sciendo

PRODUCTION ENGINEERING ARCHIVES 2021, 27(2), 108-111

PRODUCTION ENGINEERING ARCHIVES

ISSN 2353-5156 (print)
ISSN2353-7779 (online)

Exist since 4th quarter 2013
Available online at www.pea-journal.eu

Investigation of corrosion rate of X55CrMo14 stainless steel at 65% nitrate acid at 348 K

Tomasz Lipiński[1]

[1] University of Warmia and Mazury in Olsztyn, Oczapowskiego 11 St., 10-957 Olsztyn, Poland
Corresponding author e-mail: tomasz.lipinski@uwm.edu.pl

Article history
Received 09.03.2021
Accepted 17.05.2021
Available online 14.06.2021

Keywords
steel
stainless steel
corrosion
corrosion rate
profile roughness

Abstract

A number of factors determine the mechanical, but also physical and chemical properties. One of the most important are the steel microstructure and its working conditions. A few corrosion processes in crevices and awkward corners can be avoided at the design stage (low roughness parameters, round-section and other). But still the construction material is exposed to corrosion. These steels often come into contact with an aggressive environment based on nitric acid. Stainless steel is more and more often used in many sectors of industry.

The purpose of this article is to investigate corrosion resistance in different time (48, 96, 144, 192, 240, 288, 336, 384 and 432 hours) using weight loss and profile roughness parameters of martensitic steel in grade X55CrMo14 in nitric acid 65% pure-basic at temperature 348 K. Corrosion tests show that the tested steel in nitric acid as a corrosive environments is characterized through continuous corrosion process whose measure may be surface roughness.

DOI: 10.30657/pea.2021.27.13 JEL: L69, M11

1. Introduction

Stainless steels are becoming more and more widely used not only as construction materials used in machine building, utility construction, but also in medicine, pharmacy and household tools (Pan et al., 2020; Lipiński, 2016; Scendo et al., 2012). These steels have three main microstructures, which include: ferritic, austenitic and martensitic (outokumpu).

Industry places high demands on construction materials. The reason for this is both the safety of persons and construction. One with the main problem apart strength (Ulewicz et al., 2017; Ulewicz et al., 2014; Vicen et al., 2019; Scendo et al. 2014) and desirable is corrosion resistance (Uhlig et al., 1985). The factor is main in prevents rapid destruction of the material. One of the more important is that the negative corrosion effect have mostly important for the reason for example other metals inclusions (Dudek et al., 2014; Lipiński et al., 2015; Szabracki et al., 2013) which are dependent on their shape, numbers, size and distribution determined properties of alloys, too (Duryahina et al., 2007; Szabracki et al., 2014). To achieve this goal, it is required to conduct experimental research and reduce the testing costs by computer simulations (Pietraszek et al., 2014; Krynke et al., 2012; Ulewicz et al., 2013; Lipiński, 2017). In order to reduce the costs of testing, they are usually conducted on a laboratory scale (Majewski et al., 2020; Pietraszek et al., 2015; Lipiński, 2017; Ulewicz et al., 2019; Selejdak 2003).

Martensitic steels have exceptionally high strength properties and high abrasion resistance. Martensitic stainless steels are non-weldable or difficult to weld (Miletić et al. 2020). The low chromium content together with high carbon content in the martensitic grades lower corrosion resistance compared to the other classes of stainless steels. Thus, they are usually broadly selected but only for mild corrosion ambient when were requiring a combination of high tensile and high hardness strength and corrosion resistance. They are used for the production of parts of devices that require hardness, such as screws, pins, parts subject to abrasive wear, valves of hydraulic presses. In addition, they are used to make cutting tools include cutlery, surgical instruments, measuring tools, shafts, ball bearings, turbine equipment, and petrochemical equipment and much more (Yang et al., 2012; Cheng et al. 1988; Saha et al., 2020; Christopher et al. 2018; Dalmau et al. 2018).

Martensite provides to stainless steel very high tensile strength up to 1100 MPa. Unfortunately, martensitic stainless steels are magnetic. The low chromium and other expensive alloying element content in chemical compositions of the martensitic stainless steels mainly is the reason them less costly than the other stainless steels (El-Meligy et al., 2020; Liu et al., 2020; Seidametova et al., 2018, Führer et al., 2018).

2. Experimental

The research presented in this paper was performed on martensitic X55CrMo14 stainless steel plate t = 6.00 mm thickness with chemical composition according to the EN 10088-1:2014 Stainless steels - part 1: list of stainless steels.

The specimens from plate t = 6.00 mm thickness was cut mechanically samples to size 36 x 10 mm (area of 13 cm^2). Next the samples were polished with water paper successively form Ra = 0.32 µm to 0.40 µm, and cleaned by water and next by 95% C_2H_5OH. Corrosion tests were conducted in nitric acid 65% pure-basic at temperature 348 K in time intervals: 48 h, 96 h, 144 h, 192 h, 240 h, 288 h, 336 h and 384 h. After each of these time intervals, the samples were removed from the bath, washed with water, quenched and washed with alcohol to break the corrosion process. Mass losses after the corrosion process were determined using a KERN ALT 310-4 AM scale with an accuracy of 0.00001 g.

Profile roughness parameters were analyzed by the Diavite DH5 profilometer for which the maximum length of the measuring section is lt=15 mm.. By profile roughness parameters determined of: R_a - arithmetic average of absolute values [µm], R_p - maximum peak height [µm], R_q - root mean squared [µm], R_t - Maximum Height of the Profile [µm] for different corrosion time.

The corrosion rate of X55CrMo14 steel measured in mm per year was calculated with the use of the below formula (1), measured in g·m-2 was calculated with the use the below formula (2):

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

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

where:

t – time of treatment in a corrosive solution of boiling nitric acid [hours],

S – surface area of the sample [cm^2],

m – average mass loss in boiling solution [g],

ϱ – sample density [g/cm^3].

The influence of 65% nitric acid on the X55CrMo14 martensitic 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. The time range of research was: 48, 96, 144, 192, 240, 288, 336, 384 and 432 hours.

3. Results and discussion

The average chemical composition of the analyzed the X55CrMo14 steel is presented in Table 1.

Table 1. average chemical composition of the analyzed X55CrMo14 steel

C	Mn	Si	P	S	Cr	Ni	Mo	V
0.49	0.84	0.78	0.02	0.01	14,4	0.05	0,58	0.12

The result of time influence the soaking the X55CrMo14 steel in nitric acid at temperature 348 K on the relative mass loss (RML) with determination coefficient is presented in Fig. 1 and its regression equation with determinations coefficient at (3).

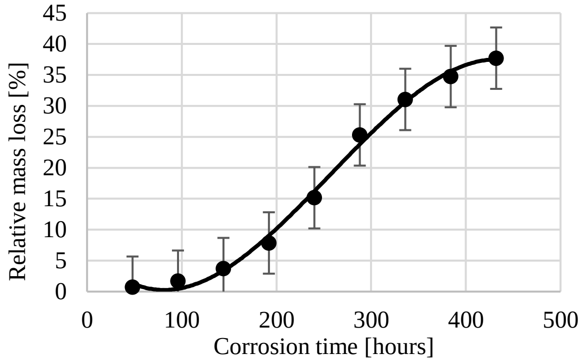

Fig. 1. Relative mass loss the X55CrMo14 stainless steel soaking in 65% nitrate acid at 348 K

$$RML = -2 \cdot 10^{-06} \cdot t^2 + 0.0013 \cdot t + 7.1603 \tag{3}$$

and $r^2 = 0.9956$

The result of time influence the soaking the X55CrMo14 steel in nitric acid at temperature 348 K on the corrosion rate in mm per year (r_{corm}) with determination coefficient is presented in Fig. 2 and its regression equation with determinations coefficient at (4).

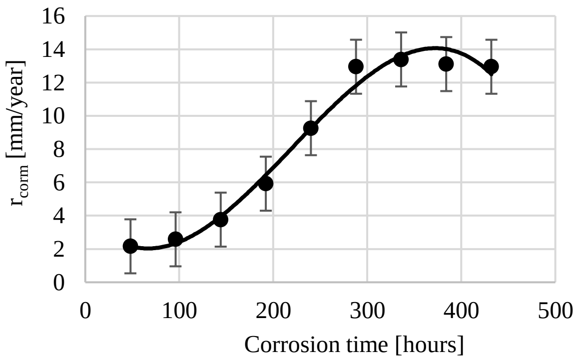

Fig. 2. Corrosion rate in mm per year the X55CrMo14 stainless steel soaking in 65% nitrate acid at 348 K

$$r_{corm} = -8 \cdot 10^{-07} \cdot t^3 + 0.0006 \cdot t^2 - 0.0631 \cdot t + 4.0138 \tag{4}$$

an $r^2 = 0.9856$

The result of time influence the soaking the X55CrMo14 steel in nitric acid at temperature 348 K on the corrosion rate in grams per square meter (r_{corg}) with determination coefficient is presented in Fig. 3 and its regression equation with determinations coefficient at (5).

$$r_{corm} = -8 \cdot 10^{-07} \cdot t3 + 0.005 \cdot t2 - 0.0566 \cdot t + 3.6015 \tag{5}$$

and $r^2 = 0.9202$

During the first 48 hours of soaking in nitric acid, a slow weight loss (RML - Fig. 1) was noted as well as a slow increase in the corrosion rate (Fig. 2 and Fig. 3). After extending the soaking time from 48 hours to 288 hours, the above parameters increased rapidly. After exceeding 288 hours, the relative mass loss continues to increase, but less intensely, while the corrosion rate stabilizes at a comparable level.

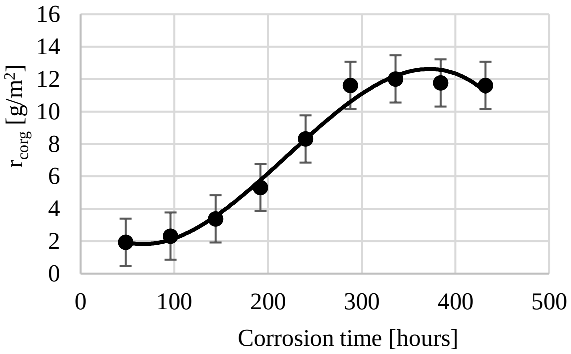

Fig. 3. Corrosion rate in grams per square meter the X55CrMo14 stainless steel soaking in 65% nitrate acid at 348 K

The regression equations and the coefficients of determination for Ra and Rq are presented in (6) and (7).

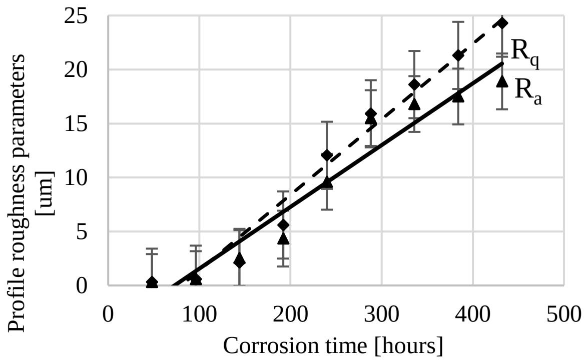

Fig. 4. R_a and R_q roughness parameters the X55CrMo14 stainless steel soaking in 65% nitrate acid at 348 K

$$R_a = 0.0572 \cdot t - 4.1615 \text{ and } r = 0.9415 \quad (6)$$

$$R_q = 0.0699 \cdot t - 5.5856 \text{ and } r = 0.9707 \quad (7)$$

The regression equations and the coefficients of determination for R_t and R_z are presented in (8) and (9).

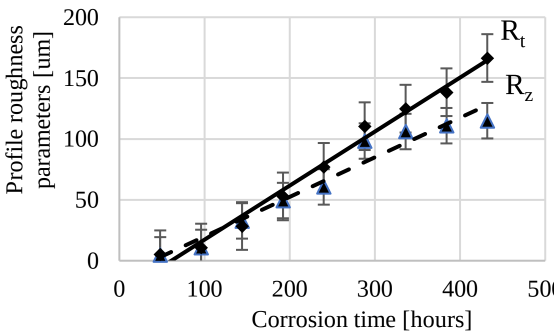

Fig. 5. R_t and R_z roughness parameters the X55CrMo14 stainless steel soaking in 65% nitrate acid at 348 K

$$R_t = 0.4438 \cdot t - 27.086 \text{ and } r^2 = 0.9862 \quad (8)$$

$$R_z = 0.3252 \cdot t - 12.631 \text{ and } r^2 = 0.9576 \quad (9)$$

Profile roughness of X55CrMo14 steel after corrosion tests in 65% nitric acid at temperature 348 K for 240 hours is presented in Fig. 6 and for 432 hours in Fig. 7.

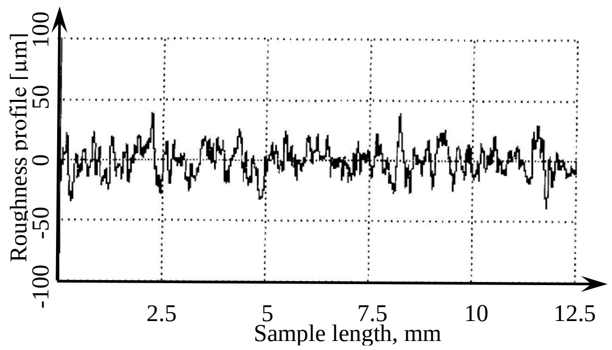

Fig. 6. Profile roughness the X55CrMo14 stainless steel soaking in 65% nitrate acid at 348 K for time 240 hours

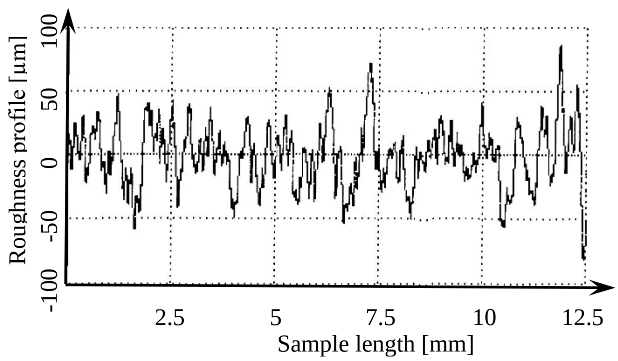

Fig. 7. Profile roughness the X55CrMo14 stainless steel soaking in 65% nitrate acid at 348 K for time 432 hours

The difference between the Fig. 6 and Fig. 7 is visible in the size of the unevenness. It may indicate that the corrosion places were formed at the beginning of the process in places less resistant to nitric acid. Over time soaking alloy confirmed only roughness development was noted over time. Fig. 4 and Fig. 5, what confirm this view. After 144 hours soaking the X55CrMo14 steel in 65% nitrate acid at 348 K the surface of the steel (Fig. 8) is already degraded to a degree that could affect the facility operated.

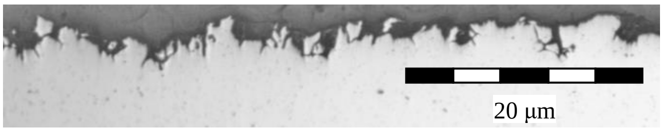

Fig. 8. Microstructure the X55CrMo14 steel after 144 hours soaking in 65% nitrate acid at 348 K

4. Conclusion

Based on the results of the research, it was found that:

- the tested steel with martensite microstructure has high resistance to nitric acid in the first period,
- the tested steel, after exceeding the first corrosion period, quickly degrades,
- the surface roughness of the steel increases to a certain level when reached and remains constant,

- there are correlations between the degree of corrosion degradation of the material and roughness,
- a clearly accelerated increase in the corrosion rate and roughness of parameters after the initiation of the corrosion process was observed. On this basis, it was found that this steel is resistant to the environment of nitric acid only in the first for a very quite short period of time. When it is exceeded, the development of corrosion is rapid.

Reference

Dalmau, A., Richard, C., Igual–Muñoz, A., 2018. Degradation mechanisms in martensitic stainless steels: Wear, corrosion and tribocorrosion appraisal, Tribology International, 121, 167-179.

Dudek, A., Wrońska, A., Adamczyk, L., 2014. Surface remelting of 316L+434L sintered steel: microstructure and corrosion resistance, Journal Solid State Electronics, 18(11), 2973-2981.

Duryahina, Z.A., Makhorkin, I.M., Lazko, H.V., Bychyns'kyi, V.I., 2007. Evaluation of temperature fields in corrosion-resistant steels under the action of laser radiation, Materials Science, 43(6), 800-806.

El-Meligy, M., El-Bitar, T., 2020. Hot workability of 420 J1 martensitic stainless steel, Procedia Manufacturing, 50, 771-776.

Führer, U., Aktaa, J., 2018. Modeling the cyclic softening and lifetime of ferritic-martensitic steels under creep-fatigue loading, International Journal of Mechanical Sciences, 136, 460-474.

Cheng X.L., Ma H.Y., Chen S.H., Chen X., Chen S.H., Yang H.Q., 1998. Corrosion of Iron in Acid Solutions with Hydrogen Sulfide Corrosion Sciences, 41(2), 321-329.

Christopher, J., Choudhary, B.K., 2018. On the onset of necking instability in tempered martensitic 9% Cr steels, Mechanics Research Communications, 94, 114-119.

Krynke, M., Selejdak, J., Borkowski, S., 2012. The Quality of Materials Applied for Slewing Bearing Raceway, Materials Engineering, 19(4), 157-163.

Lipiński, T., 2016. Corrosion Resistance of 1.4362 Steel in Boiling Nitric Acid, Manufacturing Technology, 16(5), 1004-1009.

Lipiński, T., 2017. Corrosion Effect of 20% NaCl Solution on Basic Carbon Structural S235JR Steel. 16th International Scientific Conference Engineering for Rural Development, Proceedings 16, Jelgava, 24-26.05.2017, 1069-1074.

Lipiński, T., Wach, A., 2015. Dimensional Structure of Non-Metallic Inclusions in High-Grade Medium Carbon Steel Melted in an Electric Furnace and Subjected to Desulfurization, Solid State Phenomena, 223, 46-53.

Liu, Z., Wang, X., Dong, C., 2020. Effect of boron on G115 martensitic heat resistant steel during aging at 650 °C, Materials Science and Engineering, 787, 139529.

Majewski, G., Orman, Ł.J., Telejko, M., Radek, N., Pietraszek, J., Dudek A., 2020. Assessment of thermal comfort in the intelligent buildings in view of providing high quality indoor environment, Energies 13(8), 1973.

Martensitic stainless steel, www.outokumpu.com, (accesss 15.02.2021)

Miletić, I., Ilić, A., Nikolić, R.R., Ulewicz, R., Ivanović, L., Sczygiol, N., 2020. Analysis of Selected Properties of Welded Joints of the HSLA Steels, Materials, 13, 1301, DOI: 10.3390/ma13061301

Pan, L., Kwok, C.T., Lo, K.H., 2020. Friction-stir processing of AISI 440C high-carbon martensitic stainless steel for improving hardness and corrosion resistance, Journal of Materials Processing Technology, 277, 116448

Pietraszek, J., Gądek-Moszczak, A., Radek, N., 2015. the estimation of accuracy for the neural network approximation in the case of sintered metal properties. Recent Developments in Computa-tional Collective Intelligence, 125-134.

Pietraszek, J., Skrzypczak-Pietraszek, E., 2014. The Optimization of the Technological Process with the Fuzzy Regression, Advanced Materials Research, 874, 151-155.

Saha, N., Basu, J., Sen, P., Majumdar, G., 2020, Electrochemical behaviour of martensitic stainless steel with blood, Materials Today: Proceedings, 26(2), 677-680.

Scendo, M., Trela, J., Radek, N., 2012. Purine as an effective corrosion inhibitor for stainless steel in chloride acid solutions, Corrosion Reviews, 30(1-2), 33-45.

Scendo, M., Trela, J., Radek, N., 2014. Influence of laser power on the corrosive resistance of WC-Cu coating, Surface & Coatings Technology 259, 401-407.

Seidametova, G., Vogt, J., Serre, I., 2018. The early stage of fatigue crack initiation in a 12%Cr martensitic steel, International Journal of Fatigue, 106, 38-48.

Selejdak, J., 2003. Influencing factors onto quality of welded pipes, Metalurgija, 42(1), 65-67.

Szabracki, P., Lipiński, T., 2013. Effect of Aging on the Microstructure and the Intergranular Corrosion Resistance of X2CrNiMoN25-7-4 Duplex Stainless Steel, Solid State Phenomena, 203-204, 59-62.

Szabracki, P., Lipiński, T., 2014. Influence of sigma phase precipitation on the intergranular corrosion resistance of X2CrNiMoN25-7-4 super duplex stainless steel. 23rd International Conference on Metallurgy and Materials METAL, 2014, 476-481.

Lipiński, T., 2016. Corrosion rate of the X2CrNiMoN22-5-3 duplex stainless steel annealed at 500°C, Acta Phisica Polonica A, 130(4), 993-995.

Uhlig, H.H., Revie, R.W., 1985. Corrosion and corrosion control, 3rd Edition, John Wiley and Sons.

Ulewicz, R., Mazur, M., Bokůvka, O., 2013. Structure and mechanical properties of fine-grained steels, Periodica Polytechnica Transportation Engineering, 41(2), 111-115.

Ulewicz, R., Nový, F., 2017. Fatigue resistance and influence of cutting technology on the mechanical properties of modern steels used in the automotive industry, Procedia Engineering, 192, 899-904.

Ulewicz, R., Nový, F., 2019, Quality management systems in special processes, Transportation Research Procedia, 40, 113-118.

Ulewicz, R., Nový, F., Selejdak, J., 2014, Fatigue strength of ductile iron in ultra-high cycle regime, Advanced Materials Research, 874, 43-48

Vicen, M., Bronček, J., Nový, F., 2019. Investigation of tribological properties of CarbonX coating deposited on 100Cr6 steel, Production Engineering Archives, 25(25), 52-55.

Yang, Y., Cheng,Y.F., 2012. Parametric effects on the erosion–corrosion rate and mechanism of carbon steel pipes in oil sands slurry, Wear, 276-277, 141–148.

X55CrMo14不锈钢在348 K硝酸盐浓度为65％时的腐蚀速率研究

關鍵詞
钢
不锈钢
腐蚀
腐蚀率
轮廓粗糙度

摘要
许多因素决定了机械性能，但也决定了物理和化学性能。最重要的之一是钢的微观结构及其工作条件。在设计阶段可以避免在缝隙和尴尬的角落中发生一些腐蚀过程（低粗糙度参数，圆截面和其他）。但是，建筑材料仍然会受到腐蚀。这些钢经常与基于硝酸的侵蚀性环境接触。不锈钢越来越多地用于许多工业领域。　本文的目的是使用X55CrMo14级马氏体钢在硝酸65中的失重和轮廓粗糙度参数研究不同时间（48、96、144、192、240、288、336、384和432小时）的耐腐蚀性％纯碱在348　K的温度下。腐蚀试验表明，在硝酸中作为腐蚀环境的被测钢通过连续腐蚀过程来表征，其测量方法可能是表面粗糙度。