CORROSION OF S235JR STEEL IN NACL ENVIRONMENT AT 3 °C

LIPIŃSKI Tomasz[1]

[1]*University of Warmia and Mazury in Olsztyn, The Faculty of Technical Sciences, Olsztyn, Poland, EU*
tomaszlipinski.tl@gmail.com

Abstract

Steel S235JR is one of the most popular structural material using on welding constructions. The microstructure of this steel consists of two phases: ferrite and perlite. This is the reason for this steel's low resistance to a number of aggressive environments. Despite this weakness, this steel is widely used in industry. The reason for its popularity is relatively low price and ease of joining in the process of manufacturing welded constructions. S235JR steel is often used in construction works in the NaCl environment. The corrosive processes occurring in the sodium chloride environment depend on the concentration and the state of the environment. A lot of papers showing corrosion processes in this environment use NaCl as an aerosol. Industry also needs information on the corrosion resistance of this steel in aqueous solution of NaCl. The experiment was performed with low carbon S235JR (1.0038) steel designation according to EN 10025-2:2004, plate - thickness t = 5 mm. Steel was held in aqueous solution for 432 hours testing its wear every 48 hours. Corrosion tests show that tested steel in both corrosive environments are characterized through a continue corrosion. Roughness parameters for every one of research times are determined and the level of steel corrosion. Loss of weight during the steel retention process in NaCl was determined in g / m^2 and mm / year. The dependence of corrosion time on steel surface quality was determined.

Keywords: Steel, structural steel, corrosion, corrosion rate, roughness

1. INTRODUCTION

Low-carbon structural steels very often are uses for construction elements. For good weldability they have low contents of carbon and alloying elements. Such chemical composition provides them with a ferritic-pearlitic microstructure. Thus, in practice, the microstructure of these steels, apart from the impurities, is composed of two phases: ferrite and secondary cementite. The presence of these phases side by side causes lowering of corrosion resistance of this steel group [1-6]. The main problem with the use of these steels is their tendency to corrode. This disadvantage greatly limits their application. Corrosion not only lowers the aesthetics of the structure but also reduces its strength, which over time leads to the need for accelerated material wear [7-12]. A typical representative of this group is S235JR steel. This steel is uses inter alia for construction elements, bridges, tanks, pressure pipes, grids, reinforcing bars for concrete. Since the range of these steel applications is very wide, their working conditions are also different. One of the corrosive agents in which S235JR steels work is the aqueous NaCl solution. Variable factors of corrosion process may be: the type of solution, its concentration, electrochemical parameters, operating temperature [3, 12].

The literature gives a lot of information about corrosion steels in air with 3 % NaCl [13-16], but very little information on the corrosion structural steels in NaCl solution in water. Because of this, it was decided to conduct tests on this process. The aim of the research was to present the corrosion resistance of S235JR steel in 5, 15 and 20% aqueous NaCl solution at 3 °C.

2. MATERIALS AND METODS

The experiment was performed with low carbon S235JR (1.0038) steel designation according to EN 10025-2:2004 [17], plate - thickness t = 5.0 mm. The microstructure of S235JR steel is composed with two phases:

the elongated ferrite phase at the background the perlite. The chemical composition of the 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

Real mechanical properties at ambient temperature of the S355JR steel, according to EN 10025-2:2004 is presented in **Table 2**.

Table 2 Mechanical properties at ambient temperature of the S235JR steel

Mechanical properties		
R_{eH}	R_m	A
MPa	MPa	%
247	386	27

Before experiments, the test of pieces with an area of 13 cm^2 (40 x 10 x 5 mm) were successively polished with emery paper to about R_a = 0.6 μm, next cleaned with 95 % alcohol.

The samples with ferritic-perlitic microstructure were tested accordance to standard dedicated for stainless steel PN EN ISO 3651-1 [10, 18-20]. Corrosion test in 5, 15 and 20 % NaCl water solution medium was tested by measurement of loss in mass (Huey test).

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

$$r_{corm} = \frac{87600 \cdot m}{S \cdot t \cdot \rho} \tag{1}$$

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

where:

t - time of corrosion test (for each sample counted from zero) [hours],
S - surface area of the sample [cm^2],
m - average mass loss in corrosion process [g],
ρ - sample density [g / cm^3].

The influence of NaCl on the S355JR steel corrosion resistance was investigated using weight loss. The mass of samples were measured by Kern ALT 3104AM general laboratory precision balance with accuracy of measurement 0.0001 g. Every with measurements was repeated five times.

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

3. RESULTS AND DISCUTTIONS

Exemplary profile roughness of S235JR steel is presented in **Figure 1**.

Arithmetical mean roughness (R_a) value of S235JR steel in 5, 15 and 20 % NaCl at temperature of 3 °C between 48 to 432 hours with determination of coefficient R^2 is presented in **Figure 2**.

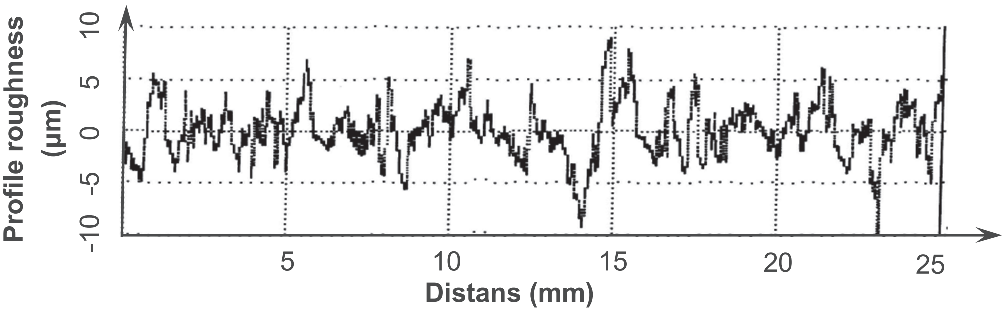

Figure 1 Profile roughness of S235JR steel after corrosion tests in 20 % NaCl and time 432 hours

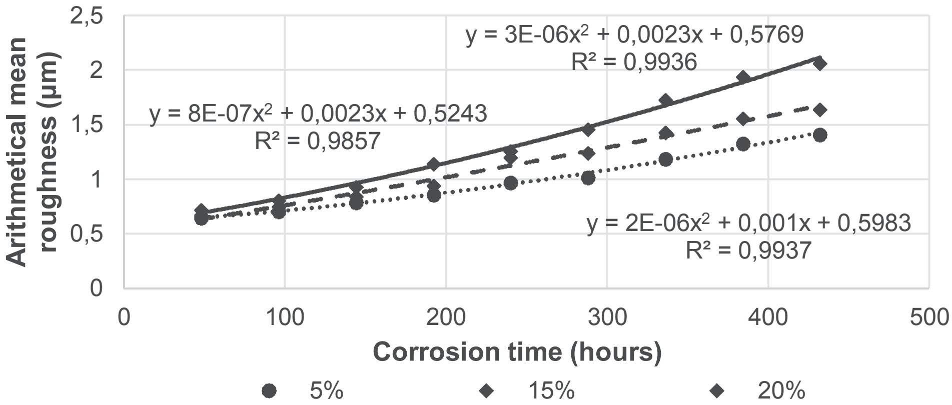

Figure 2 Arithmetical mean roughness (R_a) value of S235JR steel after corrosion tests in 5, 15 and 20 % NaCl at temperature of 3 °C

Mean peak width (R_q) value of S235JR steel in 5, 15 and 20 % NaCl at temperature of 3 °C from 48 to 432 hours with determination of coefficient R^2 is presented in **Figure 3**.

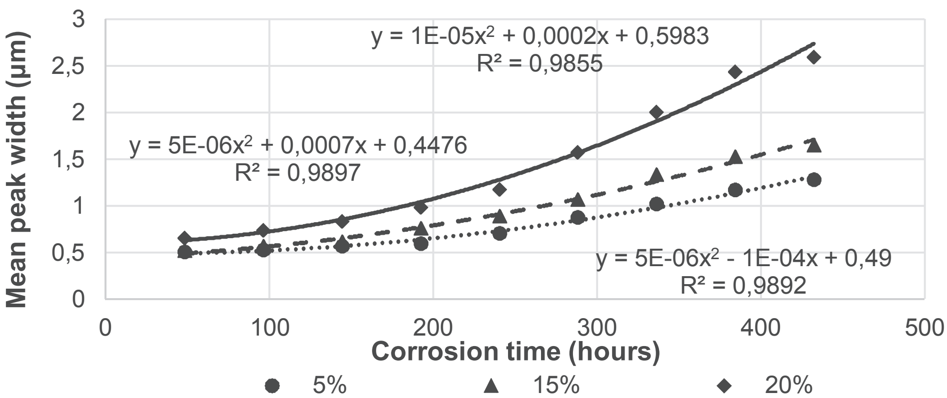

Figure 3 Mean peak width (R_q) value of S235JR steel after corrosion tests in 5, 15 and 20 % NaCl at temperature of 3 °C

Maximum peak height (R_p) value of S235JR steel in 5, 15 and 20 % NaCl at temperature of 3 °C from 48 to 432 hours with determination of coefficient R^2 is presented in **Figure 4**.

Total height of the roughness profile (R_t) value of S235JR steel in 5, 15 and 20 % NaCl at temperature of 3 °C from 48 to 432 hours with determination of coefficient R^2 is presented in **Figure 5**.

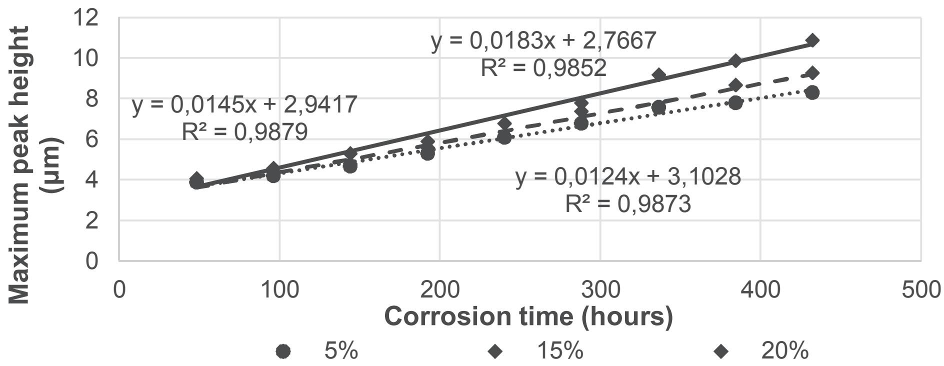

Figure 4 Maximum peak height (R_p) value of S235JR steel after corrosion tests in 5, 15 and 20 % NaCl at temperature of 3 °C

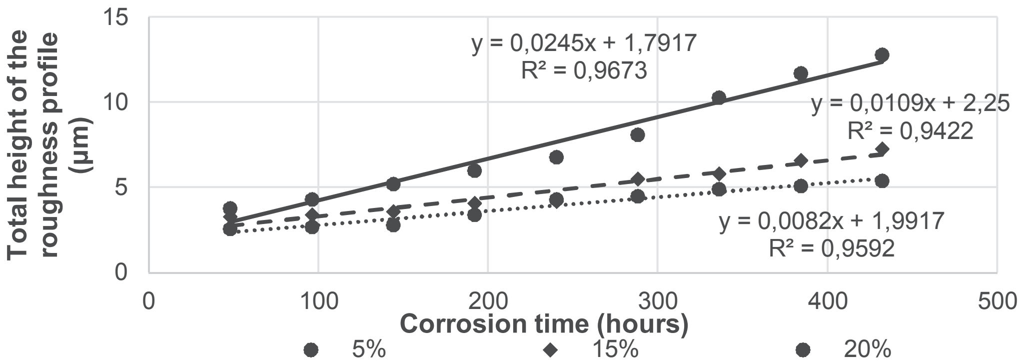

Figure 5 Total height of the roughness profile (R_t) value of S235JR steel after corrosion tests in 5, 15 and 20 % NaCl at temperature of 3 °C

Effects of corrosion time on the relative mass loss (RML) of S235JR steel after corrosion tests in 5, 15 and 20 % NaCl at temperature of 3 °C from 48 to 432 hours with determination of coefficient R^2 is presented in **Figure 6**. Relative mass loss is the quotient of mass loss and initial mass expressed as a percentage.

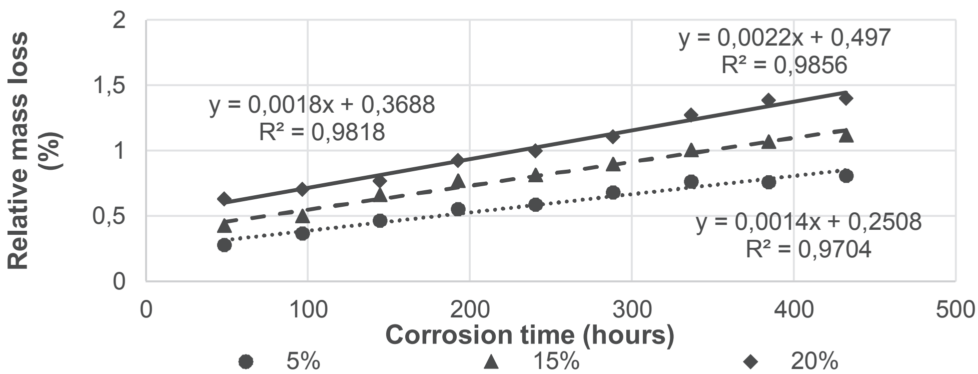

Figure 6 Effects of corrosion time on the relative mass loss (RML) of S235JR steel after corrosion tests in 5, 15 and 20 % NaCl at temperature of 3 °C

Effects of corrosion time on the corrosion rate measured in mm per year of S355JR steel after corrosion tests in 5, 15 and 20 % NaCl at temperature of 3 °C from 48 to 432 hours with determination of coefficient R^2 is presented in **Figure 7**.

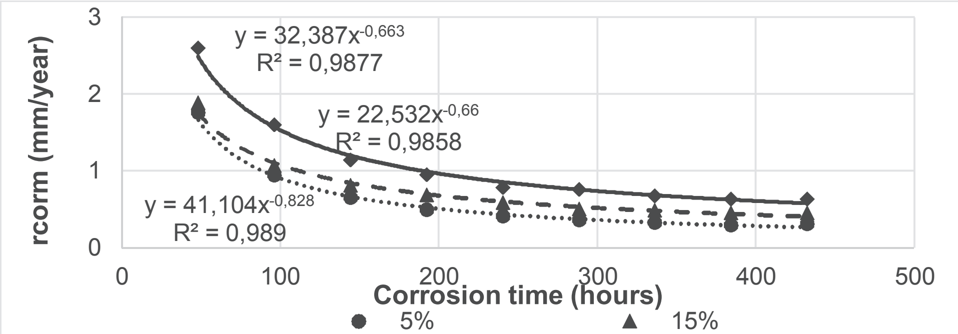

Figure 7 Effects of corrosion time on the corrosion rate of S235JR steel after corrosion tests in 5, 15 and 20 % NaCl at temperature of 3 °C

Effects of corrosion time on the corrosion rate measured in gram per m^2 of S235JR steel after corrosion tests in 5, 15 and 20 % NaCl at temperature of 3 °C from 48 to 432 hours with determination of coefficient R^2 is presented in **Figure 8**.

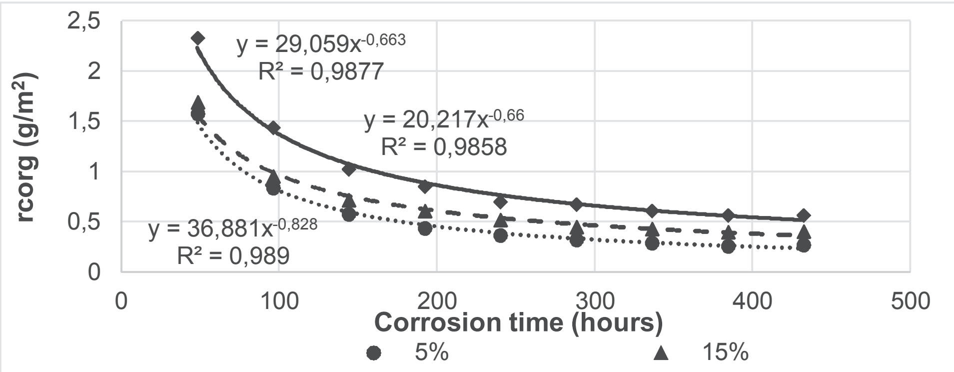

Figure 8 Effects of corrosion time on the corrosion rate of S235JR steel after corrosion tests in 5, 15 and 20 % NaCl at temperature of 3 °C

4. CONCLUSION

- The results of the tests indicate that the loss of weight of S235JR steel at tested temperature are depends of time of corrosion and on temperature of environment. Its indicator is relative mass loss.
- Analyzing the course of changes in roughness, it was found that its description of the function of the first degree is statistically adequate and has a high degree of fit (R^2>0.95).
- The obtained roughness curves in the first corrosion period are proportional. In the second period of corrosion, there was more and more roughness in each subsequent unit of time. For this reason, the description of the curves of the roughness as a function of the second degree is more accurate.
- Equations describing the corrosion functions expressed in mm/year and g / m^2 are similar. Differences depend only on their position relative to the corrosion rate expressed in different units. Therefore, choosing one of these functions for the same corrosion conditions is optional (free).
- Counted (for each sample) from zero time of corrosion test showed a reduction in corrosion rate. In this way based on the graph or equation it is possible to estimate total corrosion rate at any time, counted from the beginning of the corrosion measurement.
- By using equations describing material roughness or corrosion rate, it is possible to determine conditions for automatic control of the condition of an object.

REFERENCES

[1] AL-DUHEISAT, S. A., EL-AMOUSH, A. S. Effect of deformation conditions on the corrosion behavior of the low alloy structural steel girders. *Materials and Design,* 2016, vol. 89, pp. 342-347.

[2] NAVEEN, E., RAMNATH, B. V., ELANCHEZHIAN, C., MOHAMED NAZIRUDEEN, S.S. Influence of organic corrosion inhibitors on pickling corrosion behaviour of sinter-forged C45 steel and 2% Cu alloyed C45 steel. *Journal of Alloys and Compounds,* 2017, vol. 695, pp. 3299-3309.

[3] PRADITYANA, A., SULISTIJONO, S., SHAHAB, A. Effectiveness of myrmecodia pendans extract as eco-friendly corrosion inhibitor for material API 5L grade B in 3.5% NaCl solution. *Advanced Material Research*, 2013, vol. 789, pp. 484-491.

[4] SELEJDAK, J., ULEWICZ, R., INGALDI, M. The evaluation of the use of a device for producing metal elements applied in civil Engineering. In *23rd International Conference on Metallurgy and Materials*. Ostrava: TANGER, 2014, pp. 1882-1888.

[5] THOMPSON, N. G., YUNOVICH, M., DUNMIRE, D. Cost of corrosion and corrosion maintenance strategies, *Corrossion Reviews* 2007, vol. 25, pp. 247-262.

[6] KOCAŃDA, D., MIERZYŃSKI, J., MROZIŃSKI, S., TORZEWSKI, J. Fatigue Behaviour of S235JR Steel after Surface Frictional-Mechanical Treatment in Corrosive Environment. *Key Engineering Materials*, 2014, vol. 598, pp. 105-112.

[7] DOSCH, H., MITTEMEIJER, E., RÜHLE, M., VAN DE VOORDE, M. H. *Europen White Book of Fundamental Research I Material Sciences*. *1st ed.* Stuttgart: Max-Planck-Institut für Metallforschung, 2001.

[8] SZABRACKI, P., LIPIŃSKI, T. Effect of aging on the microstructure and the intergranular corrosion resistance of X2CrNiMoN25-7-4 duplex stainless steel. *Solid State Phenomena,* 2013, vol. 203-204, pp. 59-62.

[9] UHLIG, H. H., REVIE, R. W. *Corrosion and corrosion control. 3rd ed.* London: John Wiley and Sons, 1985. 174 p.

[10] LIPIŃSKI, T. Corrosion Resistance of 1.4362 Steel in Boiling 65% Nitric Acid. *Manufacturing Technology* 2016, vol. 16, no 5, pp. 1004-1009.

[11] CHANDRAMOULI, R., KANDAVEL, T. K., SHANMUGHASUNDARAM, D., ASHOK KUMAR, T. Deformation, densification and corrosion studies on sintered P/M plain carbon steel preforms. *Materials and Design,* 2007, vol. 28, pp. 2260-2264.

[12] SANTANA RODRIQUEZ, J. J., GONZALEZ GONZALEZ, J. E. Identification and formation of green rust 2 as an atmospheric corrosion product of carbon steel in marine atmospheres. *Materials and Corrosion,* 2006, vol. 57, no. 5, pp. 411-417.

[13] ALIZADEH, M., BORDBAR, S. The influence of microstructure on the protective properties of the corrosion product layer generated on the welded API X70 steel in chloride solution, *Corrosion Science,* 2013, vol. 70, pp. 170-179.

[14] EL-ETRE, A. Y., ABDALLAH, M. Natural honey as corrosion inhibitor for metals and alloys. II. C-steel in high saline water. Corrosion Science, 2000, vol. 42, no 4, pp. 731-738.

[15] BOHNI, H. *Corrosion in reinforced concrete structures*. CCR Press England, 2005. 247 p.

[16] COSTA, J. M. Trends in electrochemistry and corrosion at the beginning of the 21 st century. Universitat De Barcelona. Barcelona, 2004. 1241 p.

[17] EN 10025-2:2004. Hot rolled products of structural steels - Part 2: Technical delivery conditions for non-alloy structural steel.

[18] PN EN ISO 3651-1, Determination of resistance to intergranular corrosion of stainless steels. Part 1: Austenitic and ferritic-austenitic (duplex) stainless steels

[19] SZABRACKI, P., LIPIŃSKI, T., Influence of sigma phase precipitation on the intergranular corrosion resistance of X2CrNiMoN25-7-4 super duplex stainless steel, In: *METAL 2014: 23rd International Conference on Metallurgy and Materials*. Ostrava: TANGER, 2014, pp. 476-481.

[20] LIPIŃSKI, T. Corrosion Rate of the X2CrNiMoN22-5-3 Duplex Stainless Steel Annealed at 500 degrees C. *Acta Physica Polonica A,* 2015, vol. 130, no 4, pp.993-995.