmospheres may not be the same as in industrial atmospheres [19]. Other disadvantages include the sophistication of some accelerated tests, difficulties in the interpretation of results, and a lack of commercial testing equipments.

The presence of sulphur dioxide (SO_2) in urban and industrial atmospheres led some researchers to consider this pollutant in their studies on the behaviour of materials in atmospheres of that type. Thus, Haynie and Upham [20] included it in their sophisticated controlled environmental exposure chambers with programmed dew/light cycles. They saw that SO_2 had a major effect in accelerating the corrosion rate of WS and the predicted corrosion agreed reasonably well with actual atmospheric exposure. The simple "Kesternich" cyclic test has commonly been used to evaluate the laboratory behaviour of organic [21] and metallic coatings [22] on ferrous metals. However, the literature does not report any studies that have used this test to evaluate weathering steels.

The laboratory simulation of marine atmospheres has been long been achieved by means of prolonged exposure to salt fog [23]. However, the classic salt spray test has largely fallen into disrepute because of the recognition that its reproducibility and correlation with outdoor exposure are often poor [24]. In contrast, intermittent application of salt spray provides a much closer approximation to marine and coastal conditions [25]. Cyclic salt spray testing, along with alternate electrolytes such as the "Prohesion" test solution, have been found to produce more realistic results [26,27]. As in the case of the Kesternich test, the literature does not report any studies using the Prohesion test to evaluate weathering steels.

In 1966 the Belgian Centre for Corrosion Study (CEBELCOR) developed an electrochemical method [14,28,29], known in the literature as the "Cebelcor" test, which uses classic alternating conditions of immersion in a test solution, emersion and drying following a prescribed cycle. The simple principle upon which this test is based is that if a steel is passive it will exhibit a high electrode potential in aerated water. In contrast, if a steel is corroding it will exhibit a low electrode potential. Attempts were made to quantify the correlation factors between this accelerated method and real exposure conditions.

The originality of this work lies in the use for the first time of two wet/dry cyclic tests, Kesternich and Prohesion, which are easy to perform and are commonly used in the laboratory as accelerated tests of metallic and organic coatings to evaluate the behaviour of weathering steels. This work also compares the results of these two tests with those obtained in the Cebelcor test, which has been used on numerous occasions in the evaluation of weathering steels.

2. Experimental procedure

This study considers two types of steels: a WS and a CS for reference (Table 1). The WS composition corresponds to ASTM A 242 Type 1 specification [30]: C(max), 0.15%; Mn(max), 1.00%; P(max), 0.15%; S(max), 0.05% and Cu(min), 0.20%). The test specimens measured 70 × 30 mm and were 2 and 8 mm thick, respectively. Both presented ferrite–pearlite metallographic structures (Fig. 1). The microstructure corresponding to WS shows a higher pearlite content than that corresponding to CS. The higher content of alloying elements (Cr, Ni and Cu) in the WS could be the responsible of the increase in the pearlite ratio due to the modification of the transformation curves during the cooling of the steel from the austenitic phase.

The mechanical properties of the steels, listed in Table 2, have been obtained by means of tensile testing with a MicroTest Model EM2/100/FR testing machine, applying a crosshead speed of 0.9 mm min^{-1} up to the yield strength and subsequently raised to 2 mm min^{-1}, in accordance with standard ISO 6892-1 2010 [31].

The test specimen preparation process consisted of removing the millscale layer by sand blasting (white corindon particle size Gr. 46) to ASa3 finish [32] and cleaning with detergent and high purity water (10 μS cm^{-1}) in an ultrasonic bath, successive rinsing with high purity water, ethanol and acetone in an ultrasonic bath, and finally drying with hot compressed air.

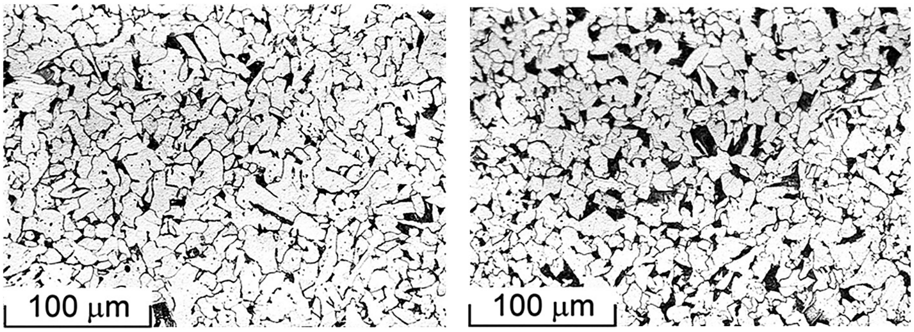

Fig. 1. Metallographic microstructures of CS (left) and WS (right).