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Simulation of steel rod atmospheric corrosion by alternate immersion in salt solution

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Abstract. Corroded B235 reinforcing steel rods, which were exposed to an open air environment for 25 years, with a certain specific mass loss, were studied. Test pieces were prepared from them by lathe machining. The test pieces were subjected to accelerated corrosion through an alternate immersion in NaCl solution. The same specific mass loss as on the initial corroded rods was achieved for 52 days. Further the test pieces were cleaned, observed, photographed and tensile tested. The cleaned surfaces and the stress-strain curves of the test pieces were compared with results, obtained from the initial corroded rods. It was found out about the tested steel rods that alternate immersion in salt solution for 52 days is a good simulation of twenty-five-year atmospheric corrosion.

1. Introduction

Atmospheric corrosion is a common phenomenon that reduces the mechanical properties of steel parts and structures. It is caused by moisture in the air and depends on many factors – humidity, temperature, winds, presence of salts or other chemicals, pollution, pH, climate, location. Atmospheric corrosion is usually uneven and creates spots, ulcers and pits.

Atmospheric corrosion in steel is a slow process. Obtaining corroded test pieces by exposing them to natural conditions takes a long time. For example, [1] describes a 10-years experiment in which unprotected steel specimens are attached to the exposed surfaces of 8 steel bridges. Reinforcing rods after 30 and 40 years of service as steel-concrete structure in natural environment are studied in [2] searching for a relation between natural and accelerated artificial corrosion. The study [3] uses test pieces whose preparation, in a combination of artificial and natural environment, took 26 years. These examples show that the field tests duration are not always acceptable for the laboratory practice. It is usually appropriate to use accelerated corrosion methods for test pieces preparation. In [4, 5] it is summarized that the corrosion influence on the mechanical properties of steel is mainly a geometric effect. The shape, depth, and density of the pits are crucial. And the corroded surface relief strongly depends on the process conditions. The distribution of pits, obtained in two different environments – air exposure and immersion in sea water – is given in [5]. They are quite different, as the stay in sea water gives a smoother surface. Thus, the impact of the shapes of the defects on the mechanical properties is studied in [4]. The defects in [4] are not produced by a corrosion process, but by machining. The test pieces preparation is maximally facilitated and accelerated in this way. Computer simulations can also take advantage of the available accurate information about machined test piece geometry. Despite these obvious advantages, the surface relief obtained by machining is very different from that caused by corrosion and is therefore not preferred by researchers.

One of the most common accelerated corrosion methods is the Salt Spray Test. Salt mist (5% NaCl, 35° C, 10-60 days) is used in [2], causing about 11% mass loss on reinforcing rods with a diameter of 10 mm. The tensile test results are compared with those from naturally corroded rods with similar mass loss. It is found out that there is no direct relationship between the two types of results. The reason is the big difference in the surface relief caused by the two corrosion methods. The same problem is observed with other two easy to implement and frequently used methods – immersion in a corrosive solution and the galvanostatic method. The most common corrosive solution is sea water. A study of its impact on the mechanical properties of steel test pieces is made in [6]. In addition to causing a smoother surface than atmospheric corrosion, this method often has a long duration – the preparation of test pieces in [6] takes 1 year. To accelerate the corrosion process, electric current is often used – the galvanostatic method. Such an experiment is described in [7], where steel fibers are tested. It is found out that uniform corrosion is obtained, which leads to significantly better mechanical properties than in case of pitting caused by cyclic wetting and drying.

Cyclic Corrosion Testing (CCT) is the best way to obtain in a short time artificial pitting corrosion similar to that in natural atmosphere [8]. The test pieces are periodically exposed to a corrosive solution, while many important parameters are controlled – temperature, humidity, ultraviolet radiation, and others. A simplified and standardized version of CCT is the Alternate Immersion Test (AIT) [9]. This method is easier to implement, and it is preferred for the presented study. The relevant equipment and technology are described in [10, 11].

The aim of the present work is to determine whether the atmospheric corrosion effects on B235 steel rods can be simulated and investigated by periodically immersing the same rods in salt solution, using a standard method [9] and an available technique [10]. The studied rods have been stood outdoors for 25 years (corrosion in natural atmosphere), in vertical position, in a temperate continental climate zone, without anti-corrosion protection. Their specific mass loss and mechanical properties was determined in [11]. Here, new test pieces are made from these rods and then subjected to AIT until the same specific mass loss is obtained. The surfaces and stress-strain curves obtained after both methods of corrosion, are compared and analyzed.

2. Test pieces

Figure 1 (a) shows a photo of the initial corroded material – B235 steel rod with a nominal diameter of 6.5 mm [12, 13]. Two types of test pieces are made of it. Figure 1 (b) shows 3 test pieces intended for tensile testing. They have a diameter of 5 mm in gauge length. Figure 1 (c) shows specimens prepared to determine the specific mass loss at different exposure times during the AIT. They have a diameter of 5 mm and a surface area of 244.73 mm^2.

(a) (b) (c)

Figure 1. Test pieces: (a) Initial corroded rod; (b) Test pieces for tensile testing; (c) Specimens for specific mass loss determination during AIT.

3. Alternate Immersion Test

The accelerate corrosion method AIT used here is described in detail in [10, 11]. A water solution of 3.5% NaCl is used; the wetting/drying cycle includes 10 min of immersion in the solution followed by 50 min of air-drying at a temperature of 25 ºC.

B235 steel can be assumed to be an analogue of the widespread brand of structural steel S235JR, whose corrosion behavior was studied in [10]. The blue line in figure 2 shows the specific mass loss of S235JR steel rod with diameter of 6 mm. The target specific mass loss is 1462.25 g/m^2, as obtained in [11] for the initial B235 rod. It can be assumed that the needed AIT duration is approximately 50 days.

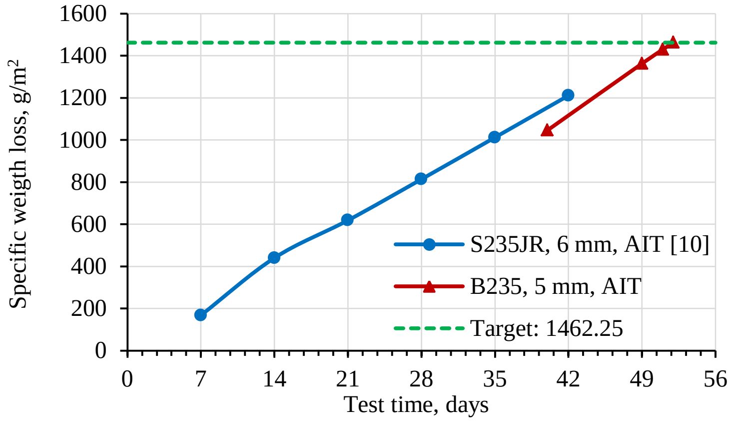

Figure 2. Specific weight loss of steel rods.

For more precise determination of the necessary AIT duration, which will lead to the target specific mass loss, the specimens shown in figure 1 (c) were used. They were pre-weighed with a precision of ±0.001 g, and divided into groups of 3 pieces. All groups were subjected to AIT simultaneously, together with the test pieces for tensile testing, and one group was removed every few days, starting on day 40. After cleaning, re-weighing and averaging the results, the specific mass loss for the respective days of exposure was established. The results are given in table 1, and are plotted as a red line in figure 2.

Table 1. Specific mass loss of B235 steel specimens after 40-52 days AIT.

AIT duration, days	40	49	51	52
Specific mass loss, g/m^2	1046.05	1362.73	1430.15	1462.84

Due to the achievement of desired specific mass loss, the AIT exposure was discontinued on day 52.

4. Surface observations

Pictures of the cleaned initial steel rod, after 25 years exposure to atmospheric environment are shown in figure 3 (a). Pictures of the cleaned test piece after 52 days of AIT are shown in figure 3 (b). The photos on the left were taken with a camera, and the photos on the right – with a microscope at magnification of ×15. The two types of test pieces from the same material have practically equal specific mass loss (approximately 1462 g/m^2) and their properties can be compared.

As can be seen in figure 3, the shape and the size of the pits are approximately the same. The depth of the surface defects is also similar. There is a difference in the pit distribution – the number of pits caused by natural corrosion is higher and they are more evenly distributed than the ones caused by

AIT. Due to the similarity in the pit shape and depth, similarity in mechanical properties can also be expected during the tensile test.

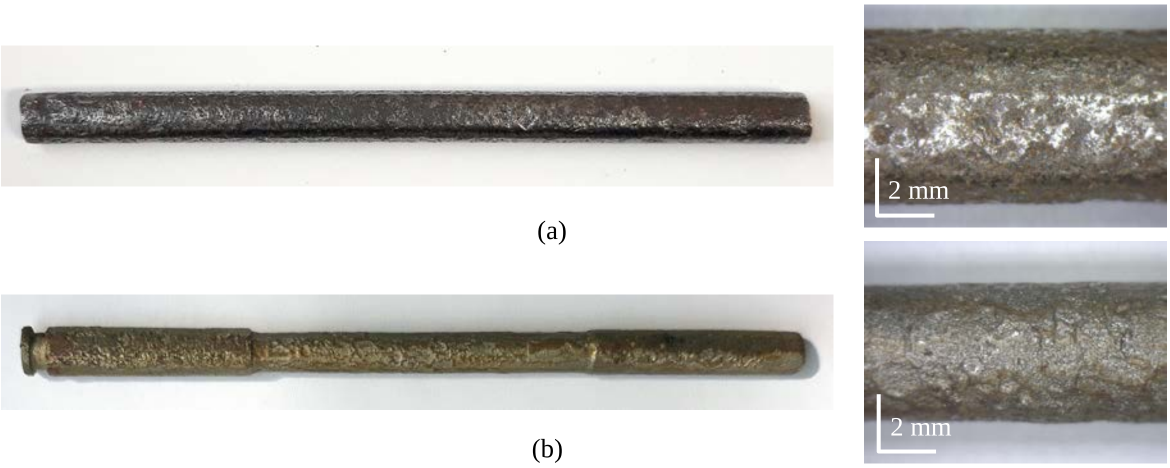

Figure 3. General appearance and close look at the cleaned corroded test pieces:
(a) Initial steel rod after 25-year atmospheric corrosion; (b) Test piece after 52 days of AIT.

The two types of test pieces differ in appearance – the cleaned initial rod is dark in color and glossy, while the AIT-subjected one is matte and yellowish. This difference is caused by the cleaning methods. The oxide layer mechanical strength and density are very high after a long exposure to natural atmosphere and very low after the short period of accelerated corrosion impact. Corrosion products were very difficult to remove from the initial rod. Chemical and mechanical methods (scrubbing with a soft brush) were used, which smooths the protrusions, and minimal residues of hard and dark-colored oxides remained in the depressions. In the case of an artificially corroded test piece, the cleaning was easy and entirely chemical, according to a standard procedure [14], which completely removes the corrosion products and creates a more contrasting texture, shown in figure 3 (b). These visual differences do not affect the mechanical properties determined by the tensile test.

5. Tensile test

The experiments were performed in accordance with EN ISO 6892-1:2019 [15]. A testing machine with a screw load mechanism and precise digital control was used [16]. Longitudinal strain was measured with a 25 mm gauge length extensometer. The loading rate was 120 N/s.

The three test pieces shown in figure 1 (b) were tensile tested. The tensile force and longitudinal strain were continuously recorded during the test. The stress-strain curves were drawn, the upper yield strength R_{eH} and the tensile strength R_m were determined. The values of these mechanical properties are shown in table 2.

Table 2. Mechanical properties of corroded B235 steel rods.

Corrosion method:	Atmospheric corrosion, 25 years			Alternate immersion test, 52 days		
Test piece	Nominal diameter, mm	R_{eH}, MPa	R_m, MPa	Nominal diameter, mm	R_{eH}, MPa	R_m, MPa
1	6.5	272	346	5	259	331
2		266	340		254	327
3		268	345		261	327
Average:		*269*	*344*		*258*	*328*

Figure 4 shows the stress-strain curves of the two types of test pieces as well as the curve of the virgin B235 steel.

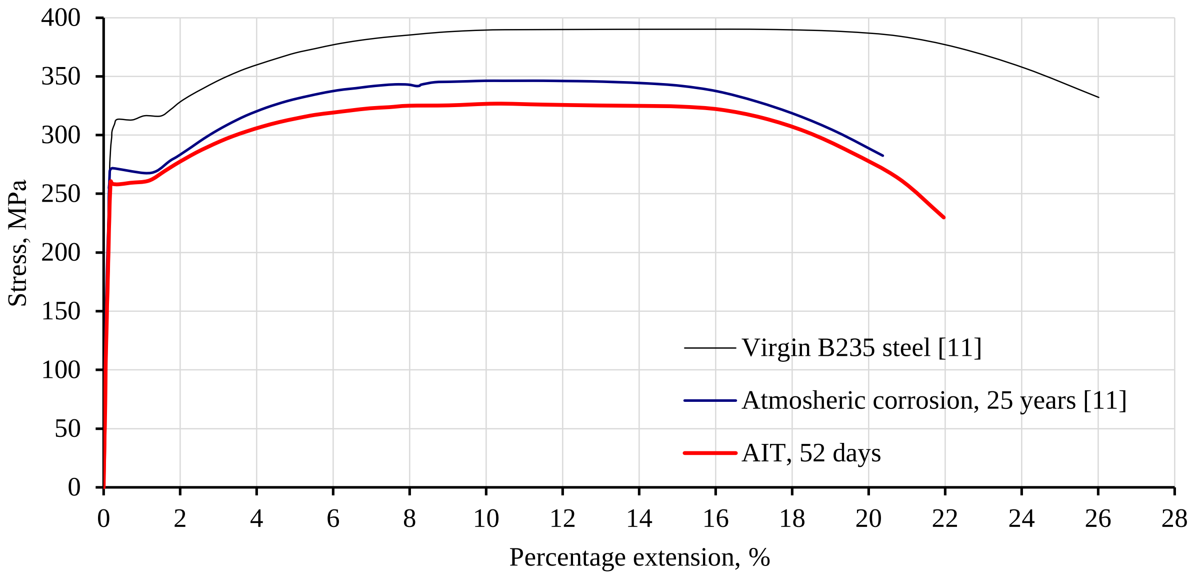

Figure 4. Stress-strain curves – test piece No 1 of each type.

6. Conclusions

AIT artificial corrosion disrupts the circular cross-sections of the test pieces. Pits are formed on the surface, similar in shape and size to those on naturally corroded specimens. The stress-strain curves obtained from test pieces with equal specific mass loss achieved by exposure to natural atmosphere or AIT are also close. The difference in the yield strength R_{eH} and tensile strength R_m is between –4 and –5%. The difference in maximum percentage extension is slightly larger: +7.8%, but there is generally a significant scattering in the experimental results according to this parameter.

The smaller diameter test pieces (5 mm, AIT) have greater percentage cross-section area losses than the larger diameter test pieces (6.5 mm, natural atmosphere). This explains the slightly lower strength of the AIT-exposed test pieces. An additional study is planned to determine the impact of the initial diameter on strength properties of the corroded rods.

The similar relief of the corroded surfaces, as well as the close strength and deformation parameters of B235 steel rods show that 25 years of atmospheric corrosion can be successfully simulated by 52 days accelerated corrosion test with periodic immersion in salt solution.

Acknowledgements

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