

CORROSION OF 1.4110 STAINLESS STEEL AT NITRATE ACID AT 323 K

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Abstract. Corrosion is a common process of destroying construction materials. The material during these processes loses its properties, it causes deterioration of functions, loses its usefulness, applicability. One of the important aggressive environments in the agricultural industry is nitrogen, from which nitric acid may be formed. Due to high hardness and also a good resistance to abrasion and corrosion the 1.4110 steel is commonly used in industry as knife blades, machining tools, measuring tools, pump construction, valves. Stainless steel is steel with good resistance to homogeneous or local environmental attack. The aim of the research was to determine the corrosive wear of 1.4110 steel (X55Cr), corrosion resistance with martensitic microstructure using the Huey test. The tested steel contains 0.52 % C, 13.4 % Cr and 0.65 % Mo. The samples were weighed before start of the corrosion processes and after them. Samples were kept in nitric acid 65 % at temperature 323K. The holding times of the samples in nitric acid were 48, 96, 144, 192, 240, 288, 336, 384 hours. The percentage of mass losses was determined by the weight method. Each sample was examined metallographically using an optical microscope and the surface roughness test using a profilometer. The test results were analyzed in order to determine the corrosion rate of steel in mm/year and g/m² as well as percentage mass loss and determine the corrosion resistance in this environment. After corrosion of the steel, the roughness has increased. Mass loss and corrosion velocity were presented by a linear function, but greater accuracy is obtained by using the 3rd degree polynomial. Then it was confirmed that as the holding time in boiling nitric acid increases, corrosive wear increases. Generally, the tested steel 1.4110 has a good corrosion resistance in the nitric acid environment.

Keywords: steel, stainless steel, corrosion, corrosion rate, roughness.

Introduction

In technics corrosion mainly concerns metal materials and within them also iron alloys. Stainless steel is steel with good resistance to homogeneous or local environmental attack. Corrosion-resistant steels created have resistance only in specific conditions [1-7]. Their corrosion resistance depends i.a. on the chemical ingredients, microstructure, surface condition. Corrosion-resistant steels have at least 10.5 % chromium and a maximum of 1.2 % carbon, elements that conduce to forming of the surface layer (passive), with dense structure and consistent with the base, causing a jump of the chemical potential, it has a tendency to self-rebuilding and provides corrosion resistance. Along with the increasing content of the chromium, nickel, molybdenum the corrosion resistance is gaining. Corrosion is a phenomenon of material damage as a result of the chemical and electrochemical environment influence [8-12].

In alloys and metals changes occur as a result of interaction with the surrounding environment. The corrosion process begins at the point of contact with the environment, on the surface of the metal, it goes deep into the material. As a result of this process, the material loses its features until it loses usability. The progressive corrosion causes a significant reduction of usefulness and mechanical functions of machines, devices and components [13-17]. There are also economic losses that result from the corrosive use of pipelines, tanks, chemical installations, car mufflers and machine parts. Factors affecting the phenomenon of corrosion can be divided into: internal and external. Stainless steels, among metal materials, have a high corrosion resistance in many different corrosive environments because of a phenomenon called passivation. This phenomenon is creating a very thin passive layer on the surface of stainless steel, it is closely related to the base. It prevents contact between more or less aggressive environment with metal. In case of mechanical damage of the passive layer, the coating is self-rebuilding [18-26]]. Animal products and biological substances are important corrosive environmental factors in agricultural industry. Therefore, corrosion in agricultural industry is very a difficult and also dangerous process [27-32].

The environment, which agricultural machines and devices work in, is classified as very aggressive [29-32]. The reason for this, among others, is high nitrogen content in the atmosphere and in animal waste, which can form chemical compounds. Considering the wide use of stainless steel in grade 1.4110 in agricultural machinery and equipment, it was decided to check its rate of corrosion in the nitric acid environment.

Materials and methods

The tests were performed on steel grade 1.4110 (X55Cr using the Huey test. [33]) The tested steel contained 0.52 % C, 13.4 % Cr and 0.65 Mo. Samples were cut from a 8 mm thick sheet of metal on an electrical discharge machine. In order to remove overheating after the cutting process and to make the samples with the same roughness, the steel was grinded on sandpaper with a grit size of 400 to $R_a > 0.32 \mu\text{m}$ and degreasing. Corrosion tests were conducted in nitric acid 65 % pure-basic (INTRIC ACID 65 % PURE P.A.-BASIC) at temperature 323 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. Metallographic studies were carried out on an Olympus IX70 microscope at magn. 5-100x. Roughness measurements were made using the DIVIATE DH-5 profilometer, recording R_a (arithmetic mean deviation of the roughness profile), R_z (roughness value among 10 points).

Relative mass loss of 1.4110 stainless steel grade was calculated with (1). The corrosion rate was calculated in mm per year with formula (2) or in grams per square meter with formula (3):

$$r_{rel} = \frac{\Delta m}{m_0} 100 \% , \quad (1)$$

$$r_{corn} = \frac{8760 \cdot m}{S \cdot t \cdot \rho} , \quad (2)$$

$$r_{corg} = \frac{10000 \cdot m}{S \cdot t} , \quad (3)$$

where Δm – loss of smple mass due to corrosion, g;
 m_0 – initial weight of sample, g;
 t – time of soaking in a corrosive solution of nitric acid V 65 % at temperature 323 K, hours;
 S – contact surface of the sample with nitric acid of the sample, cm^2 ;
 m – average mass loss after the test in nitric acid V 65 % at temperature 323 K, g;
 ρ – tabular density of the tested steel, $\text{g} \cdot \text{cm}^{-3}$.

Results and discussion

Relative mass loss with standard error is presented in Fig. 1. The corrosion rate calculated in mm per year with formula (2) and its standard error are presented in Fig. 2 and in grams per square meter calculated with formula (3) in Fig. 3. An example of the steel surface roughness after 288 hours is shown in Fig. 4.

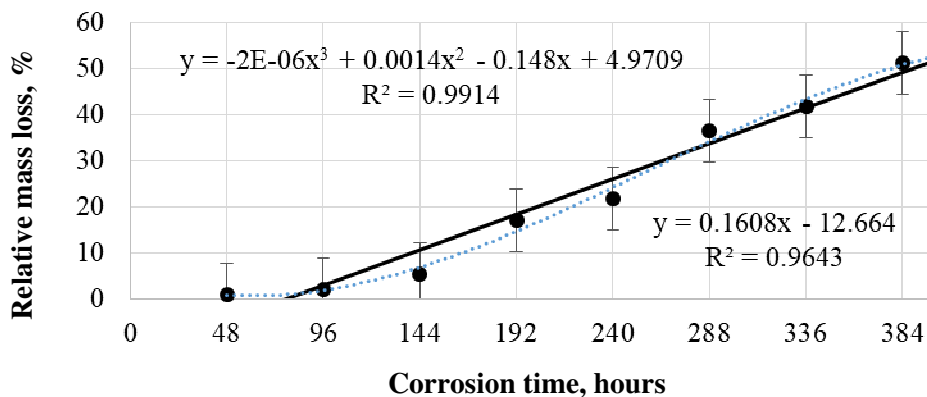


Fig. 1. Relative mass loss of 1.4110 stainless steel soaking in nitric acid V 65 % at temperature 323 K

After analysis of the changes of relative mass loss and corrosion rate of 1.4110 steel soaking in nitric acid V 65 % at temperature 323 K, a very slow increase of the mass loss was found for the first 96 hours (Fig. 1- Fig. 3). For the time interval of 96-144 hours a much greater increase in the corrosion rate was noticed. With further extension of the steel time in nitric acid, the analyzed mass loss and corrosion rate stabilized and to the final stage of the research (384 h) changes were observed oscillating around the fixed values of relative mass loss and corrosion rate. Similar to the above-described processes, it was noted for the roughness parameters, mainly R_z . After analysis of the changes in the R_a parameter over time, a little slowdown was found after exceeding 240 hours of the corrosion process. It was also observed that the parameter R_a is more stable for corrosion time interval of 96 to 192 h and 244 to 386 h than the parameter R_z .

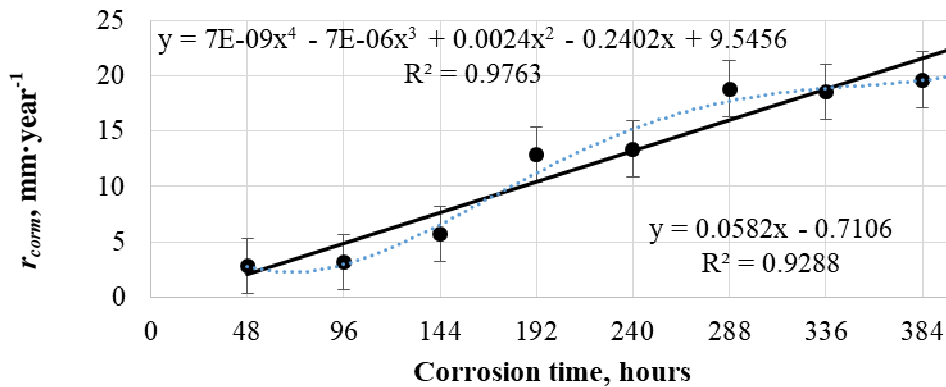


Fig. 2. Corrosion rate in mm per year of 1.4110 stainless steel soaking in nitric acid V 65 % at temperature 323 K

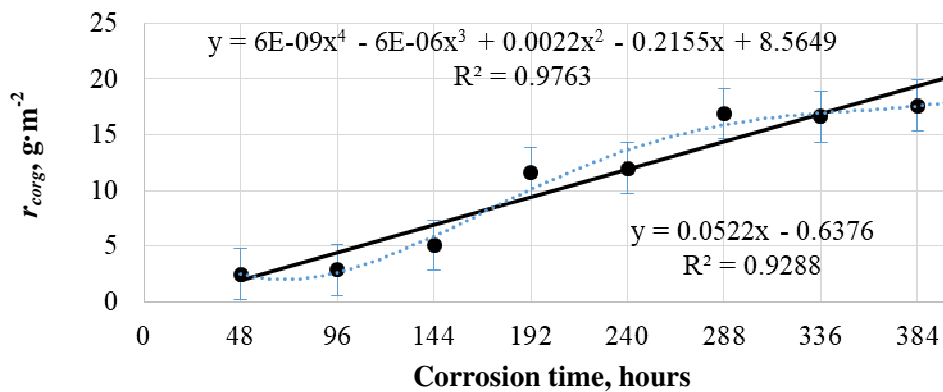


Fig. 3. Corrosion rate in grams per square meter of 1.4110 stainless steel soaking in nitric acid V 65 % at temperature 323 K

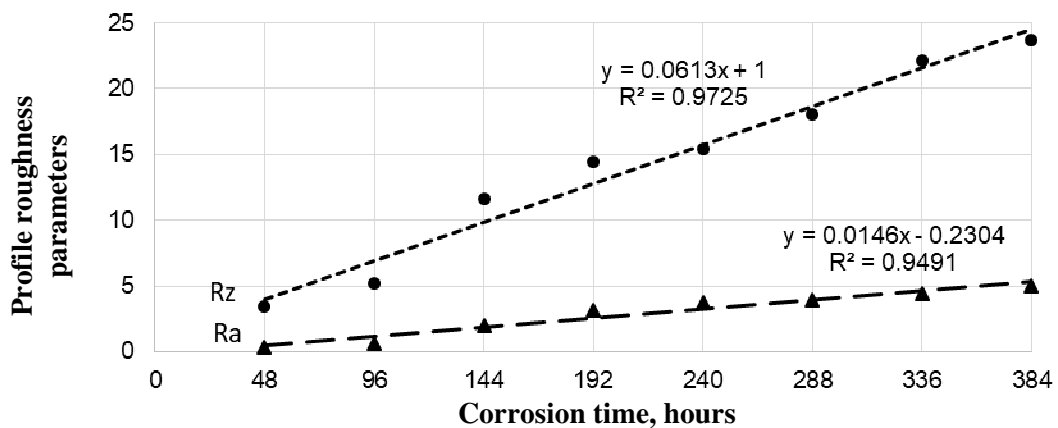


Fig. 4. Roughness parameters of 1.4110 stainless steel soaking in nitric acid V 65 % at temperature 323 K

Relative mass loss of 1.4110 stainless steel in the first period soaking in nitric acid V 65 % at temperature 323 K (up to 96 hours) increases slightly, then the consumption increases to 144 to 384 hours soaking (until the end of observation) achieving a constant relative mass loss. In order to better illustrate the process, apart from the linear function, the third-degree mathematical function was used (Fig. 1). Analyzing the corrosion rate change in time measured in mm per year (Fig. 2) or grams per square meter of 1.4110 stainless steel soaking in nitric acid V 65 % at temperature 323 K in the first period (up to 96 hours) the corrosion rate increases slightly, then between 96 and 144 hours the soaking corrosion rate increases rapidly. Over a period of from 144 to 288 hours soaking the steel the corrosion rate achieved a constant (second corrosion stage) but higher than at the first stage. After exceeding 288 hours to 384 hours (until the end of observations), the corrosion rate decisively decreased, reaching a constant rate (the third stage). In order to better illustrate the process consisting of three stages, the fourth order mathematical function was used next to the linear function.

The slowdown of the roughness increase represented by the Ra parameter during the tested time interval can be explained by dissolution of protruding metal particles above the average roughness profile by nitric acid, which results in flattening of the profile and, as an effect, a slower growth of the analysed parameter, as confirmed in Fig. 5.

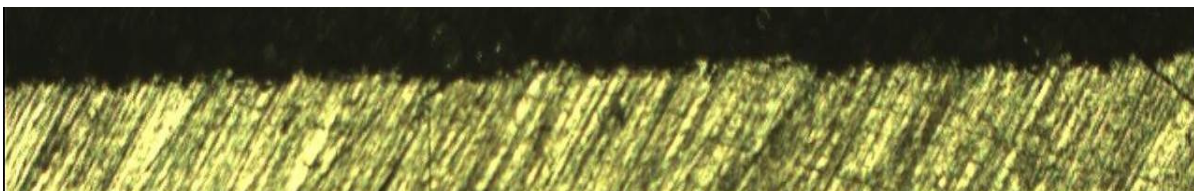


Fig. 5. Roughness of 1.4110 stainless steel soaking in nitric acid V 65 % at temperature 323 K for 288 h

The numerous, descriptive literature presents corrosion problems solved based on potentiostatic studies [34-37]. This approach to the problem facilitates its analysis and documentation of the process, but requires adaptation before applying the results in industrial practice. Corrosion tests presented in the paper enable direct transfer to the industry.

Conclusions

1. Tested martensitic steel 1.4110 has good corrosion resistance in the environment of nitric acid.
2. The weight loss and corrosion rate of 1.4110 steel can be presented by a linear function with sufficient statistical accuracy. However, taking into account the small lack of proportionality, greater accuracy of results of corrosion rate is obtained by using the 4th degree polynomial. The proposed 4th stage function allows to observe the three periods of corrosion and is much more accurate both for the observation of the corrosion rate as well as its numerical analysis.
3. The obtained equations can be used to model the corrosion process of 1.4110 steel in the environment of nitric acid at 323 K.

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