EFFECT OF 10% NaCl ON BASIC CARBON STRUCTURAL P235TR2 STEEL AT 10 ºC

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Abstract. Metal alloys working in real conditions are exposed to aggressive environments. The degree of aggressiveness of the environment may vary. Therefore, various construction materials are used to build machines and devices. One of the groups of materials widely used in industry are low-carbon steels. They owe their popularity mainly to the low price and relatively good technological and functional properties. These steels usually work in a low-aggressive environment. Pipelines are a typical application for low carbon steels. Pipelines are protected from corrosion on the outside, while the inside (working side) is not protected. One of the media in the pipelines is a liquid with a low concentration of NaCl. Pipelines are usually located underground, so their operating temperature is almost constant in the annual cycle and amounts to approx. 10 ºC. Taking the above into account, tests were carried out on one of the most frequently used steel grades, P235TR2, for the construction of pipelines. The tests were carried out at a temperature of 10 ºC in a 10% NaCl aqueous solution. After preparation, the samples were soaked in a corrosive solution for up to 432 hours. Corrosion loss was determined by the gravimetric method. Relative corrosion and corrosion rate of steel in the tested medium were calculated. On the basis of the tests carried out, it was found that P235TR2 steel has good corrosion resistance in the environment of 10% NaCl at 10 ºC. The corrosion was divided into two stages. In the first, a slow progress of the corrosion process was noted, in the second, a gradual increase in the corrosion rate was noted. The increase in the corrosion rate is the result of the surface development that occurs as a result of corrosion. With the possibility of contact of the corrosive medium with a larger surface, even with the constant impact of the corrosive agent, there is a greater corrosion loss, which translates into an increase in the rate of corrosion.

Keywords: steel, carbon steel, corrosion, corrosion rate.

Introduction

The production of certain products requires the use of materials with specific properties. Modification of working surfaces is also used [1; 2]. Pipes are an example of such products. They can be produced by rolling and then joining the material or as seamless. Each of the production technologies requires the use of a material with appropriate properties. Pipes produced in seamless technology have high mechanical parameters [3-11].

The working conditions of pipelines are different. Some work at elevated temperatures, others at reduced or ambient temperatures. Underground pipelines have the most stable working conditions. Their working temperature fluctuates slightly and amounts to about 10 ºC, extending deep into the material. The course of the corrosion process is determined, among others, by: the type of material, type of corrosive medium, parameters of the flowing medium [12-23]. A common corrosive medium is a NaCl solution [24-28]. The most common type of corrosion of carbon steels is uniform corrosion. It runs on the surface without any particular destruction of the material occurring from the surface of contact with the medium into the depth [29-36]. Previous research shows that the temperature of the corrosion medium also plays a significant role in the corrosion process. Generally, at higher temperatures, the corrosion process is faster [12; 14; 25; 28; 30; 35; 37]. The concentration of NaCl has a similar effect [27]. The literature provides many ways to determine the corrosion resistance of the material used [7; 37-43]. Unfortunately, the different research methods used by many authors make it impossible to compare the durability of materials with each other. In the presented tests, it was decided to determine the rate of corrosion of typical steel used for the production of seamless pipes in the environment of 10% NaCl water solution at 10 ºC.

Materials and methods

A seamless steel pipe with a diameter of 168.3 mm and a wall thickness of 6.3 mm, grade P235TR2 acc. EN 10216-1 [44]. The chemical composition of the tested steel is shown in Table 1. Samples were cut from the pipe with a power saw while maintaining the parallelism of the opposite walls. After cutting, the samples were subjected to normalizing annealing. After heat treatment, the cut surfaces of the samples were ground to a width of 10 mm and a length of 40 mm using a grinding wheel with strip sandpaper to a roughness of Ra = 0.40 µm. The outer and inner surfaces of the pipe were cleaned of impurities. Despite the microstructure composed of ferrite and pearlite, the test results were presented

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using the PN-EN ISO 3651-1:2004 [45] standard, which provides an algorithm for the analysis of results for austenitic steel.

Table 1

Chemical composition of the tested P235TR2 steel

Chemical elements in% by mass								
C	Si	Mn	P	S	Cr	Mo	Ni	Cu
0.11	0.30	0.58	0.02	0.01	0.21	0.03	0.01	0.18

The use of such calculation algorithm will make it possible to compare the corrosion of structural steels with typical steels intended for work in an aggressive environment. The aggressive environment was a 10% NaCl aqueous solution at 10 ºC. The progress of corrosion was measured by weight loss of the samples after particular soaking times. 6 samples removed every 48 hours of soaking were used for the study. The experiment was repeated three times. Each sample was weighed three times. The profile was also tested three times for each sample, keeping the direction of needle movement parallel to the axis of symmetry of the pipe. The arithmetic mean of three determinations was used for calculations.

Corrosion losses of the tested steel are calculated with the use of the below formula (1) and (2):

$$r_{corm} = \frac{8760m}{St\rho}, \quad (1)$$

$$r_{corg} = \frac{10000m}{St}, \quad (2)$$

where t – time of treatment in the corrosive solution of 10% NaCl, hours;
S – surface area of the sample, cm^2;
m – average mass loss in boiling solution, g;
ρ – sample density, $g \cdot cm^{-3}$.

Weight measurements of the samples were made on a Kern ALT 3104AM balance. The reading was made with an accuracy of 0.0001 g. The profile was examined with a Diavite DH5 profilometer. For this device, the maximum measuring length was 15 mm.

Results and discussion

The microstructure of the tested steel after normalizing annealing is shown in Fig. 1. The microstructure of the tested steel consists mainly of ferrite and pearlite. The arrangement of ferrite grains indicates their deformation as a result of plastic working.

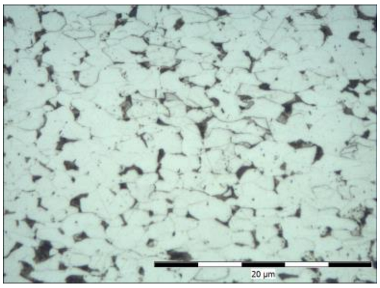

Fig. 1. **Microstructure of P235TR2 steel after normalizing annealing, et.: Nital**

The equation showing the relative mass loss of the P235TR2 steel depending on the soaking time is presented in (3). For this equation, the correlation coefficient is 0.9913.

$$rml = 10^{-0.5} \cdot t^2 - 0.0014 \cdot t + 0.1535 \quad (3)$$

where t – time, hours.

Relative mass loss of the P235TR2 steel after corrosion tests in 10% NaCl at 10 ºC depending on the soaking time is shown in Fig. 2.

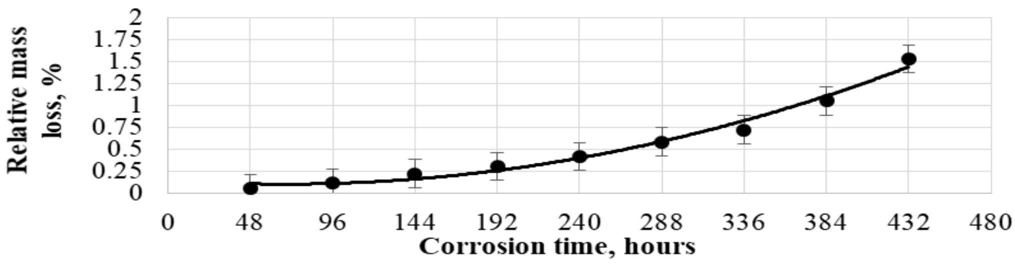

Fig. 2. **Effects of the corrosion time on the relative mass loss of P235TR2 steel after corrosion tests in 10% NaCl at 10 ºC**

The corrosion rate measured as the loss of steel thickness measured in mm per year depending on the soaking time is shown in Fig. 3.

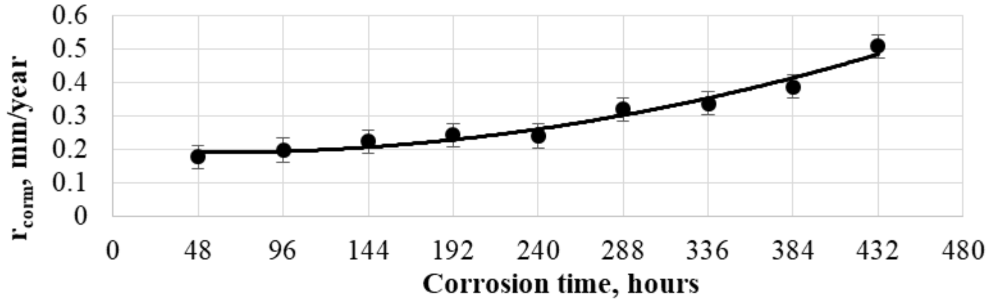

Fig. 3. **Effects of the corrosion time on the corrosion rate measured in mm per year of P235TR2 steel after corrosion tests in 10% NaCl at 10 ºC**

The equation showing the corrosion rate measured as the loss of steel thickness measured in mm per year of the P235TR2 steel depending on the soaking time is presented in (4). For this equation, the correlation coefficient is 0.9841.

$$r_{corm} = 2 \cdot 10^{-0.6} \cdot t^2 - 0.0002 \cdot t + 0.1974 \quad (4)$$

where t – time, hours.

The corrosion rate measured as the loss of steel thickness measured in grams per m^2 of surface depending on the soaking time is shown in Fig. 4.

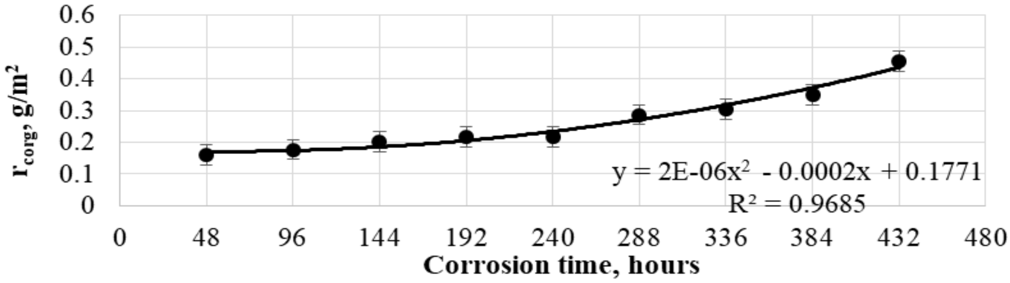

Fig. 4. **Effects of the corrosion time on the corrosion rate measured in gram per m^2 of P235TR2 steel after corrosion tests in 10% NaCl at 10 ºC**

The equation showing the corrosion rate measured as the loss of steel thickness measured in gr per m^2 of the P235TR2 steel depending on the soaking time is presented in (5). For this equation, the correlation coefficient is 0.9841.

$$r_{corm} = 2 \cdot 10^{-0.6} \cdot t^2 - 0.0002 \cdot t + 0.1771 \quad (5)$$

where t – time, hours.

The surface of the P235TR2 steel sample after soaking in 10% NaCl at 10C for 144 hours is shown in Fig. 5. The relative weight loss of the samples (Fig. 2) soaked in a 10% NaCl aqueous solution until 96 hours is small, which is confirmed by the corrosion rates determined from dependence (1) and (2)

(Fig. 3 and Fig. 4). In the samples soaked for more than 96 hours, a gradual increase in relative weight loss was observed.

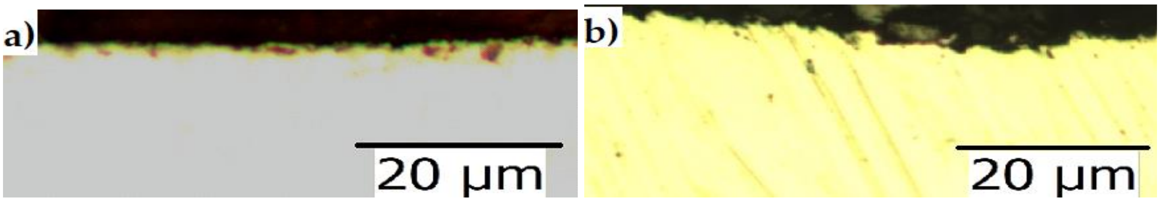

Fig. 5. **Surface of P235TR2 steel after soaking in 10% NaCl at 10 ºC for hours:** a – 144; b – 288

The corrosion rate in the range from 144 to 240 hours slowly increases gradually in direct proportion to the time of soaking, and the character of changes in this time interval can be described as a linear function, similarly to the period up to 96 hours. When the steel was soaked for more than 240 hours, the relative weight loss and the rate of corrosion were noted to vary over time. The analysis of the course of relative loss and corrosion rate leads to generalizations consistent with the classical corrosion processes. Steel in the initial period of soaking in a water solution of NaCl is subject to a slow corrosion process. This should be explained by the high smoothness of the surface of the samples. Considering the fact that the corrosive medium is mild in the period up to 96 hours of soaking, the process hardly progresses. After exceeding this time, the aggressive action of NaCl causes a gradual development of the surface (Fig. 5), which increases after exceeding 240 hours. Then, the contact surface of the corrosive environment with the tested samples is larger, so even assuming the same corrosion rate in relation to its surface unit, it leads to an increase in the corrosion rate of the sample. It should be mentioned that the weight of the sample was referred to the initial weight of the sample throughout the test period, which in effect flattens the effect of the corrosive environment.

The relative mass loss of the P235TR2 steel after corrosion tests in 10% NaCl at 10 ºC can be described with sufficient accuracy by the first degree function up to a soaking time of 330 hours, and for a corrosion rate of 240 hours. After these soaking times, a greater surface development was observed, and thus a larger contact surface with the corrosive environment, resulting in a non-linear increase in corrosion parameters. For these soaking times, the increase in the corrosion rate most accurately reflects the second-stage function. Analyzing the mass losses of the samples and the corrosion rate, it should be stated that this steel is not suitable for operation in the analyzed corrosive environment. It should be noted, however, that the tests used are accelerated tests. Combining the above facts, it can be concluded that P235TR2 steel can work in contact with a medium containing periodically small concentrations of NaCl. Of course, the more aggressive the medium, the shorter the time of periodic work in this medium. Considering the theoretical behavior of the pipeline material in real conditions, it should be noted that the flowing medium may cause smoothing of the pipeline walls, and therefore the corrosion process may last longer in the first and second stages discussed above. The occurrence of such a condition may extend the operational capacity of the pipeline.

Conclusions

1. P235TR2 steel can work in contact with aqueous NaCl solution to a limited extent;
2. When soaking steel in 10% NaCl at 10 ºC for up to 240 hours (0.24 mm per year, 0.21 $g \cdot m^{-2}$), a directly proportional course of the process was observed (which could be described by the first degree function), after exceeding this time, the corrosion rate accelerated, forcing its description with the second degree function;
3. For the soaking time of 432 hours, the corrosion rate was: 0.51 mm per year, 0.46 $g \cdot m^{-2}$;
4. The equations used to describe the corrosion process parameters of steels intended for use in an aggressive environment enable a direct comparison of these parameters with the parameters of other steels. It can be assumed that an increase in the medium temperature will increase the rate of corrosion.

Author contributions

Conceptualization, methodology: T.L.; validation, formal analysis, investigation, writing and editing: T.L. and J.P. All authors have read and agreed to the published version of the manuscript.

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