

## CORROSION DIAGNOSTICS TECHNOLOGY IMPROVEMENT OF REINFORCED CONCRETE SUPPORTS OF THE RAILWAYS CATENARY SYSTEM

*A.A. Kuznetsov, A.A. Zaprudskiy, A.S. Bryukhova, K.I. Fomichenko*

*Abstract:* The article deals with the processes of corrosion in the reinforced concrete supports of the catenary system and describes the reactions accompanying the steel reinforcement corrosion. It is described the experiment of electrochemical of reinforcement corrosion. It is made samples with various degrees of steel reinforcement corrosion. It was changed the concentration of the aqueous electrolyte solution accelerating the corrosion process to determine the required characteristics. It was investigated the change in the degree of corrosion by passing an electric current in the anode – cathode system. The anode was steel reinforcement and the cathode was a copper electrode. The experiment involved samples with different concrete porosity. In addition, it was performed the simulation of cracks occurring during operation and accelerating the corrosion process. It was carried out the X-ray graphic control of steel reinforcement in concrete and it was determined the amount of iron that released to the concrete surface. Spectral analysis was performed to determine the quantitative content of corrosion products on the concrete surface. The analysis results confirmed the dependence of the corrosion products concentration on the concrete surface with the removal of metal from the steel reinforcement volume. The conclusions are about the possibility of using mobile spectral analyzer including the presented methodology.

*Keywords:* railway, reinforced concrete, reinforcement, catenary system, corrosion, diagnosis, X-ray radiography, spectral analysis, intensity, spectrum.

### Introduction

It is used reinforced concrete support when laying overhead power lines for wire suspension. The main types of support of the catenary are reinforced concrete supports (95%) of the total quantity. The reliability of the supports determines the continuity of power supply and the safety of train traffic. It is known that a heavy reinforced concrete support is able to knock down the entire anchor span, and therefore monitoring their condition allows us to prevent accidents and avoid large expenses of recovery and a lay-over of the railway track.

Nowadays it is used different methods of control for corrosion diagnostics condition, among which the most common are acoustic and electrochemical. The disadvantage of such methods is the indirect measurement values associated with the corrosive condition of functional relationships.

This paper presents a direct analysis of corrosion products on the surface of reinforced concrete structures. We suggest the results of experimental studies confirming the possibility of using spectral methods of control. The prospect of the conducted researches is the use of mobile spectro-analyzers in tandem with the methodology that is led in this research [1].

### 1. The causes of steel reinforcement corrosion

Accidents occur when the bearing capacity of the support is lost, the causes of which are cracks, factory defects and corrosion damage. Concrete has an alkaline medium with pH=12-13, sometimes more. In this case, the steel reinforcement is in a passive condition as it is resistant to an alkaline environment, the potential of the steel is in the positive area and oxidation does not occur. However, due to the fact that the underground part of the support is in a high humidity condition and oxygen has access to the reinforcement, due to the porosity of the concrete corrosion of the reinforcement is raised, which has an electrochemical character. The electrolyte is a porous layer of concrete which is filled with water and oxygen. And due to stray currents and leakage currents, the reaction rate increases.

Concrete structurally is porous material and it can actively absorb moisture and the air from the environment.

The porosity depends on the degree of air fullness of the total volume of the material. The reason for the appearance of pores is the manufacturing technology and the quality of the concrete components. During the process of solidification, some amount of water chemically binds to the minerals of the cement, and

Table 1. Sample parameters

Sample number	Saturated sample mass, m, kg	Non-saturated sample mass, m, kg	Sample volume, V, m <sup>3</sup>	Saturated sample density, ρ, kg/m <sup>3</sup>	Non-saturated sample density, ρ <sub>0</sub> , kg/m <sup>3</sup>	Porosity P <sub>0</sub> , %
1	2,551	2,488	0,987	2,585	2,521	2,5
2	2,455	2,377	0,931	2,637	2,553	3
3	1,865	1,721	0,720	2,590	2,390	7,7
4	2,404	2,357	0,987	2,436	2,388	1,9

the rest of water evaporates, that is why the pores are formed. The porosity value can be determined by knowing the mass of a moisture-laden and dried concrete sample. In the research, it was calculated the total porosity of the samples in the volume of concrete P(total), %, according to formula (1):

$$P_{\text{обш}} = \left(1 - \frac{\rho_0}{\rho}\right) \times 100, \quad (1)$$

where ρ<sub>0</sub> – is the density of a sample that is not saturated with water [kg/m<sup>3</sup>];

ρ – is the density of the saturated sample, [kg/m<sup>3</sup>].

For the experiment we prepared 4 samples of concrete, the size is 60×60×200, a reinforcement bar is 10 mm in diameter. The appearance of the sample before the tests is shown in Fig. 1.



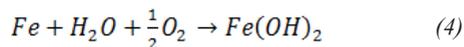
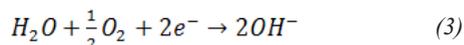
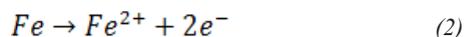
Fig.1. Appearance of the reinforced concrete sample before the tests

Two samples had a homogeneous structure of concrete and they did not contain any defects in the reinforcement. The third sample was made with increased porosity, in comparison with others, and it also had artificial cracks in concrete and had no defects in the reinforcement, the fourth sample also had artificial cracks in the concrete and the defect of the reinforcement in the form of a thinning of the diameter. Artificial cracks were modeled by a cylindrical hole 2 mm in diameter from the surface

of the specimen to the reinforcing bar. It is presented the initial data and the porosity values in Table 1.

The value of porosity directly affects the corrosion resistance of the reinforcement inside the concrete. Corrosion resistance is the most important parameter of reinforced concrete supports of the overhead lines, which affects the durability and reliability of the supports.

Corrosion in the article was considered as an electrochemical process that arises from the interaction of water and oxygen, where the basic oxidation-reduction reactions can be described by equations (2) and (3) representing anodic oxidation of iron and cathodic reduction of copper, respectively. The overall reaction is represented by equation (4), here Fe(OH)<sub>2</sub>, is one of the several possible corrosion products, depending on the environment.



The scheme of the reinforced concrete corrosion process is shown in Fig. 2. After breakdown of passivity a pit is formed and iron dissolution proceeds according to equation (3). Electrons are transferred from the anode to the cathode (electronic current), where oxygen recovery occurs, according to the equation (4) [3 - 5].

The manufactured samples, which are previously calculated porosity, were subjected to electrocorrosion by placing an electrolyte in a water solution with different concentrations of NaCl and connected to an external voltage source. Electrochemical corrosion reinforcement can be increased by leakage current or stray currents from the electrified rail vehicles.

## Section IV: MEASUREMENTS IN THE INDUSTRY

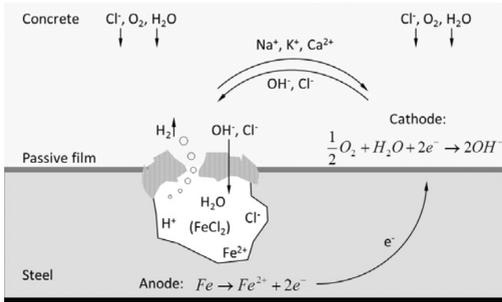


Fig.2. Schematic representation of the corrosion process

The anode is a draining electrical current position from the reinforcement. The iron oxidation occurs at the anode. Electrolysis will take place in a layer of concrete saturated with various ions. A similar mechanism of electrocorrosion occurs in the soil under the influence of sneak currents. Each sample was placed in a solution of sodium chloride, as shown in Fig. 3, the anode was a steel reinforcement and the cathode was a copper plate which were connected to an external power source.

Samples 1, 2 and 3 were placed in one, two and three percent solutions of sodium chloride, sample 4 was also placed in a three percent solution but it had a porous structure of concrete. The voltage, which was impressed to all four samples, was identical, and the current was different due to different concentrations of the electrolyte solutions and porosity. Electrolysis had occurred for 30 hours.

For the completion of the electrolysis, it was found brown spots containing corrosion products on the concrete surface, which indicates the decomposition of steel reinforcement bars. Fig.4

It was produced X-ray control which shows changes in the diameter of the concrete steel rods inside the concrete and further comparison with the concentration of corrosion products on the concrete surface. In Fig. 5 a, b shows a reduction in the reinforcement cross section.

The reinforcement cross section, it was corroded before and after that, was broken into elementary area in steps of 1 mm, and the area is calculated by integrating along the contour of the image of a given brightness. After the calculation of the area, it was revealed that the reinforcement cross-section was decreased by 5%. Thus, about 5% of the iron came out on the surface of iron.

From all investigated samples and one which



Fig 4. Sample after electrocorrosion

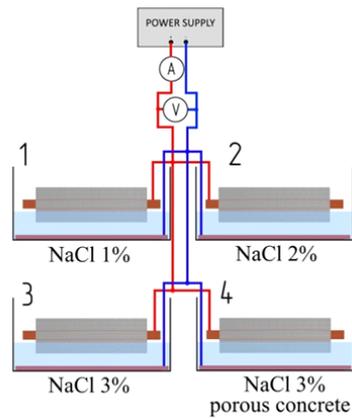


Fig. 3. Installation scheme of testing samples in different environments for electrocorrosion process investigation

is not taking place in electrolysis, the top layer of the concrete was removed, the obtained powders were placed in the craters of graphite electrodes and filled with glue. In addition, samples were prepared containing only rust, pure concrete, and a clean electrode with and without it [6].

It was carried out using the "ARGON-5SF" emission spectrometer for all testing electrodes under spectral analysis. In Fig. 6 shows the graphite rod analysis scheme.

It is presented the numerical values of the intensities of the spectral lines of iron (275.574 nm), carbon (193.090 nm), and the relative intensity for the samples under investigation in Table 2.

The obtained spectra superimposed on each other, with different corrosion degrees, are shown in Fig. 8.

### Conclusion

1. It was prepared reinforced concrete samples with various degrees of corrosion to determine the degree of real objects corrosion, which is obtained

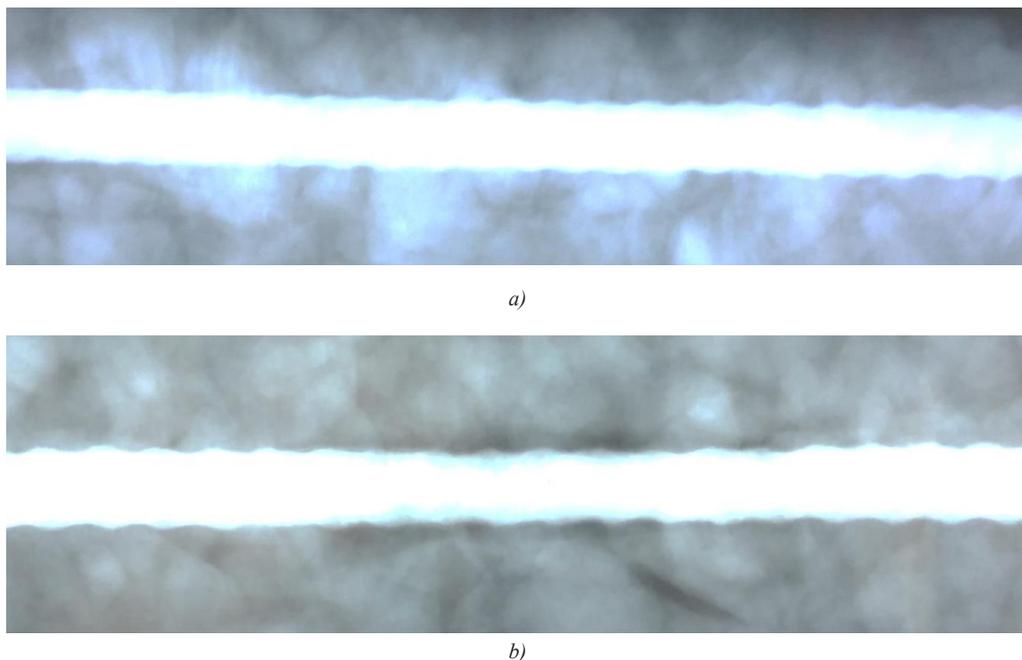


Fig 5. X-ray images of the sample №2  
 a) before corrosion effect; b) after corrosion effect

Table 2. Carbon and comparison line intensities

Sample	$I_{Fe}$	$I_C$	$I_{rel}$
1%	1118252	4979994	0,225
2%	2964327	3576839	0,829
3%	1172748	759444	1,544
3%II	1460473	598319	2,441
Rust	4244541	3272797	1,297
Concrete	771789	3350958	0,230
Glue	67166	3647528	0,018
Graphite	48344	5942766	0,008

by varying parameters of the environment and various electric current impact.

2. It was carried out X-ray examination of metal reinforcement inside concrete after various effect factors affecting to rate of its corrosion.

3. It was performed spectral analysis of the chemical composition on the concrete surface of various samples. It is presented spectrograms of samples with different quantitative content of

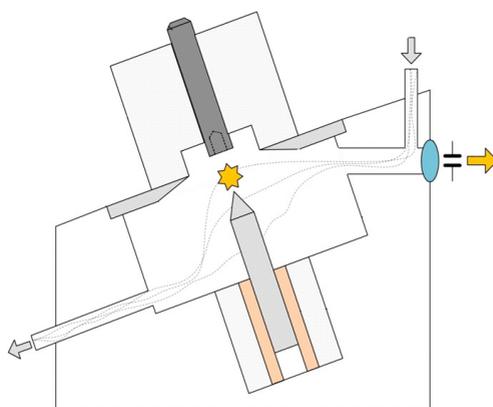


Fig 6. Analysis scheme for graphite electrodes on the Argon-5SF spectrometer

elements on the surface (Fe, Cl, Na). It is proposed the research method for the Argon-5SF spectrometer.

4. In further research it is proposed to evaluate the strength characteristics of reinforced concrete supports of the overhead line with the results

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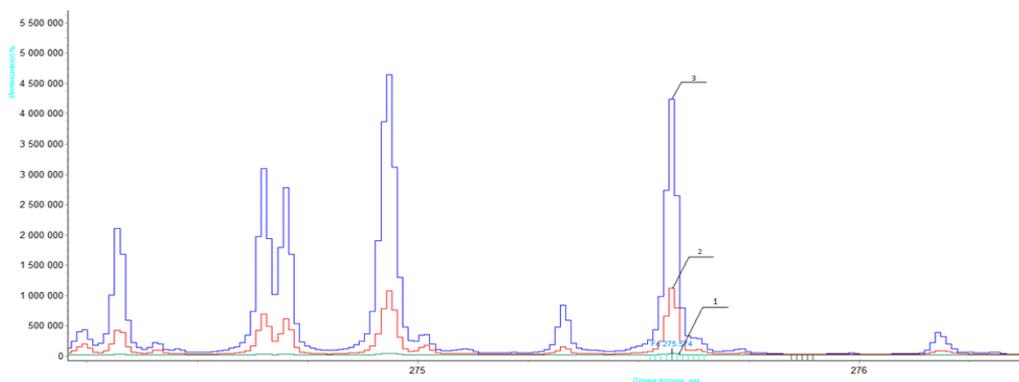


Fig. 8. Spectral lines intensity of three samples, with different corrosion degrees:  
1 - pure graphite; 2 - average content of corrosion in concrete; 3 - rust

of instrumental measurements of the number of elements on the surface accompanying corrosion.

### References

[1] **В. И. Подольский.** Железобетонные опоры контактной сети. Конструкции, эксплуатация, диагностика / Труды ВНИИЖТ. – М.: Интекст, 2007, 152 с.

[2] ГОСТ 12730.4-78. Бетоны. Методы определения показателей пористости.

[3] **D. A. Cremers, L. J. Radziemski** Handbook of Laser-Induced Breakdown Spectroscopy, 2013 John Wiley & Sons, Ltd. 418 p.

[4] **Millar S., Wilsch G., Eichler T., Gottlieb C., Wigenhauser H.** Laser Induced Breakdown Spectroscopy (LIBS) im Bauwesen – automatisierte Baustuffanalyse // Beton- und Stahlbetonbau 110 (2015), Heft 8. P. 501–510.

[5] **С. Н. Алексеев.** Коррозия и защита арматуры в бетоне. НИИЖБ Госстроя СССР/ Стройиздат, 1968. – 233 с.

[6] **А. С. Иванов.** Рентгенография металлов. Пермь: Изд-во Перм. нац. исслед. политехн. ун-та, 2014, 77 с.

[7] **С. А. Гончуков.** Рамановская спектроскопия каротиноидов [Текст]: учебное пособие / С. А. Гончуков, М. Е. Дарвин, Ю. Ладемани; М-во образования и науки Российской Федерации, Нац. исслед. ядерный ун-т "МИФИ". – Москва: НИЯУ МИФИ, 2012, 36 с.

[8] **А. А. Кузнецов, А. В. Пономарев, О. Б Мешкова., О. С. Бучельникова.** Возможности

приборов ЛИБС для определения коррозионного состояния железобетонных конструкций при длительной эксплуатации // Современные наукоемкие технологии. Ч.4. № 12. 2015. С. 610–615.

[9] **Timur A. Labutin, Andrey M. Popov, Sergey M. Zaytsev, Nikita B. Zorov, Mikhail V. Belkov, Vasilii V. Kiris, Sergey N. Raikov.** Determination of chlorine, sulfur and carbon in reinforced concrete structures by double-pulse laser-induced breakdown spectroscopy / Spec-trochimica Acta Part B 99 (2014). P. 94–100.

[10] **С. Н. Родников, В. А. Лихачев, С. В. Шишкина, В. М. Кондратов.** Вопросы металловедения в гальванотехнике и коррозии: Учебное пособие. - Горький: изд. ГГУ, 1989, 104 с.

[11] **С. Шлюкер.** Поверхностно-усиленная Рамановская спектроскопия (SERS): аналитические, биофизические и био-медицинские приложения: Монография / под ред. С. Шлюкера. – М.: ТЕХНОСФЕРА, 2017, 331 с.

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