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Corrosion of the 1.4362 Duplex Stainless Steel in a Nitric Acid Environment at 333 K

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Duplex stainless steels offer economic properties of strength and corrosion resistance. They are very popular ferritic-austenitic stainless steel construction material used in industrial applications. The fraction of each phase constitutes approximately 50%. These steels present excellent corrosion resistance, which is characteristic of austenite steel and the high mechanical properties of ferrite steel. The corrosion resistance of stainless steels depends on the chromium content and the microstructure morphology. The percentage contribution of each phase (and, thus, the steel properties) depends on the composition, technological processes and heat treatments. However, the performance presented by duplex stainless steels can be drastically compromised by the precipitation of undesirable phases, such as sigma phase, chi phase, secondary austenite, and large volumes of chromium-rich carbides. The aim of this paper was to ascertain the effect of corrosion time on the relative mass loss (in %), corrosion rate and roughness parameters of the 1.4362 duplex stainless steel profile after 30 min isothermal heat treatment at the temperature of 1423 K and cooling in air. The effect of nitric acid at 333 K on the steel corrosion resistance was determined based on weight loss and profile roughness parameters.

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PACS/topics: steel, duplex steel, stainless steel, corrosion

1. Introduction

Corrosion is one of the natural processes and depends on the environment and the corrosion material. Signs of material corrosion include: general corrosion, pitting corrosion, intergranular corrosion, stress-corrosion, filiform corrosion, crevice corrosion with corrosion under tubercles, poultice corrosion, galvanic corrosion, erosion-corrosion, cavitation corrosion, fretting corrosion, sensitization corrosion, exfoliation corrosion, corrosion fatigue, hydrogen damage corrosion, and others. There are many methods of calculation of corrosion processes and corrosion resistance of materials. Generally, the corrosion rate is calculated as quotient of the aggressive environment indicator and the corrosion resistance of material. In technology, corrosion mainly concerns metal materials, including iron alloys. Stainless steel offers good resistance to homogeneous or local environmental attack. Particular corrosion-resistant steels are characterized by resistance only under specific conditions [1–10].

Among metal materials, stainless steels are highly resistant to corrosion under a wide variety of corrosive environments due to passivation. This phenomenon consists of creating a very thin passive layer on the surface of stainless steel closely bound to the material base. The ferritic-austenitic steels, called duplex steels, have become increasingly more popular among a wide variety of corrosion-resistant steels. They are used in a wide range of industrial and civil engineering applications and their properties have continuously been studied to improve the quality and performance [11–16]. Low maintenance costs, very high material reliability and good environmental-factor resistance constitute further important arguments for enhancing the array of applications of these steels. It is of great importance that duplex steels offer desirable properties for producers and end users. Duplex and superduplex stainless steels are characterized by equal amounts of the two phases: ferrite and austenite. The microstructure and performance of the steels are determined by phase transformation during thermal or technological processes. Although the percentage share of the phases which are formed during the manufacturing process are user-independent and the range of stability and percentage volume of each of the phases depends on the individual application (mainly thermal conditions) [17–19].

In view of the wide variety of applications of duplex stainless steel, grade 1.4362, in industrial machinery and equipment at high temperatures, the rate of corrosion in the nitric acid environment at the temperature of 333 K was studied.

2. Materials and methods

The tests were performed on steel grade 1.4362 using the Huey test [20]. Tested steel contained (mass%): 0.02% C, 22.5% Cr, 4.4% Ni, 1.8% Mn, 0.27% Mo, 0.22% Cu, and 0.15% N. The 1.4362 grade duplex stainless steel was subjected to isothermal heat treatments at the temperature of 1423 K for 30 min and then cooled in air. Samples were cut from a 6 mm thick metal sheet with an electrical discharge machine. In order to remove

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overheating resulting from the cutting process and to obtain samples with the same roughness, the steel was ground with sandpaper with a grit size of 800 to Ra < 0.30 μm and degreased. Corrosion tests were conducted in 65% pure-basic nitric acid (nitric acid 65% pure p.a.-basic) at the temperature of 333 K in the following time intervals: 48, 96, 144, 192, 240, 288, 336, 384, and 432 h. After each of these time intervals, samples were removed from the bath, washed with water, quenched and washed with alcohol to break the corrosion process. The post-corrosion mass losses were determined using a KERN ALT 310-4 AM scale with an accuracy of 0.00001 g. Metallographic studies were carried out with an Olympus IX70 microscope at the magnitude of 5–600×. Roughness measurements were conducted using the DIVIATE DH-5 profilometer, recording arithmetic mean deviation of the roughness profile (Ra), roughness value — 10 points (Rz). The arithmetic mean of 5 measurements was used for the analysis.

The relative mass loss in 1.4362 grade stainless steel was calculated with (1). The corrosion rate was calculated in mm per year using the formula (2) or in grams per square meter with the formula (3):

$$r_{\mathrm{rel}} = \frac{\Delta m}{m_0} 100\%, \tag{1}$$

$$r_{\mathrm{corm}} = \frac{8760m}{St\rho}, \tag{2}$$

$$r_{\mathrm{corg}} = \frac{10000m}{St}, \tag{3}$$

where Δm — loss of sample 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 333 K [h], 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 333 K [g], ρ — tabular density of the tested steel [g/cm^3].

3. Results and discussion

Profile roughness parameters of 1.4362 grade steel after corrosion tests in nitric acid environment at the temperature of 333 K for the following time intervals: 0, 48, 336, and 432 h of heat-soaking was presented in Fig. 1.

The relative mass loss including the standard error is presented in Fig. 2. The corrosion rate was calculated in mm per year using the formula (2) and its standard error was presented in Fig. 3, and in grams per square meter using the formula (3) in Fig. 4.

Based on the analysis of the changes in the relative mass loss and the corrosion rate in 1.4362 grade steel which was subjected to heat-soaking in nitric acid V 65% at the temperature of 333 K, a very slow increase in the mass loss was found during the first 144 h (Figs. 2–4). After 144 h, a much greater increase in the corrosion rate was noted. With a further extension of time of steel bathing in nitric acid, the analysed mass loss and corrosion rate stabilized and, until the final stage of the

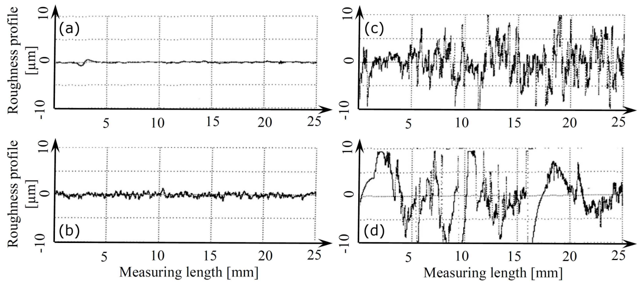

Fig. 1. Profile roughness of 1.4362 grade steel after corrosion in the nitric acid at the temperature of 333 K for different corrosion periods (a) 0 h, (b) 48 h, (c) 336 h, (d) 432 h.

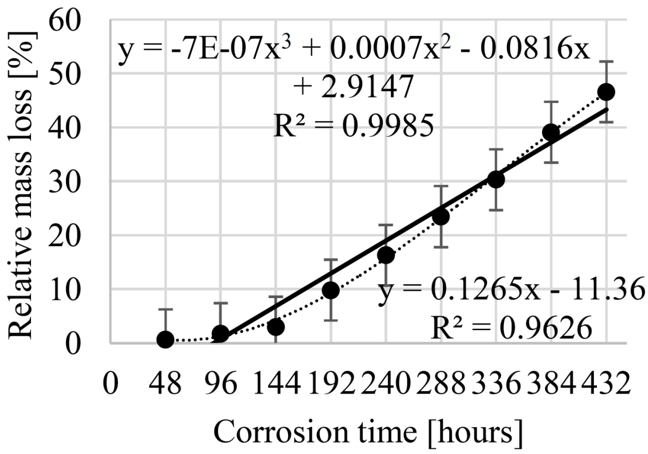

Fig. 2. The relative mass loss including the standard error of 1.4362 grade steel after corrosion in the nitric acid at the temperature of 333 K for different corrosion periods.

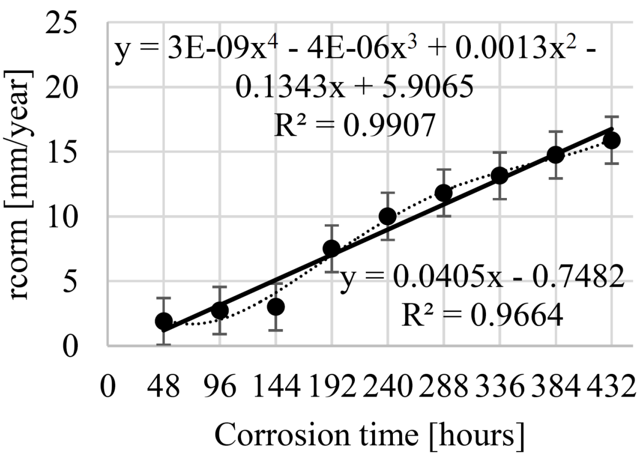

Fig. 3. The corrosion rate with standard error for 1.4362 grade steel after corrosion tests in nitric acid at the temperature of 333 K for different corrosion periods calculated in mm/year.

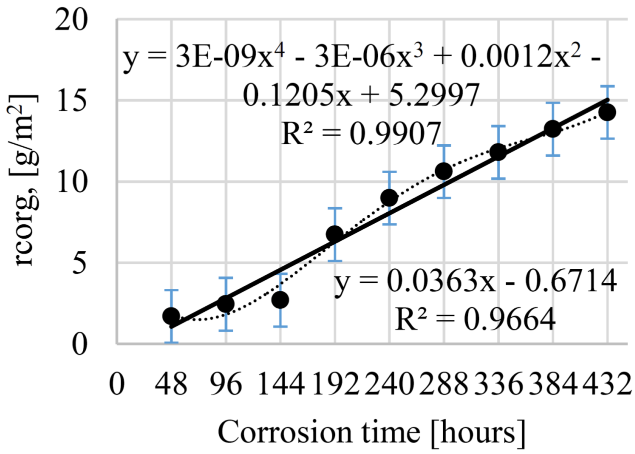

Fig. 4. As in Fig. 3, but for periods calculated in g/m^2.

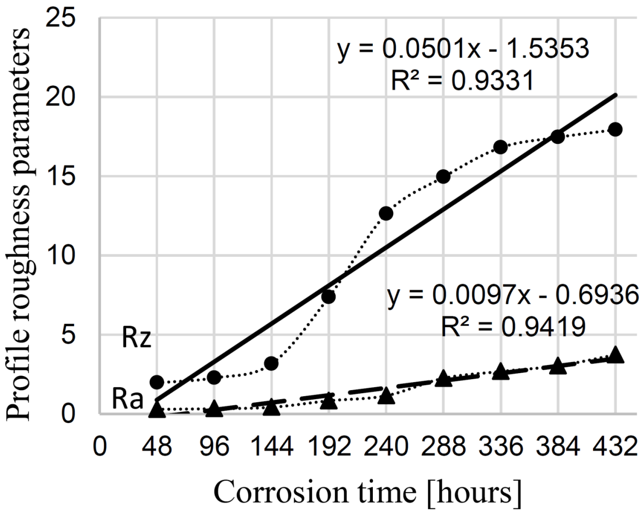

Fig. 5. Profile roughness of 1.4362 grade steel after corrosion in the nitric acid at the temperature of 333 K for different corrosion periods: *Ra*, *Rz*.

research (336 h), the observed changes in relative mass loss and corrosion rate were proportional. The roughness parameters (mainly *Rz*) behaved similarly to the above-described processes. The *Ra* parameter increased steadily during the corrosion process (Figs. 1, 5). In order to better illustrate the process, apart from the linear function, a third-degree mathematical function was used (Fig. 2).

The slowdown of the roughness increase represented by the *Ra* parameter during the tested time interval can be explained by the dissolution of protruding metal particles above the average roughness profile by nitric acid, which results in a flattening of the profile and, as an effect, a slower growth of the analysed parameter. The above assumption is confirmed in Fig. 6. The particles detached from the surface, which the acid washed, are visible on it.

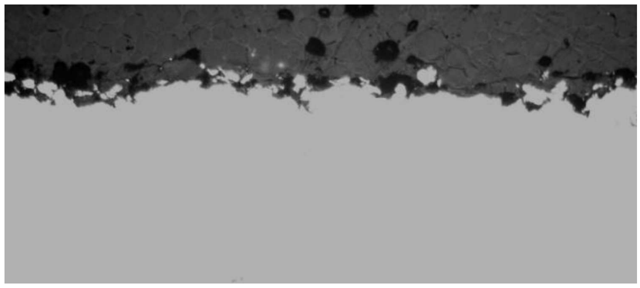

Fig. 6. Roughness 1.4362 grade stainless steel annealed at the temperature of 1423 K in 30 min kept in nitric acid V 65% at the temperature of 333 K for 384 h.

4. Conclusions

1. The tested 1.4362 grade duplex stainless steel annealed at the temperature of 1423 K in 30 min has a moderate corrosion resistance in an environment of nitric acid at the temperature of 333 K.
2. The obtained equations can be used to model the corrosion process using the corrosion rate of the results with 3rd- and 4th degree polynomials.
3. When monitoring the corrosion rate under industrial conditions, sufficient accuracy can be obtained using a linear function to describe the corrosion process.
4. Based on the test results, it is not recommended to cool the steel (intended for use in corrosive environments) in air, which was confirmed in the present study.

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