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Degradation of R35 Steel in 5% NaCl environment at 10°C

LIPIŃSKI Tomasz [1, a *] and ULEWICZ Robert [2,b]

[1]University of Warmia and Mazury in Olsztyn, Faculty of Technical Sciences Department of Materials and Machines Technology, Olsztyn, Poland

[2]Czestochowa University of Technology, Faculty of Management, Department of Production Engineering and Safety, Częstochowa Poland,

[a]tomekl@uwm.edu.pl, [b]robert.ulewicz@pcz.pl

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Abstract. Carbon steels are willingly used due to the favorable price-performance ratio. They usually do not operate in a non-corrosive state. However, there are products that are hard to protect against corrosion in their entirety. These products include pipes. It is easy to protect the outer layer of the pipe against aggressive environment. The problem with protection is caused by their inner surface. Typically, the working medium is the protective factor, usually filling the internal volume of the pipes completely. It happens, however, that corrosion occurs as a result of long storage of pipes in warehouses, usually in the open air. They are also used as working elements with partial liquid filling. They are then exposed to the environment. One of the corrosive agents is NaCl. The paper presents the results of corrosion rate tests of samples taken from R35 pipes in the environment of a 5% aqueous solution of NaCl at 10°C. The analyzes were carried out based on the determination of mass losses. On the basis of the tests carried out, the relationship between the rate of corrosion and the soaking time of the samples was determined. It was confirmed that on the basis of roughness parameters it is possible to draw conclusions about the suitability of steel for further operation.

Introduction

Non-alloy structural steels are characterized by sufficient mechanical parameters for common applications at a low price. For this reason, they are widely used for structures carrying low loads. One of the examples of the use of unalloyed steels are pipelines for the transmission of media, mainly water. The external surface of the pipeline is protected against the influence of the environment. Paint coatings are usually the main protection. The inner surface is usually not covered with a varnish layer. The reason is the flowing medium, which, while moving in relation to the pipeline, can wash out the applied coating. complete filling of the pipeline with liquid, and thus separating its surface from air access, reduces the corrosion process. It also happens that the medium flows in the pipes and does not completely fill their surface. This is one of the reasons for the corrosion of the inner surface of pipelines. Corrosion-resistant steels created have resistance only in specific conditions. Their corrosion resistance depends i.a. on chemical ingredients, microstructure, surface condition [1-7].

In practice, the process of material degradation attributed to corrosion is more complex. By the term corrosion, researchers describe the degradation of a material resulting from reactions occurring from the metal surface, usually of a chemical or electrochemical nature [8-11]. In exploited pipelines with a flowing medium, the process of wear of the wall surface in contact with the working medium occurs. The literature describes this process as erosion. Thus, the natural wear of the pipeline is a combination of corrosion and mechanical wear, i.e. erosion [12-14].

The corrosion rate first of all is depends of different environment [6-10]. One of the corrosive environmental factors are chlorides. They are mainly found on the coast as an aerosol of sea water, and in large quantities in large industrial areas. Because of this structural steel has been often tested with the NaCl on corrosion resistance [15-24]. Corrosion mechanism of such steel is not as complex as steel with increased corrosion resistance. Its chemical composition and microstructure indicate susceptibility to surface corrosion [25-27]. Corrosion, though the least dangerous of known corrosion types, causes systematic material destruction by oxidation. Material losesits volume and, therefore strength and stiffness. Although it does not need to carry special loads, it ultimately leads to corrosive wear of the component [18,28].

In the literature, there are a number of test results for corrosion of general-purpose steels in various aggressive environments [29-38]. The obtained results are developed on the basis of various algorithms of their presentation. As a result, there are a number of equations describing the rate of corrosion. In the paper, it was decided to present the research results in a study based on the criteria describing the corrosion of corrosion-resistant steels. The aim of the paper is to develop the relationship between the corrosion rate of R35 steel commonly used for pipelines and the soaking time in 5% NaCl at 10°C.

The phenomenon of corrosion [39-41], influenced by both organic and inorganic factors, is extremely detrimental. It results in significant maintenance and repair costs in the energy sector [42-44], biotechnological industry [45-47], and poses risks in hydraulic power systems [48-50]. Corrosion prevention is crucial to mitigate these negative effects and ensure the efficient operation of various systems. One approach to combat corrosion is the application of special coatings [51-53]. These coatings provide a protective barrier that inhibits the interaction between the corrosive environment and the underlying material.

Another method to prevent corrosion is through the design and control of surface morphology [54-56]. By manipulating the surface features and topography, the corrosive attack can be minimized, thereby extending the lifespan of the materials. Laser technology offers precise control over the surface morphology, allowing for tailored surface properties that resist corrosion.

To ensure the effectiveness of corrosion prevention strategies, the use of appropriate experimental design methodology is essential [57-59]. Design of Experiments (DOE) provides a systematic approach to investigate the effects of various factors on corrosion resistance, even with non-classic approaches [60-61]. By carefully designing experiments and analyzing the results, reliable data can be obtained with reduced uncertainty.

The implementation of effective corrosion prevention measures not only has positive implications for the environment [62] but also influences the anticipated scenarios of potential failures [63-65]. By reducing the risk of corrosion-related failures, the overall reliability and safety of systems are improved. This, in turn, leads to modifications in management processes to incorporate the new corrosion prevention strategies [66,67].

Material and Methods

The experiment was performed on popular carbon steel intended for the production of pipes in the R35 grade designation according to PN-89/H 84023/07 [68] and manufactured in accordance with PN-80/H-74219 [69]. Samples were collected from a pipe measuring 114.3 mm in diameter and 8.0 mm in wall thickness. The samples were mechanically cut to maintain consistent width measurements on both the outer and inner diameters of the pipe. The parallelism of the longitudinal axis of the samples with the axis of symmetry of the pipe was maintained. After cutting, the samples were ground at the cut to Ra less than 1.25 µm. The outer and inner surfaces of the pipe, prior to sampling, were ground in the direction transverse to the axis of the pipe with a rotary disc equipped with sandpaper strips to Ra below 1.25 µm. The real chemical composition tested steel is presented in Table 1. Average mechanical properties at ambient temperature are presented in Table 2.

Before experiments, the specimens after mechanically cut off with an area of 15.2 cm^2 (40 x 10 x 7.2 mm) were successively cleaned with water and 95% alcohol.

Table 1. *Chemical composition of the R35 steel*

Mean chemical compositions [wt. %]							
C	Si	Mn	P	S	Cr	Cu	Ni
0.09	0.53	0.21	0.030	0.035	0.01	0.12	0.01

Table 2. *Mechanical properties at ambient temperature of the R35 steel*

Mechanical properties			
R_{eH}	R_m	A	HB
MPa	MPa	%	HB
224	368	26	168

The samples with ferritic-perlitic microstructure were tested accordance with standard dedicated for stainless steel PN EN ISO 3651-1 [70] corrosive media were represented by 5% NaCl.

The corrosion rare of the S235JR steel measured in mm/year was calculated with the use of the below formula (1), measured in g/m^2 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 5% NaCl water solution [hours],
S - surface area of the sample (the starting value was assumed*)* [cm^2],
m – average mass loss in solution (measured as the difference initial mass and mass after corrosion time*)* [g],
ρ - sample density [g/cm^3].

The corrosion resistance the R35 steel in 5% water solution NaCl was tested using weight loss. The mass of samples was measured by Kern ALT 3104AM digital laboratory precision scales with accuracy of measurement 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 metallic flat products) by the Diavite DH5 profilometer.

Results

Surface roughness of R35 steel after soaking in 5% NaCl at 10°C with: Ra - arithmetical mean roughness value [µm], Rq - mean peak width [µm] and Rp - maximum roughness depth [µm], Rt - total height of the roughness profile [µm] for time range: 48, 96, 144, 192, 240, 288, 336, 384 and 432 hours of soaking are respectively presented in Fig. 1 and Fig. 2.

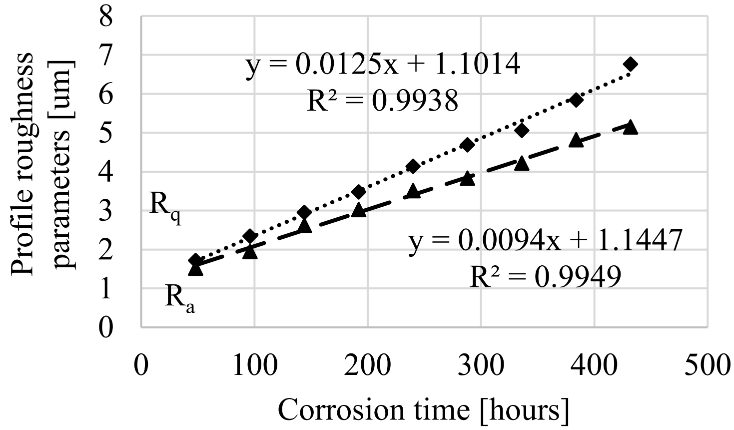

Fig.1. *Profile roughness of R35 steel after corrosion tests in 5% NaCl water solution at 10ºC for different corrosion time: Ra - arithmetical mean roughness value [µm], Rq - mean peak width [µm].*

Influence time of soaking the R35 structural steel in 5% NaCl water solution at 10ºC on the relative mass loss (RML) with regression equation is presented in Fig. 3.

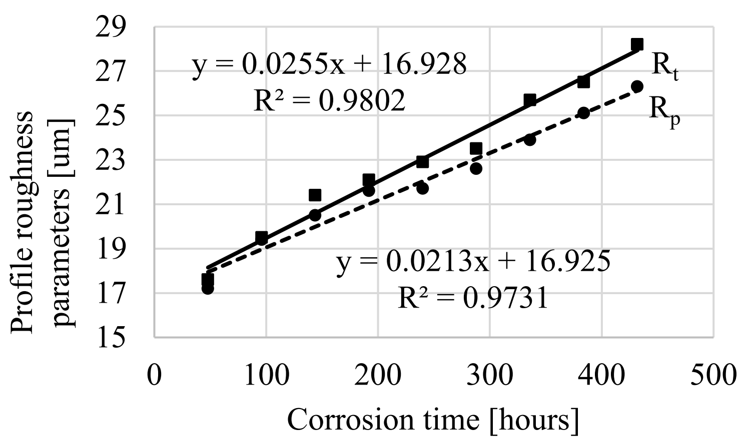

Fig.2. *Profile roughness of R35 steel after corrosion tests in 5% NaCl water solution at 10ºC for different corrosion time: Rp - maximum roughness depth [µm], Rt - total height of the roughness profile [µm].*

Influence time of soaking the R35 structural steel in 5% NaCl water solution at 10ºC on the corrosion rate measured in mm per year with regression equation is presented in Fig. 4. Influence time of soaking the R35 structural steel in 5% NaCl water solution at 10ºC on the corrosion rate measured in gram per m^2 with regression equation is presented in Fig. 5.

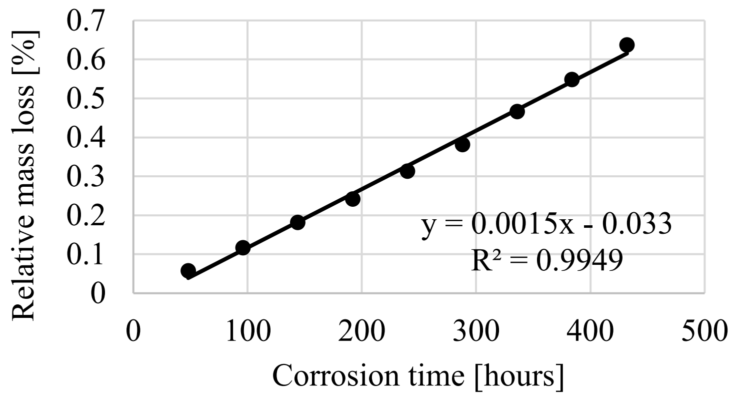

Fig.3. *Influence time of soaking the R35 structural steel in 5% NaCl water solution at 10ºC on the relative mass loss (RML).*

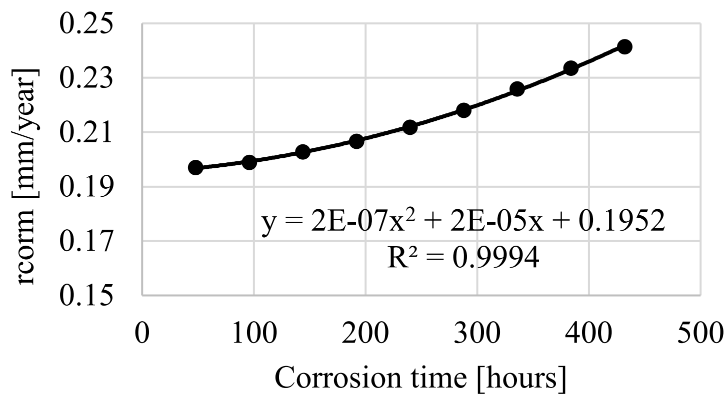

Fig.4. *Influence time of soaking the R35 structural steel in 5% NaCl water solution at 10ºC on the corrosion rate measured in mm per year.*

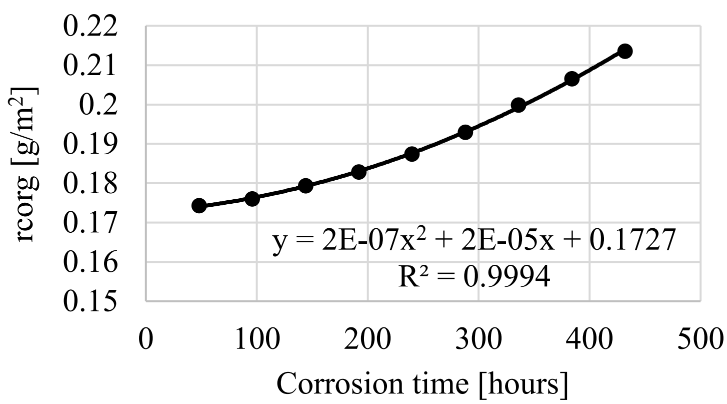

Fig.5. *Influence time of soaking the R35 structural steel in 5% NaCl water solution at 10ºC on the corrosion rate measured in gram per m^2.*

Summary
Based on the test results and their statistical analysis, it was found that all the analyzed parameters of the surface condition, which are represented by roughness and relative mass loss due to soaking R35 steel in 5% NaCl at 10ºC, can be presented with sufficient statistical accuracy using the first order function. This statement confirms the directly proportional relationship between surface roughness and sample soaking time.

Based on the analysis of the corrosion rate in Figs. 4 and 5 and the regression equations describing these relationships, it was found that the corrosion rate increases with the increase in the time of keeping the samples in the NaCl solution. Combining this fact with the increase in roughness, it can be assumed that the increase in the corrosion rate with the passage of soaking time is due to the increasing development of the surface of the tested samples. This development increases with the passage of soaking time, which entails an increase in the rate of corrosion.

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