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To cite this article: E A Guseva *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **560** 012181

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Comparative evaluation of corrosion resistance of wheel and rail steels in various media

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Abstract. In order to increase the service life of rolling stock parts and rails, it is necessary to know the value of the corrosion rate of alloys in various media. In this work, the corrosion resistance of various alloys, used in railway transport, was investigated. To determine the rate of corrosion, a polarization method with the use of the potentiostat-galvanostat "Pi 50-Pro" was used. The value of the corrosion rate was determined on the basis of processing of the polarization curves with the use of the graphical method. To control the obtained results, corrosion rate was determined by decrease of the mass of samples, made from the same alloys (gravimetric method). Obtained results showed high convergence. Studies were carried out in a simulated solution. Based on a comparison of the values of the corrosion rate, the most resistant steels were determined. Corrosion resistance increases in series: 09G2S, 110G13L, St3ps, 55G, 60G, M76T, E76KHSF12KH1, 12KH18N9T.

1. Introduction

Corrosion of railway transport not only causes huge losses to the national economy of the country, but can also cause major and current repairs of the lines of traffic of trains. Moreover, corrosion of rail transport is also dangerous because it can endanger the lives of passengers (suburban trains, passenger trains). Rails and fasteners, rolling stock wheels, various equipment, metal parts of buildings and structures, bridges, equipment, communications, wagons and locomotives operate under very severe corrosive conditions. Railways cross different climatic zones. Trains, which move on railway lines, are subjected to a very aggressive and, importantly, periodic effects of different climatic conditions [1-3]. Moreover, most of the transported cargos also have a negative impact; some can even cause and intensify the corrosion of metal. The main causes of corrosion of the railway transport are high environmental aggressiveness, humidity, heterogeneity of the structure of metal and its composition, periodic wetting of the surface by atmospheric precipitation, contamination with dust and transported particles (for examples, salt, coal, mineral fertilizers) [2-4]. The main damage from corrosion of metal is associated not only with the loss of large quantities of metal, but also with damage or failure of the metal structures



themselves, because due to corrosion, they lose the necessary strength, plasticity, impermeability, heat and electrical conductivity, reflectivity and other necessary qualities [2, 5, 6].

2. Results and Discussion

As objects of investigation, steels, used for the production of various parts and machines of railway transport, wheels, rails were chosen. The nomenclature of steels varied from low-carbon, medium-carbon, high-carbon to stainless, manganese steels is 09G2S, 110G13L, St3ps, 55G, 60G, M76T, E76XSF, 12X18N9T.

Research method. Electrochemical study of the corrosion process was carried out at the potentiostat-galvanostat "PI-50-Pro". The device supports most of the electrochemical experimental methods – voltammetry, potentiometry, coulombmetry, chronopotentiometry, cyclic and linear sweep of the potential or current, pulsed analytical methods of research, and many others. In these studies, four electrode circuits for connection to an electrochemical cell were realized, using a chlorine-silver reference electrode and an auxiliary platinum electrode. To conduct corrosion tests in the first series of experiments, a 3% NaCl solution in distilled water, recommended by GOST, was used as a supporting solution [7-9]; in the second series, water was used as the electrolyte.

The method for removing the current-potential relationship is the following.

Before the test, a 1 cm² area was isolated, the remaining surface was covered with a technical insulating varnish. Then, the open metal surface was etched in a 20% solution of hydrochloric acid for 30 minutes to a pure metal, washed with distilled water and degreased with ethyl alcohol. The samples were placed in a glass with a capacity of 500 ml in such a way that the isolated area was completely immersed in the working solution. Removal of "U-I" curves can be represented as an algorithm. Activate the potentiostat "PI - 50 - Pro", run the program PS_Pack2, select the type of device (pulse). Then, the metal sample was connected to the "Work" and "Comp" connectors; the reference electrode (silver chloride) – to the "Ref" connector; the auxiliary (platinum) – to the "Counter" connector. With the disconnected cell, the initial potential was measured until it was fully established within 5 minutes. After that, the type of experiment was chosen (linear sweep). The operating regime "potentiostat" was set with the following parameters: initial potential is minus 390 – 520 mV; maximum potential is 100 mV; minimum potential is minus 1500 mV; final potential is 100 mV; initial direction to the cathode region; scanning speed is 25 mV/s. Specified conditions were applied, and the program appeared.

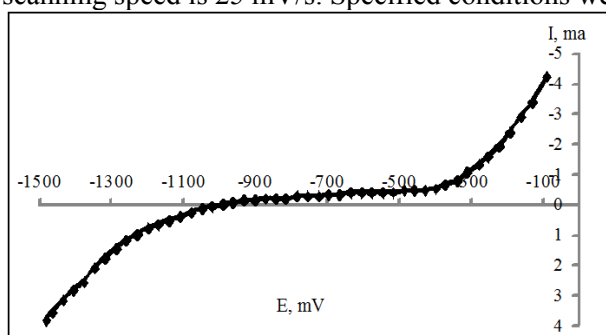


Figure 1. Dependence of the current on the potential, relative to the reference electrode on a sample of St3pc steel in a solution of 3% NaCl.

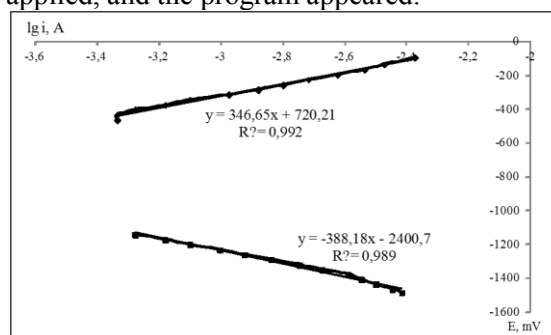


Figure 2. Dependence of the voltage on the logarithm of the current density for the anodic and cathodic polarization curves for a sample of St3pc steel in a solution of 3% NaCl.

Obtained results were analyzed with the help of a graphical method for calculating the corrosion rate, because it allows, in contrast to the analytical one, calculating the corrosion rate for very complicated cases that correspond to the actual conditions of the corrosion process. To evaluate the corrosion resistance, a ten-point scale of corrosion resistance of metals that is recommended by GOST [7] was used.

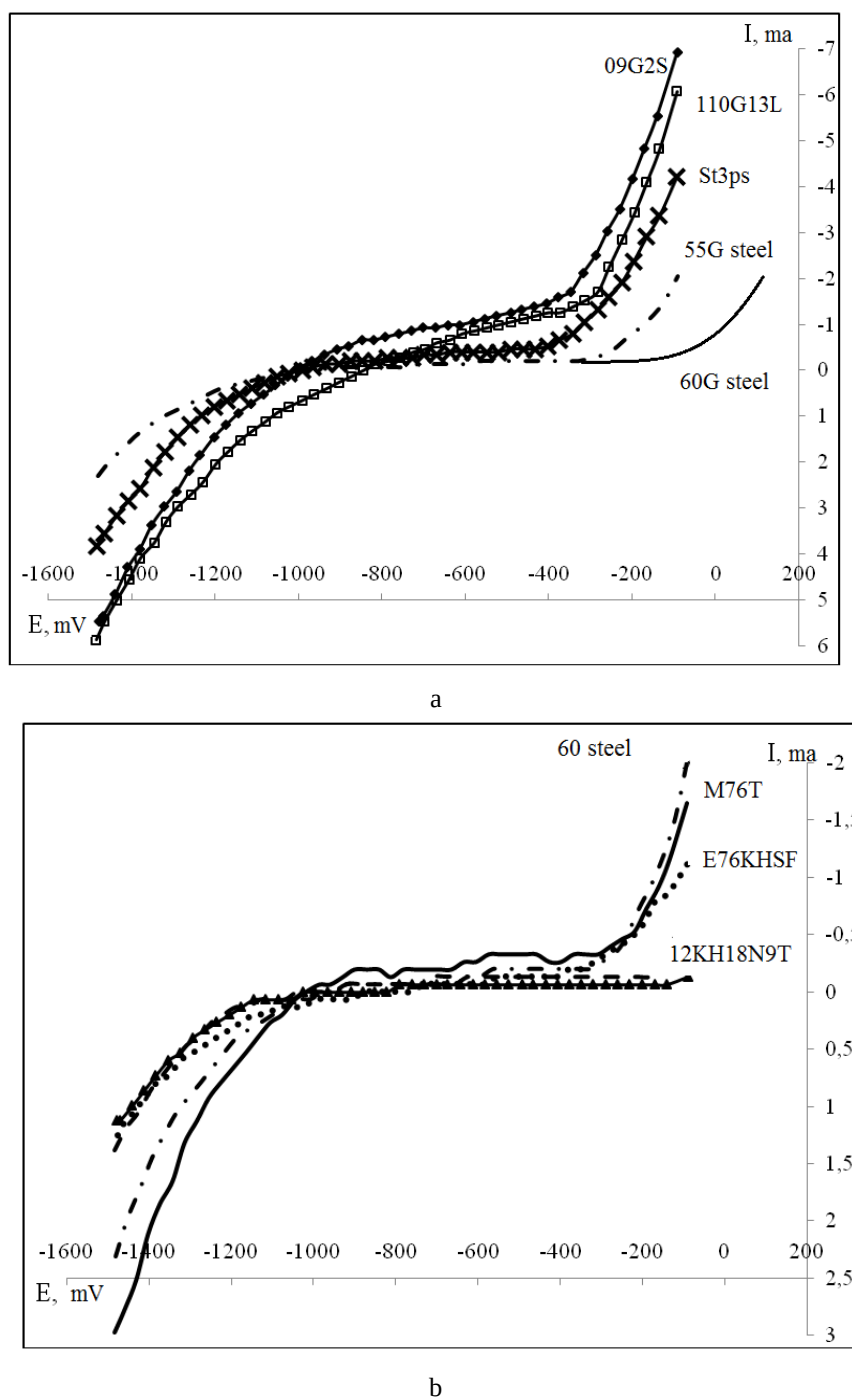


Figure 3. Dependence of the current (mA) on the potential (mV) relative to chlorine-silver reference electrode: a) for steels 09G2S, 110G13L, St3ps, 55G, 60G b) for steels 60, M76T, E76KHSF, 12KH18N9T

For a rough estimate, we will use groups of persistence, and for more accurate one - points (Table 1). An example of calculating the corrosion rate for a sample of St3PS steel in a 3% solution of NaCl is shown further.

Table 1. Results of corrosion tests of samples of alloys in 3% NaCl solution. Polarization method.

Name of sample	ρ , (g/cm ³)	Average current index of corrosion rate, (A/m ²)	Average weight index K_m , (g/m ² h)	Average depth index K_n , (mm/year)	Corrosion resistance score	Type of resistance
09G2S	7.85	1.8026	1.8783	2.0961	8	Slightly resistant
110G13L	7.82	1.5533	1.6185	1.8131	8	Slightly resistant
St3ps	7.85	0.5105	0.5319	0.5935	7	Of low resistance
55G steel	7.826	0.1801	0.1876	0.3694	6	Of low resistance
60G steel	7.80	0.2568	0.2676	0.3006	6	Of low resistance
M76T	7.80	0.29135	0.2983	0.4324	6	Of low resistance
E76KHSF	7.80	0.3066	0.3194	0.4788	6	Of low resistance
12KH18N9T	7.90	0.0195	0.0203	0.0225	4	Resistant

Obtained results (Table 1 and Figure 3a and 3b) indicate that 12Kh18N9T and E76XSF steels are the most resistant to corrosion; St3ps, 110G13L, 09G2S steels are the least resistant.

For the second series of experiments, process water was used as the electrolyte. Polarization curves for 55G, 60G, 09G2S, 110G13L and St3ps steels were taken. For the alloy, 12X18H9T, we did not try to take the polarization curves. This is due to the high corrosion resistance of this alloy in water. Every experiment was repeated 6 times for each alloy, the experimental error was from 2.5 to 11.7%, depending on the alloy. The results are shown in Table 2. Obtained results (Table 2) indicate that St3pc steel and 110G13L steel are the least resistant to corrosion in water. Corrosion resistance of the remaining steels (55G, 60G, 09G2S) is approximately the same.

Table 2. Results of corrosion tests of samples of alloys in 3% NaCl solution and water by taking the readings of polarization curves.

Name of sample	Current index of corrosion rate, (A/m ²)		Depth index K_n , (mm/year)	
	3% NaCl	Process water	3% NaCl	Process water
09G2S	1.8026	0.2215	2.0961	0.2569
110G13L	1.5533	0.3201	1.8131	0.3736
St3ps	0.5105	0.5025	0.5935	0.5843
55G steel	0.1801	0.2118	0.3694	0.2463
60G steel	0.2568	0.2534	0.3006	0.2947

Gravimetric tests of the corrosion rate for 55G, St3pc, 110G13L, 12X18N9T steels were also carried out. For each steel, the experiment was repeated 3 times, the error of the experiments was from 4.1 to 12.8%, depending on the alloy. The gravimetric method for determining the rate of total uniform corrosion consists in weighing the metal samples before and after the corrosion tests and calculating the corrosion losses by the difference in mass. The depth index of corrosion was determined by formulas 1 and 2, results of studies are presented in Table. 3. Density of alloys is indicated in Table 1.

$$K_m = \Delta m / St \quad (1)$$

where K_m – corrosion rate, $\text{g/m}^2 \cdot \text{h}$, $\Delta m = m_0 - m_1$; m_0 and m_1 - mass of samples before and after tests, S - sample area, m^2 ; t - time of corrosion tests, hour.

$$K_n = 8.76 \cdot K_m / \rho \quad (2)$$

where 8.76 – coefficient for the transition from the measurement of the mass index of the corrosion rate per 1 h to the depth index per 1 year; ρ is the density (g/cm^3).

Table 3. Results of corrosion tests of samples of alloys in water, $t = 24$ h.

Name of sample	Δm , (g)	S , (m^2)	K_m	Depth index K_n , (mm/year)		Type of resistance
				Gravimetric method	Polarization method	
110G13L	0.0218	0.00201	0.4519	0.5043	0.5843	Of low resistance
St3ps	0.0093	0.00124	0.3125	0.3501	0.3736	Of low resistance
55G steel	0.0079	0.00171	0.1925	0.2155	0.2463	Of low resistance
12KH18N9T	0.0003	0.00162	0.0077	0.0086	–	Resistant

Results of the investigations (Table 3) show that the most corrosion-resistant in water is 12Kh18N9T steel, the least resistant is St3PS steel. The dependencies, obtained with the potentiostat-galvanostat “PI-50-Pro”, were confirmed by the gravimetric method. The values of the corrosion rate for polarization tests are slightly higher than those obtained by the gravimetric method. It can be assumed that with longer-lasting gravimetric tests, corrosion products, which eliminate a corrosion effect of the medium, are formed.

3. Conclusion

The conducted investigations on the corrosion rate of steels and alloys (K_p , mm/year), used in the railway industry, both in simulated solution and in process water, showed that the corrosion resistance increases in 09G2S, 110G13L, St3ps, 55G, 60G, M76T, .E76XSF steel, and the most resistant of them is 12X18H9T steel.

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