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EVALUATION OF THE CORROSION RESISTANCE OF STEEL ELEMENTS IN THE INDUSTRIALLY AGGRESSIVE ENVIRONMENTS USING THE ACCELERATED CORROSION TESTING METHODS[**]

Abstract

This work presents the methods for testing the resistance of materials due to corrosion of structural steel, in the presence of corrosion agents in the immediate vicinity of the industrial complex RTB in Bor. General corrosion testing was performed near the Sulfuric Acid Plant, Electrolytic Refining Plant and next to the automatic air quality monitoring station in Bor for 6 months, as well as in the salt chamber for 120h and 240h and by immersion of samples in electrolyte solution from the Electrolytic Refining Plant for of a month. The results were compared with the standard samples stored in the laboratory. A method based on measuring the loss of mass was used to evaluate the material corrosion resistance. Samples are rectangular, dimensions adopted according to the standard EN 10002-1. The steel used is S235, and its mechanical characteristics were obtained from the tensile test.

Keywords: *corrosion, corrosion resistance, mass loss, comparative analysis*

INTRODUCTION

Methods, based on measuring the loss of mass or measuring the depth of corrosion destruction of samples that have been exposed to an aggressive environment for a certain period of time, are most often used to evaluatethe corrosion resistance of metals. The corrosion resistance degree of metals can be very reliably determined by testing the mechanical properties of metals. The procedure is reduced to comparing the individual mechanical characteristics of two groups of samples: groups of samples exposed to the action of certain aggressive agents, and groups of samples not exposed to this action. [4]

Research on corrosion in the industrially polluted environments is very important, since corrosion is a factor that affects the load-bearing capacity and durability of steel structures, which causes the huge costs for the maintenance of structures. The corrosion process develops the fastest during the winter months due to the increase in concentration of pollutants in the air, such as SO_2, CO_2, chloride ions and dust. Various combinations of these factors are typical of the industrial environment. The most important climatic factors that affect the corrosion process are relative humidity, number of sunny hours, air and metal

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surface temperature, wind speed and duration and frequency of rain, dew and fog. Condensation is considered as an important cause of metal corrosion, especially indoors. Its formation depends on relative humidity and temperature changes.

The character and speed of corrosion, in addition to the above factors, are greatly affected by the stress state of an observed metal element. Tests have shown that the tensile stresses in particular have a great effect on the acceleration of corrosion process. This is explained by a destruction of protective oxide coating and formation of microcracks. In such cases, the stress corrosion is referred to.

There are a number of corrosive destructions, namely: surface uniform corrosion, surface uneven corrosion, local corrosion-shallow, local corrosion-deep, point corrosion, subsurface corrosion, selective corrosion, intercrystalline corrosion and transcrystalline corrosion. The cases of simultaneous action of several types of corrosion are also possible, with a particularly dangerous combination within which the stress corrosion is also present.

All corrosion destructions affect the load-bearing capacity of steel structures, and thus increases the maintenance costs. Laboratory tests have a task of giving approximate results as well as corrosion tests on atmospheric cells, only for accelerated weather.

The subject of this paper research is the physical and mechanical properties of structural steel due to the corrosion propagation caused by the presence of corrosion agents in the industrial environment of RTB Bor. General corrosion testing is performed in the field, in selected atmospheric corrosion stations, near the Sulfuric Acid Plant, Electrolytic Refining Plant (Electrolysis) and next to the automatic air quality monitoring station in Bor (Figure 1). Also, a number of samples, steel tubes, were tested in chambers for accelerated aging and by immersion in electrolytes. All samples were compared to the standard samples stored in the laboratory conditions. Methods, based on measuring the loss of mass and testing the mechanical properties of samples exposed to the aggressive environments over time, will be used to evaluate the corrosion resistance of metals.

EXPERIMENT

Tests were performed on steel tubes of adopted dimensions on the basis of the standard EN 10002-1 (Figure 1). The material used is the commercial steel S235. Chemical composition was tested on a standard measuring, size 30x40x8mm, by the use of optical emission spectrometry and is given in the following Table (Table 1):

Table 1 *Chemical composition of tested steel*

Steel designation	C	Si	Mn	Cr	Mo	Ni	P	S
	0.12	0.012	0.27	0.012	0.003	0.013	0.005	0.008
S235	Al	Cu	B	Nb	V	Ti	Sn	Fe
	0.036	0.041	0.0003	<0.004	<0.0005	<0.001	0.0006	99.40

In this paper, 8mm thick samples were analyzed. All tested samples, from all places, were previously measured, exposed to the appropriate aggressive environments, cleaned and then measured again. In general, after 6 months of exposure [3], all tubes were 100% covered with corrosion.

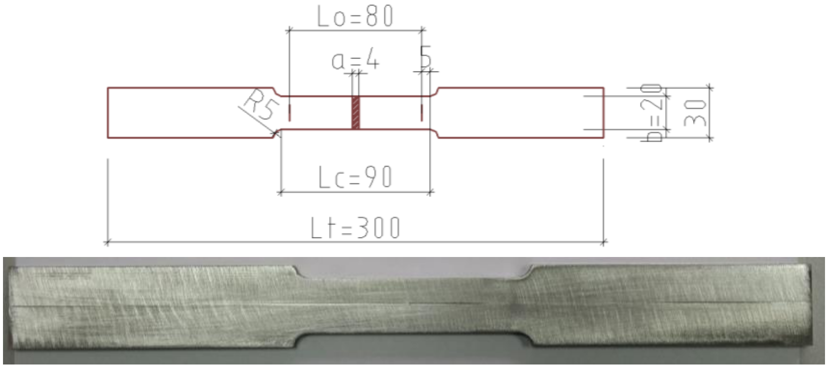

Figure 1 *Dimensions and appearance of sample before exposure*

Mechanical characteristics were obtained by the tensile testing of all tubes. Tensile testing is performed on the universal testing machines or torches with hydraulic or mechanical drive. The main parts of tensile testing machines are: stand (or frame), loading device, force measuring device and device for automatic drawing of force-deformation diagrams. A "Servo-hydraulic Universal Testing Machine Instron 1332 with FastTrack8800control system" was used in the experiment. The maximum tensile force is 100 kN.

ACCELERATED METHODS FOR CORROSION TESTING

It is desirable that the corrosion resistance tests are performed in the real operating conditions or on the atmospheric corrosion stations. These are specially selected places, most often with an industrial atmosphere, where samples are exhibited and changes in them and monitored due to corrosion. Atmospheric corrosion stations perform not only the tests of resistance of metals, alloys and their welded joints to the general corrosion, but also the tests of other types of corrosion (pitting, selective corrosion, stress corrosion, etc.). Tests on corrosion stations are long-lasting, so the accelerated laboratory tests are often used, during which corrosion destruction occurs in a relatively short time. Acceleration of corrosion processes is achieved by the action of aggressive components, imposition of a certain electrode potential, increasing temperature and degree of humidity, etc. The corrosion testing methods used in this paper are explained below.

Continuous immersion in solution

This is technically the simplest method. The time required to reach the desired level of corrosion damage to material depends on the chemical composition of solution and corrosion resistance of t sample. During these tests, the acceleration of corrosion process is achieved by continuous or alternating immersion of samples in solutions of a certain composition, at certain temperature. The tests are most often performed in chloride solutions (NaCl, $FeCl_3$), usually with the addition of an oxidizing agent (H_2O_2, $KCrO_4$). In this way, not only the general corrosion of metals, alloys and their welded joints is tested, but also the other types of corrosion (pitting, stress corrosion, etc.).

In this work, electrolyte solutions from the Electrolysis were used as a corrosive medium, which fulfilled the condition that solution corresponds to the industrial environment. The immersion was continuous, lasting for a month.

Accelerated aging chambers

In the chambers for corrosion tests, the acceleration of corrosion process is done increasing the temperature and relative humidity of air, with introduction the aggressive components into the atmosphere of chamber. The most important tests are in a wet chamber, chamber with SO_2 and in salt chamber (NSS, ASS and CASS method). All these methods are used to test not only the general corrosion of metals and alloys and their welded joints, but also to test the other types of corrosion, such as pitting, corrosion in gaps, stress corrosion, etc. In this experiment, a test was performed in the salt chamber "Industrial filter" with an external compressor according to ISO 9227, with neutral spray (NSS test) for 120h and 240h. The concentration of sodium chloride solution is 5% (pH 6.5 ÷ 7.2), at a temperature of 35°C (± 2°C).

Scab test

This method is used for accelerated testing in the external field conditions, in selected atmospheric corrosion stations. In this experiment, locations near the Sulfuric Acid Plant, Electrolytic Refining Plant (Electrolysis) and next to the automatic air quality monitoring station in Bor were selected (Figure 1). Exposure of samples (steel tubes) lasted 6 months. Samples are placed on a wooden frame so that they rest on it with the smallest surface. They are placed at an angle of 45 ° to the ground, as a horizontal, and facing south, which in many tests is considered as the position in which the largest surface of sample is affected by corrosion in the longest time interval [2]. The Scab test is the subject of ISO 11474: 2014, which defines repeated spraying of salt solutions. In this experiment, the standard in terms of spraying was deviated, because an attempt was made to obtain the material degradation due to corrosion with real agents in the industrially aggressive environments, with atmospheric conditions in winter months between November and May.

CLEANING OF SAMPLES FROM CORROSION PRODUCTS

Corrosion products from all samples, after exposure, as well as from control, standard, were removed according to the standard SRPS C.A5.005. This standard specifies procedures for removal the corrosion products from metals and alloys, which are created on samples for corrosion testing during their exposure to the corrosive media. The procedures set out in this standard are intended to remove corrosion products without significant removal of the parent metal. This enables accurate determination the loss of metal mass or alloy, which occurs during exposure to the corrosive environments.

An ideal cleaning method involves removing only the corrosion products, while the base metal remains intact. To determine the mass loss of parent metal when removing the corrosion product, the parallel uncorroded, control sample is cleaned by the same procedure as sample under test. By measuring the mass of control sample before and after cleaning, the value of mass loss, caused by cleaning, is obtained and this value is used to correct the mass loss for sample from which the corrosion products are removed.

Figure 2 *Placement of samples in the field*

Chemical cleaning methods involve exposing of samples for corrosion testing to a specific chemical solution that removes corrosion products with minimal dissolution of any parent metal. Chemical cleaning is often performed with prior light brushing of test specimens to remove bulky corrosion products that do not adhere to the substrate. Periodical removal of samples from solution for easy brushing can facilitate the removal of corrosion products that adhere firmly. On the test tubes exposed to the atmospheric effects, first the products were removed mechanically, and then chemically, for duration defined in standard. The reference samples were followed by the same method, according to the recommendations of standard, in order to take into account the mass losses, due to the effect on the base material.

ANALYSIS OF THE RESULTS

The degradation level of mechanical properties and changes in mass due to the corrosion on samples after 6 months of exposure to the atmospheric effects in Bor, at three sites, then on samples exposed 120 h and 240 h in a salt chamber, samples immersed in electrolyte solution for one month and samples stored in the laboratory conditions, are shown in Table 2. Designation E indicates standard samples, A immersed in electrolyte solution, EF samples placed in the Electrolytic Refining Plant, MP samples next to the station of automatic air quality monitoring (in order to further correlate the corrosion level and percentage content of corrosion inhibitors in the air). The AF samples were placed in the immediate vicinity of the Sulfuric Acid Plant. SSI is a designation of samples exposed to the NSS test for 120 hours, and SSII exposed to 240 hours.

Table 2 *Comparative values of change in mass and breaking force on samples from standard, immersed in solution, exposed to the atmosphere and in a salt chamber*

Sample designation		Exposure period	Mass before exposure (g)	Mass after exposure (g)	Mass loss in percent	Breaking force (N)
E	E5	6 months	521.467	521.440	0.005	63597.00
	E6	6 months	513.088	513.056	0.006	62120.00
A	A5	1 month	521.264	489.223	6.147	57798.00
	A6	1 month	518.690	485.432	6.412	57479.00
EF	EF5	6 months	521.256	520.341	0.176	63154.00
	EF6	6 months	503.781	502.714	0.212	61382.00
AF	AF5	6 months	519.034	511.258	1.498	61680.00
	AF6	6 months	521.248	513.691	1.450	61972.00
MP	MP5	6 months	521.210	518.870	0.449	63303.00
	MP6	6 months	513.096	511.491	0.313	62127.00
SSI	SSI5	120h (5 days)	522.374	521.100	0.244	62563.00
	SSI6	120h (5 days)	521.472	520.077	0.268	62126.00
SSII	SSII-5	240h (10 days)	507.020	505.051	0.388	60053.00
	SSII-6	240h (10 days)	510.228	508.441	0.350	60791.00

All of the above samples were premeasured, exposed to the appropriate aggressive media and re-measured to determine the change in mass. Corrosion products from all samples, as well as from control, standard, were removed according to the standard SRPS C.A5.005 in a solution of hydrochloric acid, hexamethyl tetraamine and distilled water. The standard samples, as expected, have negligible weight losses, compared to the other samples that have been exposed to the corrosive agents.

From the above results (Table 2), it is noticeable that the percentage mass loss of samples near the Sulfuric Acid Plant is far higher than on samples located next to the measuring station, which is 4 kilometers away from the plant. Also, the mass loss samples immersed in electrolyte solution from electrolysis is much greater than the mass loss of samples that were placed in the Electrolysis Plant. Therefore, the force that these test tubes can receive is less.

Furthermore, it can be seen from this Table that the weight loss in the test tubes exposed to the atmospheric effects is significantly higher than in the same samples exposed to the effect in salt chamber, for approximately the same values of breaking force that these tubes can receive. This data unequivocally shows that the uniform corrosion is emphasized in samples exposed to the atmospheric effects, which is expected, while the other types of corrosion are present in samples from salt chamber, such as pitting or spot corrosion, which is noticeable on the surface of samples. [1]

However, based on the breaking forces, it can be concluded that the exposure time of 6 months in the industrial environment with increased CO_2 content in the air corresponds to the exposure period in a salt chamber with neutral solution (NSS test) between 120 h and 240 h, since between these values can be reported good correlation. This proves that in accurately conducted laboratory conditions, with greater or lesser accuracy, the atmospheric corrosion of industrial environments can be simulated, thus simplifying and acelerating the experimental process.

CONCLUSION

When comparing samples from different places, one must be very careful. The chosen methods cause different types of corrosion. Those that cause the non-uniform types of corrosion are more complex and require more careful analysis in order to approach the real conditions in the exploitation of steel elements.

The obtained results and data from this work should contribute to the perception and study of bearing capacity and durability of corrosion - weakened steel structures in the industrial environments, where there are many inhibitors of atmospheric corrosion. First of all, it is necessary to check the laboratory accelerated corrosion methods in the real operating conditions, which would reduce the time required to perform the experiments.

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