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Corrosion of the S235JR Carbon Steel after Normalizing and Overheating Annealing in 2.5% Sulphuric Acid at Room Temperature

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Abstract. The low-carbon steels offer economical properties of mean hardness, strength, and low corrosion resistance, but the steel can be welded without restrictions, usually. The structural low carbon steels have a ferritic-perlitic microstructure. The microstructure depends on the manufacturing technology and heat treatments of steel. This steel is not intended for heat treatment. However, due to the technological process, which is welding, the material often overheats. This overheating causes microstructure growth. The effect of larger grains of the steel microstructure is the reduction of its functional properties. Corrosion resistance is an essential factor in structural steel's quality and application. The purpose of this article is to investigate corrosion resistance using weight loss and profile roughness parameters of typical structural steel in grade S235JR in 2.5% sulphuric acid solution in distilled water. Samples were tested after normalizing and superheating annealing. Corrosion tests show that continued corrosion characterizes tested steel in both corrosive environments. Roughness parameters for every one of the research times determine the size of steel corrosion.

Introduction

Low-carbon steel is a very popular construction material. The mechanical, physical, and chemical properties of low carbon steel are influenced by different factors, including chemical composition, manufacturing technology, the morphology of microstructure, inclusions, etc. Steels from the low carbon group are a wide range of industrial applications, mainly as a good welded construction material. The microstructure and properties of these steels are still tested to improve the quality. The structural low carbon steels have a ferritic-perlitic microstructure in normal conditions [1-3].

Steel structures with low-carbon structural steel can be built quickly by welding at a low price, but the main problem is their corrosion protection. Corrosion resistance is an essential factor in structural steel's quality and application. Corrosion processes can extract metal atoms from the metal lattice, which atoms during the process pass to corrosion products. Particularly dangerous is the corrosion causing the local diffusion of metal atoms. The problem is enormous because low-carbon structural steel is sensitive to corrosion. The corrosion rate depends on different environments [1, 4-8]. The risks of losing steel properties due to corrosion occur especially clearly in aggressive atmospheres. In the atmosphere, gaseous pollutants classified as compounds of nitrogen, ammonia, and sulfur, including hydrogen sulfide, occur more and more often [9]. They occur in large amounts, usually around industrial plants. The aggressive factors include sulfur compounds. The activation of corrosive processes by sulfur compounds causes high chemical activity, which is dangerous for metal alloys. Sulfur dioxide dissolved in water creates aggressive SO_3^{2-} ions. In the hydrochloric acid environment, the corrosion rate of carbon structural steel increases intensively with increasing acid concentration and with increasing carbon content in the steel. In addition, the corrosion products of some metal alloys, including iron alloys, promote the rapid oxidation of sulfurous anhydride, contributing to the intensification of corrosion [4, 10, 11].

Another problem affecting the corrosion rate of steel is its grain size. As a result of the production process, e.g. welding, hot-forming, etc., the material may overheat, resulting in grain growth.

One of the corrosive environmental factors is sulfur compounds. They occur mainly in the vicinity of industries polluted by sulfur. Because of this, structural steel has often been tested with sulfur acid on corrosion resistance. Regarding the importance of the problem, this study was carried out to investigate the corrosion resistance of the overheated low carbon structural steel in 2.5% sulphuric acid reaching water at ambient temperature.

The subject of the article may be of interest to a broad audience related to corrosive, aggressive environments at room temperatures, e.g. biotechnologists [12], water supply system conservators [13, 14], and housing infrastructure conservators [15, 16]. The problems of such corrosion are also crucial for the machine industry [17], in particular for the quality management systems implemented in this industry [18, 19] and the latest automation systems for management supported by dense IT networks [20].

Materials and Methods

The experiment was performed on low carbon S235JR (1.0038) steel designation according to EN 10025-2:2004, plate - thickness t = 5.00 mm. The actual chemical composition tested steel is presented in Table 1.

Table 1. *Chemical composition of the S235JR steel*

Mean chemical compositions [wt. %]								
C	Si	Mn	P	S	Cr	Cu	Ni	N
0.19	0.22	0.90	0.03	0.04	0.03	0.02	0.02	0.01

Before experiments, the specimens, after being mechanically cut off with an area of 13 cm2 (40 x 10 x 5 mm), were successively polished with water paper to Ra = 0.32 µm and next cleaned with 95% alcohol.

The samples with ferritic-perlitic microstructure were tested in accordance with the standard dedicated for stainless steel PN EN ISO 3651-1 [21] corrosive media were represented by 2,5% sulphuric acid.

The corrosion rare of the S235JR steel measured in mm/year was calculated with the use of the below formula (1), measured in g/m2 were calculated with the use the below formula (2):

$$r_{corm} = \frac{8760 \cdot m}{S \cdot t \cdot \rho} \tag{1}$$

$$r_{corg} = \frac{10000 \cdot m}{S \cdot t} \tag{2}$$

where:

t – time of soaking in a corrosive solution of 2.5% sulphuric acid water solution [hours],

S – the surface area of the sample (the starting value was assumed) [cm^2],

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M – average mass loss in solution (measured as the difference between initial mass and mass after corrosion time) [g],

P – sample density [g/cm^3].

Two variants of heat treatment were used for the tests. In the first variant, the alloy was normalized at 860°C for 8 minutes and cooled in air. In the second variant, the alloy was superheated, annealed at 1100°C for 30 minutes, and cooled in air.

The corrosion resistance of the S235JR steel in 2.5% sulphuric acid was tested using weight loss. The mass of samples was measured by Kern ALT 3104AM digital laboratory precision scales with an accuracy of 0.0001 g.

Profile roughness parameters were analyzed according to the PN-EN 10049:2014-03 standard (Measurement of roughness average Ra and peak count RPc on flat metallic products) by the Diavite DH5 profilometer.

Results and Discussion

The microstructure of raw overheated S235JR steel is presented in Fig. 1. The effect of overheating on the microstructure presents the enlarged, equaxial grains ferrite phase (white area) at the background of the perlite (a gray area).

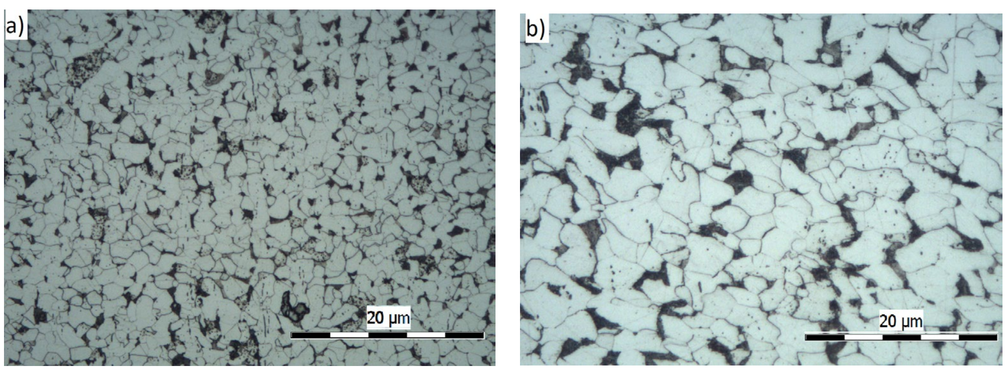

***Fig. 1.** Microstructure of S235JR: light etched ferrite and dark etched perlite: a) after normalizing annealing, b) after overheating*

Influence time of soaking the S235JR structural steel in 2.5% sulphuric acid at ambient temperature on the relative mass loss (RML) with regression equation and correlation coefficient r is presented in Fig. 2.

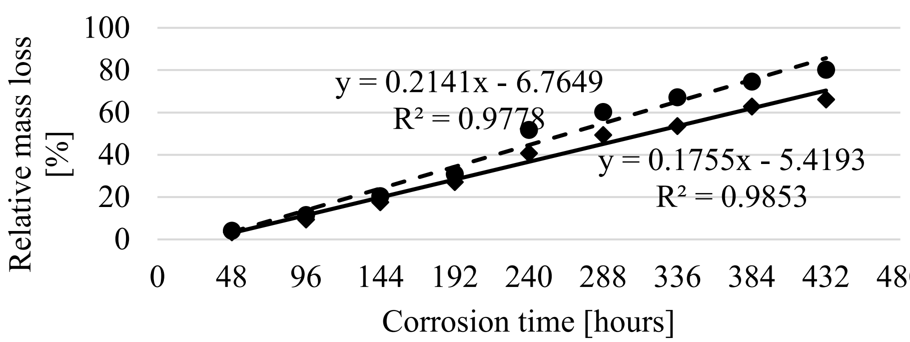

***Fig. 2.** Influence time of soaking the S235JR structural steel in 2.5% sulphuric acid on the relative mass loss (RML) at ambient temperature; solid line alloy after normalizing annealing, dashed line alloy after overheating*

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Influence time of soaking the S235JR structural steel in 2.5% sulphuric acid at ambient temperature on the corrosion rate measured in mm per year with the regression equation and correlation coefficient r is presented in Fig. 2 and the corrosion rate measured in gram per m^2 with the regression equation and correlation coefficient r is presented in Fig. 3.

Profile roughness parameters of S235JR steel after corrosion tests in 2,5% sulphuric acid the regression equations and correlation coefficients r are presented in Fig. 4 with Ra – arithmetical mean roughness value [µm], Rp – maximum roughness depth [µm] for time range: 48, 96, 144, 192, 240, 288, 336, 384 and 432 hours of soaking is presented in Fig. 4 and for Rq - mean peak width [µm], Rt - total height of the roughness profile [µm]in Fig. 5.

Relative mass loss (RML – Fig. 1) in the initial period of samples soaking is similar for both states of heat treatment. As the soaking time increases, the difference becomes more and more apparent. Steel after superheating annealing loses its corrosion resistance (Fig. 1) faster than steel after normalizing. This is due to the larger grains obtained after overheating the steel. Analyzing the corrosion rates (Fig. 2 and Fig. 3), it was found that in the soaking process up to 192 hours, the corrosion rate increased for the steel after overheating compared to the normalized steel. From 240 hours of soaking, the corrosion rate of the steel after overheating stabilizes compared to the corrosion rate of normalized steel. It follows that coarse grain steel in the initial period corrodes at a higher rate than fine grain steel. This difference stabilizes over time. Nevertheless, a higher corrosion rate of coarse grain steel than that of fine grain steel was observed.

The analyzed roughness parameters indicate that steel increases the surface roughness with increasing soaking time (Fig. 4 and Fig. 5).

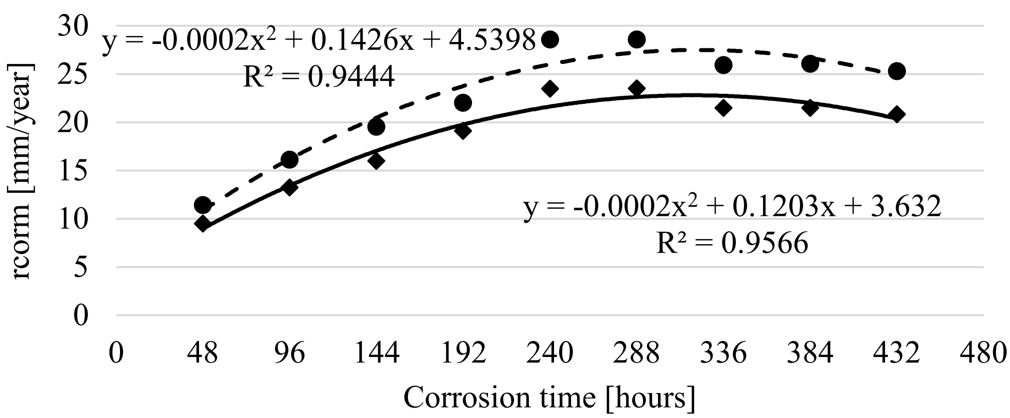

Fig. 3. *Influence time of soaking the S235JR structural steel in 2.5% sulphuric acid at ambient temperature on the corrosion rate measured in mm per year; solid line alloy after normalizing annealing, dashed line alloy after overheating*

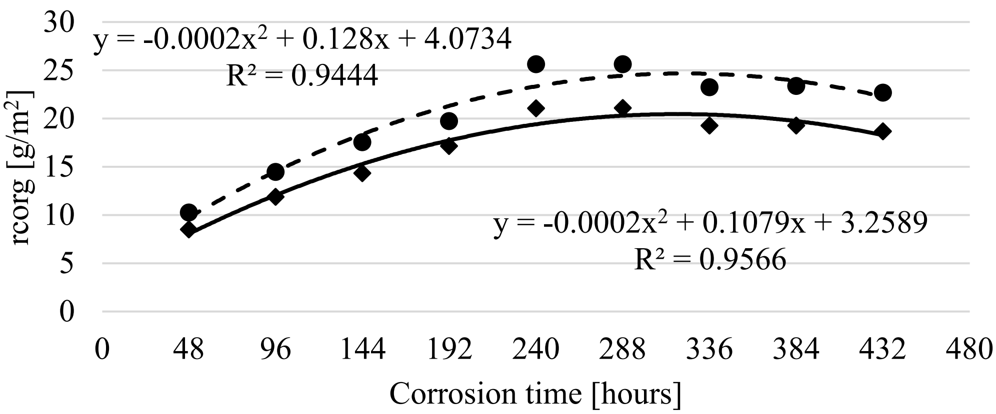

Fig. 4. *Influence time of soaking the S235JR structural steel in 2.5% sulphuric acid at ambient temperature on the corrosion rate measured in gram per m^2; solid line alloy after normalizing annealing, dashed line alloy after overheating*

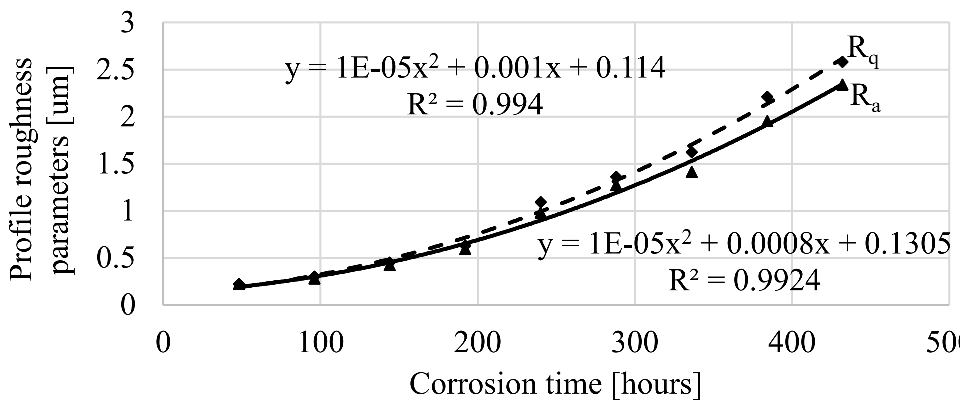

Fig. 5. *Profile roughness of S235JR steel after corrosion tests in 2.5% sulphuric acid at ambient temperature for different corrosion times: Ra - arithmetical mean roughness; alloy after overheating*

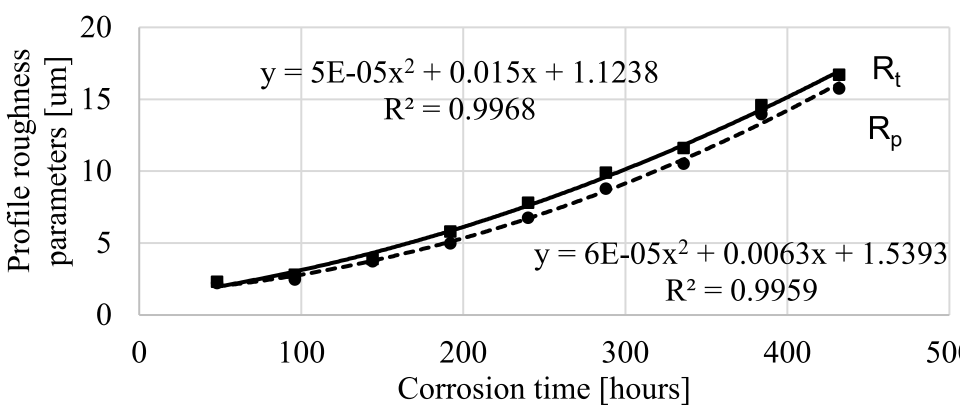

Fig. 5. *Profile roughness of S235JR steel after corrosion tests in 2.5% sulphuric acid at ambient temperature for different corrosion times: Rp - maximum roughness depth [µm], Rt - total height of the roughness profile [µm]; alloy after overheating*

Conclusions

1. The research results show that weight loss of S235JR steel soaking in 2.5% sulphuric acid at ambient temperature depends on the type of heat treatment (microstructure morphology).
2. The roughness of the sample increases, but the corrosion rate measured as a corrosion velocity decreases with time.
3. When steel is overheated, it partially loses its corrosion resistance.

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