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The experimental and innovative research on polarization of tensioned rebars coated with sulphur polymer composites

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Abstract

This paper presents the results of the experimental research and analyses indicating the usefulness of polymer sulphur composites to the protection against corrosion of reinforcement. In paper presents materials also the domain of the personal investigations and the methodology are definite. After the analyze of the initial results the optimum compositions have been chosen to the experimental research.

This paper presents investigation results of corrosion rate for steel reinforcement bars that have been covered with polymer coating and have been exposed to tensile stresses in a solution simulating pore-liquid of concrete. Experimental investigation of tendencies that occur during corrosion process of reinforcing steel covered with polymer and exposed to tensile stress has been attempted. To determine an effect of tensile stress on corrosion rate for St3S-b steel that has been covered with sulphuric coating and exposed to aqueous environment that was to simulate pore-liquid of concrete contaminated with chloride ions was an aim of the investigation. The samples underwent loading in an one-axial state of the stress including varied values of tensile stress, at the same time corrosion rate was determined potentiostaticaly. Potentiostatic investigation has been carried out in order to determine parameters describing corrosion rate of samples tested. Corrosion rate for the steel has decreased by orders of magnitude when covered with protective coating even though this latest became unseal at load exceeding. A small decrease of corrosion rate has been found for the steel that has not been covered with polymer coating when placed in model pore-liquid of concrete and exposed to tensile stress increasing.

Keywords: corrosion, reinforcing steel, tensile stress, sulphur polymer composites, polarization.

1. Introduction

Corrosion is a major problem from the social, economic, technical and scientific points of view. Despite extensive research and numerous papers on this subject, the problem has not been completely solved yet. It is estimated that in highly developed countries losses due to corrosion annually amount to about a thousand dollars per capita. In Poland they are estimated at 6-10% of the GDP [8, 13-16].

Corrosion contributes to the shortening of the service life of building structures, i.e. to a reduction in their capability to perform the required functions over a given period of time.

Corrosion affects practically all building materials, not only steel, concrete or reinforced concrete (of course, no building material, structural element or building is everlasting). Generally speaking, the fight against corrosion comes down to providing a given material or element with protection whereby its failure free service life is significantly extended [8, 13-16].

Corrosion of the reinforcing steel and concrete may result from the action the ambient gaseous or water environment. It may also be due to the improper choice of components (including additions and admixtures) from which the concrete was made [8, 13-16].

The degradation of reinforced concrete may be caused by the corrosion of the reinforcing steel or the concrete or by the simultaneous corrosion of the reinforcing steel and the concrete [2-5]. The considerable porosity of concrete and cracks in or damage to the concrete cover contribute to the diffusion, absorption and adsorption of gases and to the diffusion of the substances dissolved in the pore liquid deep into the concrete. All kinds of aggressive substances from the surrounding environment diffuse into the inside of concrete and directly or indirectly cause the corrosion of the reinforcing steel, which usually ends in the loss of adhesion of the concrete to the steel, manifesting itself in the fracturing, loosening and spalling of the concrete cover [1, 5, 7-9, 13-17, 23].

Surface protection of the reinforcing steel, in the form of a hermetic protective coating, considerably reduces or prevents the access of the surrounding gas or water environment to the reinforcing steel [18]. Various materials, e.g. polymer epoxy resins [2, 3-5, 7, 19], inhibiting agents (inhibitors) [5, 13, 17, 21, 22], noble metal admixtures [5, 17], or cathodic protection [5, 10-12, 17, 23-25] are used for this purpose.

It seems that such protection can be provided by coating rebars with a polymer sulphur composite composed of a sulphuric binder, fillers and proper additives. Even though sulphur binders show: resistance to many aggressive water solutions, low absorbability, surface hydrophobicity and quite high (tangent and normal) adhesion to the surface of many materials (including metallic surfaces), they have not been used for this purpose before [6, 8, 13-16, 20].

In order to demonstrate the suitability of sulphur polymer composites for the surface protection of concrete steel experimental research was carried out in the Institute of Building Engineering at Wrocław University of Technology. The research included: the experimental determination of sulphur polymer composite composition and manufacturing conditions, tests of the composite's selected physical, chemical and mechanical properties, tests of its tangent and normal adhesion to plain and ribbed reinforcing bars and to standard cement mortar and concrete, the determination of the mass decrement resulting from storage in aqueous solutions of acids, hydroxides and salts and in water and the polarization investigation of rebars subjected to tension in a solution modelling the pore liquid in carbonated concrete contaminated with chlorine ions [8, 15].

2. Description of investigations

Sulphur polymer composites were investigated in two stages. In the first stage, compositions were fixed and thirty test sulphur polymer composites were prepared and pretested. When fixing the compositions, the binder (S_8) content was changed in a range of 55-65%. Mineral powder, silica dust from a drying plant, high-silica sand and plain sand and cement were used as the filler. Carbon black and anthracene oil were used as the additive.

The pretesting included preparing composites and determining their basic physical and mechanical properties, such as: bulk density, absorbability by wt., bending strength and splitting tensile strength. The experimental results are reported in detail in [8, 15].

The results of the preliminary tests were analyzed and the sulphur polymer composite having the best properties among the tested composites was selected for further studies. The composition of the composite is given in Table 1 and its experimentally determined properties are shown in Table 2 [8, 15].

Table 1. **Composition of selected sulphur polymer composite [8, 15].**

Content in [%] of total composite mass		
Binder	Filler	Additive
Sulphur S_8 [%]	Mineral quartz dust [%]	Carbon black [%]
63	33	4

Table 2. **Experimentally determined properties of sulphur polymer composites [8, 15].**

Average bulk density ρ_{pm} [g/cm^3]	Average absorbability by wt. n_{wm} [%]	Average bending strength f_{dm} [MPa]	Average splitting tensile strength $f_{ct,sp}$ [MPa]	Average compressive strength f_{cmc} [MPa]	Coefficient of fragility k [-]	Coefficient of direct elasticity E_{dm} under bending [MPa]	Coefficient of direct elasticity E_{cm} under compression [MPa]
2.10	0.05	11.9 4.9%	3.4 6.1%	51.2 6.2%	0.93	64840	66969

Note: the percentages under the line are coefficients of variation.

The adhesion of a 0.2-4.0 mm thick sulphur polymer composite layer to plain St3S reinforcing steel samples and ribbed 34 GS steel samples, 10 mm in diameter and 160 mm long, was tested.

The adjacent adhesion of a 1.5 mm thick sulphur polymer composite layer to rebars under tension and bending and to rebars being pushed out of this composite was tested on plain steel St3S samples and ribbed steel 34 GS samples, 10 mm and 20 mm in diameter and 160 mm long.

Also the adjacent adhesion of concrete to reinforcing bars coated with a 1.5 mm thick layer of the sulphur polymer composite was tested on plain reinforcing steel St3S and ribbed steel 34 GS samples, 10 mm and 20 mm in diameter and 160 mm long.

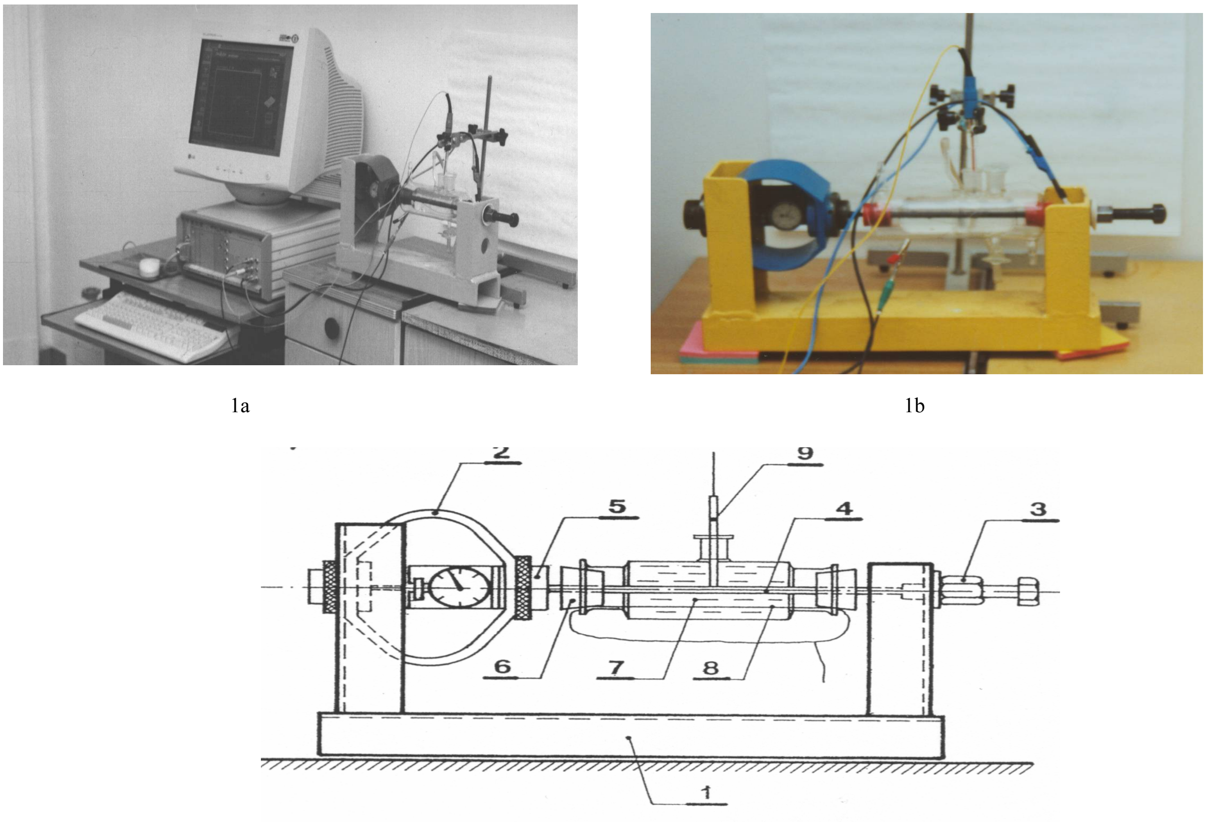
The decrement in the mass of rebars coated with the composite and stored in aqueous solutions of acids and salts and in water for 1 year was determined using plain St3S steel samples, 10 mm and 20 mm in diameter and 160 mm long.

Polarization investigations of tensioned rebars coated with the sulphur polymer composite were carried out on plain St3S reinforcing steel samples immersed in a solution modelling the porous liquid in carbonated concrete contaminated with chloride ions. The samples were 10 mm in diameter and 290 mm long. A general view of the polarization test device is shown in fig. 1: a, b, c [10, 11, 13-15, 23-25].

In order to select a polymer sulphur composite for further studies, the bending strength test fracture surfaces of the composites were examined under 50x, 100x and 200x magnification, using a Jeol JSM-800LV scanning electron microscope. The aim was to check for microfractures, cracks and other defects which had arisen during the making of the specimens. The results of the examinations are shown in Fig. 2. The results for the polymer sulphur composite under a magnification of 50x and 100x and for polymerized sulphur under a magnification of 100x and 200x are shown in respectively Fig. 2a and 2b.

The images show that the polymer sulphur composite has a very homogenous structure with uniformly distributed filler grains, without any microcracks, air voids or other defects. Whereas the fracture of the polymerized sulphur shows structural defects, in the form of microcracks and air voids, which arose in the course of solidification.

It was prepared by melting components at the temperature 150^{o}C and then by cooling to the ambient temperature. The fluid hot was used for covering the surface of a surgical steel nail and for fixation on this surface porous alumina grains.

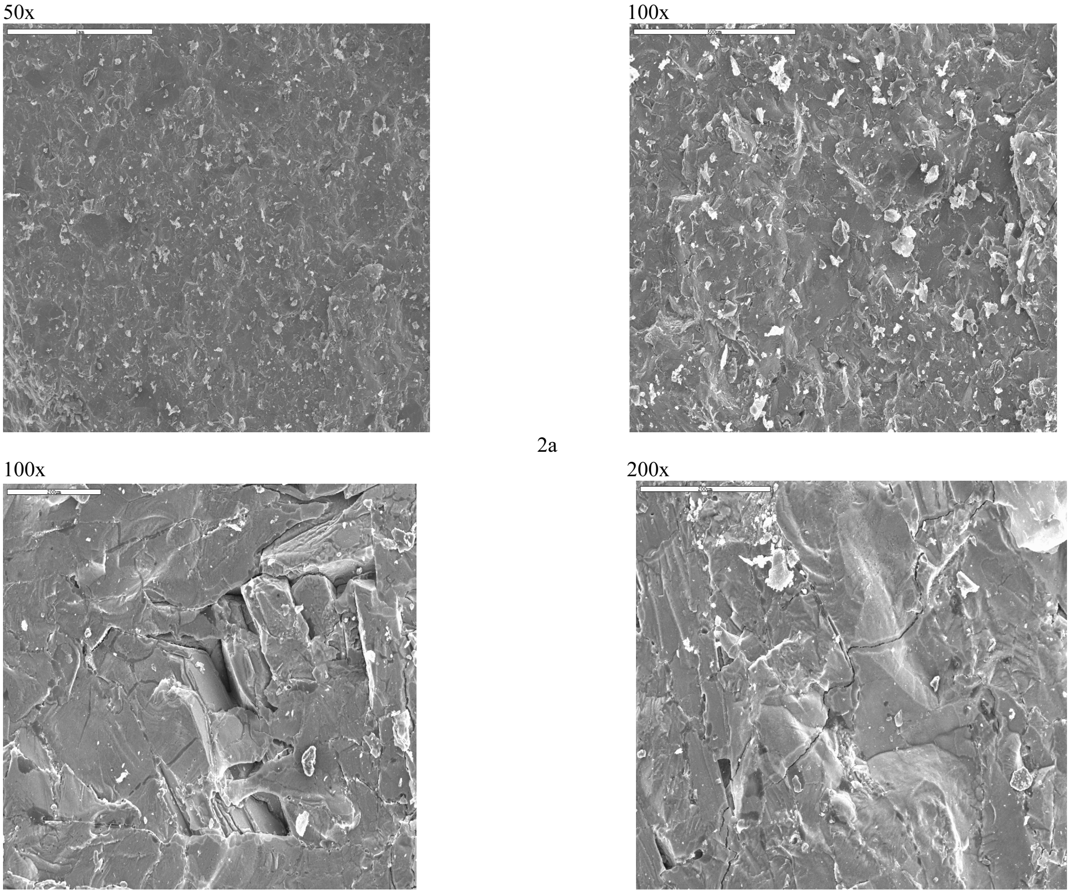


1a

1b

1c

Fig. 1. **Device for polarization testing of tensioned rebars: a), b) view of rig, c) schematic of rig (side view), 1 – metal frame, 2 – mechanical dynamometer, 3 – clamping screw, 4 – sample of rebar coated with composite, 5 –dynamometer connector, 6 – rubber stopper, 7 – glass container filled with model pore liquid solution, 8 – platinum wire, 9 – calomel electrode [13]**



2a

2b

Fig. 2. **SEM images of bending strength test fracture surfaces of: a) polymer sulphur composite, b) polymerized sulphur**

3. Test results and their analysis

3.1. Polarization investigations of tensioned rebars coated with sulphur polymer composites

Investigation results have been obtained as standard computer diagrams with stationary potentials E_0 and corrosion currents I_0 indicated.

And overview of all corrosion current densities i_0, stationary potentials E_0, at loads P, tensile stresses σ_0 and corrosion rates H_t is presented in [14]. Corrosion rate H_t has been calculated basing on current densities i_0 measured prior and with using a formula:

$$H_t = 1.123 \cdots k \cdots i_0 \qquad (1)$$

where: k = 1.042 g/Ah means the electrochemical equivalent for iron.

Fig. 3 shows corrosion rate H_t versus time (in a time interval of 3-168 hours) at a constant rebar tensile stress σ_a of 194.5 MPa. The rebars are plain rebars 10 mm in diameter, coated with a 0.5 mm and 1.5 mm thick layer of the sulphur polymer composite, immersed in a solution modelling the pore liquid in carbonated concrete contaminated with chloride ions.

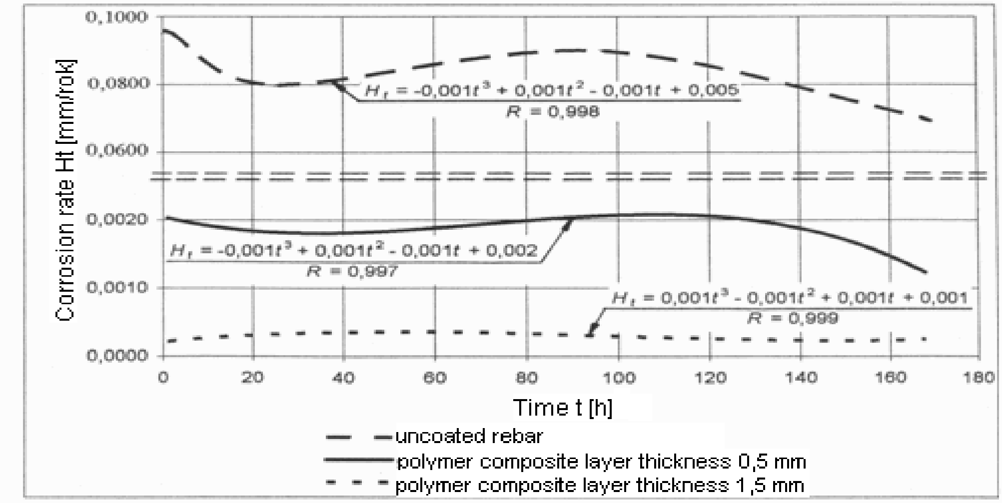


Fig. 3. **Corrosion rate versus time at constant tensile stress σ_a=194.5 MPa for plain rebars 10 mm in diameter, coated with sulphur polymer composite and for uncoated rebars**

According to the figure, after a tensile stress (σ_a) of 194.5 MPa is reached, the corrosion rate (H_t) changes in a time interval of 3-168 hours as follows: it increases initially and after 90 hours from the beginning of the test it starts decreasing, amounting to about 0.0010 mm/year after 168 hours. It is lower in the case of the rebars coated with a 1.5 mm thick layer of the sulphur polymer composite. At this layer thickness, the corrosion rate is only very slightly dependent on time and on the increasing tensile stress in the rebars. Within the test time interval it remained at an almost constant level of 0.000186-0.000242 mm/year. As the figure shows, the corrosion rate for the uncoated rebars is by three orders of magnitude higher. The corrosion rate over time is described by the equations given in Fig. 3.

The very low, nearly constant corrosion rate in the case of the rebars coated with a 1.5 mm thick layer of the sulphur polymer composite is beneficial. Therefore such a layer can be considered as contributing to the protection of the reinforcing steel against corrosion in the solution modelling the porous liquid in carbonated concrete contaminated with chloride ions.

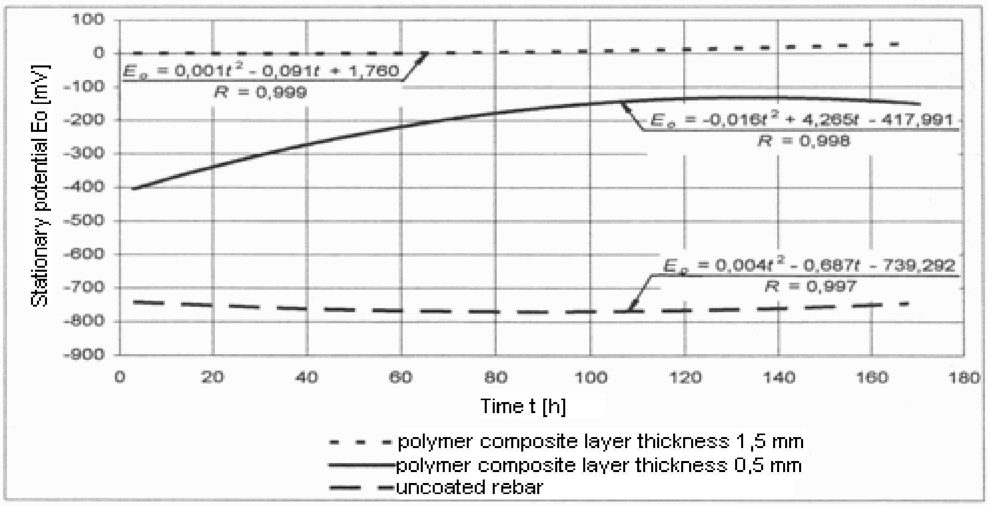


Fig. 4. **Stationary potential versus time and constant tensile stress σ_a=194.5 MPa for plain rebars 10 mm in diameter, coated with sulphur polymer composite and for uncoated rebars**

Fig. 4 shows the dependence between stationary potential E_o, time and tensile strength for the tested rebars coated with a 0.5 mm and 1.5 mm thick layer of the sulphur polymer composite. For comparison purposes, stationary potential E_o in similar uncoated rebars is shown. The dependencies are described by the included equations. According to the test results, once tensile strength σ_a of 194.5 MPa is reached in the rebars, a slight increase in stationary potential over time is observed. In the case of a 1.5 mm layer, potential E_o remains constant (close to 0 mV) in the whole test period. It also remains constant for the uncoated reference rebars, but at a level much different from 0 mV.

4. Conclusion

It can be concluded from the test results that the tested sulphur polymer composite can provide surface corrosion protection to the reinforcing steel in concrete. Sulphur composites have not been applied for this purpose before. The tests have shown that a proper thickness of the sulphur polymer composite and the type of surrounding corrosion environment are important factors here. One can conclude that the optimum thickness of the sulphur polymer composite layer should be 1.5 mm and the reinforcing steel protected with this composite should not be used in aqueous solutions of HNO_3 and KOH and NaOH. The results presented in [8, 15].

The aim of investigation that has been led was to evaluate tendencies of the corrosion process for St3S-b reinforcing steel when covered with polymer sulphuric coating and exposed to tensile stress. Steel samples were loaded in a way that their yield points were much exceeded; in the same time these samples were exposed to an action of the solution the composition of which is similar to that of pore-liquid of concrete is and additionally contaminated with chloride ions (pH = 9.14). The composition said was as follows: 0.015 M $NaHCO_3$ + 0.005 M Na_2CO_3 + 0.001 M NaCl. Corrosion rate for the steel has decreased by 2÷3 orders of magnitude when covered with protective coating even though this latest became unseal at load exceeding 88.5 MPa.

The authors are aware that although the range of the tests carried out so far is quite wide, still further tests are needed to ultimately determine the suitability of the sulphur polymer composite for the surface protection of the reinforcing steel in concrete against corrosion. Also a simple and practical technology of applying this material to the surface of reinforcing steel needs to be developed.

References

1. **Brandt A. M.** Problem of durability of high performance concrete. RILEM-3C-Workshop “Durability of HPC”, Vienna. 1994.
2. **Cairns J., Ramli B. A.** Influence of rib geometry on strength of epoxy-coated reinforcement. ACI Structural Journal, I-II. 1995.
3. **Czarnecki L., Garbacz A.** Evaluation of polymer coating-crack-bridging ability. International Colloquium “Industrial Floors”95, Esslingen. 1995.
4. **Czarnecki L., Garbacz A., Łukowski P., Clifton J.** Polymer composites for repairing of portland cement concrete. Compatibility Project, NIST Report. United States Department of Commerce, National Institute of Standards and Technology, Gaithersburg MD. 1999.
5. **Czarnecki L., Emmons P. H.** Naprawa i ochrona konstrukcji betonowych, Wyd. Polski Cement, Kraków. 2002.
6. **Gillot Z.E. et al.** “Sulphur 82”, London. 1982. P. 1-45.
7. **Hadje-Ghafari H. et al.** Bond of epoxy-coated reinforcement: cover, casting position, slump and consolidation. ACI Structural Journal, I-II. 1994.
8. **Hoła J., Książek M.** Research on usability of sulphur polymer composite for corrosion protection of reinforcing steel in concrete. Archives of Civil and Mechanical Engineering. 2009. Vol. 9. No. 1. P. 47-59.
9. **Hoła J.** Experimentally determined effects of technological and service factors on stress-induced destruction of concrete under compression. Engineering Transactions. 2002. Vol. 50. P. 251-265.
10. **Jankowski L., Pędziwiatr J., Styś D.** Some research problems due to the bond phenomenon between steel and concrete. 18th Symposium on Experimental Mechanics of Solids Jachranka. 1998.
11. **Jaśniok M., Jaśniok T., Zybura A.** Assessment the corrosion risk of reinforcing concrete using the DC and AC methods, Gliwice. 2003.
12. **Jaśniok T., Zybura A.** Modelling of polarization range of steel bars in corrosion test of reinforced concrete. 14th Conference “KONTRA 2004” Durability of Buildings and Protection Against Corrosion, Zakopane. 2004.
13. **Jaśniok M., Zybura A.** Zabezpieczenie i regeneracja zagrożonych korozją konstrukcji z betonu. O przeciwkorozyjnym działaniu otuliny betonowej na zbrojenie, “Przegląd Budowlany” No. 1/2007. P. 20-25.
14. **Klakočar-Ciepacz M., Książek M.** Investigation of the intensity of corrosion processes influence by tensile stress for reinforcing steel covered with sulphuric coating. Chemicals in sustainable agriculture, Jesenik. 2003. P. 761-765.
15. **Książek M.** Usefulness of polymer sulphur composites to the protection against corrosion of reinforcement and concrete. Doctoral dissertation. Series PRE report. No. 3/2004. Wrocław. 2004.
16. **Książek M.** The experimental research on adhesion and mass loss for reinforcing steel covered with polymeric sulphuric composites. Kompozyty. 2010. No. 4. P. 374-379.
17. **Książek M.** Polarization investigations of tensioned rebars coated with sulphur polymer composite. Kompozyty. 2009. No. 3. P.234-237.
18. **Książek M.** Examination on the influence of tensile stress on corrosion rate of reinforcing steel covered with polymeric sulphuric coating. Kompozyty. 2008. No. 4.P. 349-353.
19. **Książek M.** The mechanical destruction of sulphur composites, Issue 80. Conference. 2001. P. 105-112.
20. **Książek M.** The sulphur binders - Their potential possibilities of using in buildings, Issue 75. Conference No. 26.1999. P. 71-78.
21. **Nicles G.** Inorganic Sulphur Chemistry, Amsterdam-London-New York. 1968.
22. **Ściślewski Z.** Ochrona konstrukcji żelbetowych, Arkady, Warszawa. 1999.
23. **Thelford T.** Coating protection for reinforcement. Committee Euro-International Du Beton. State of the Art Report. 1995. P. 51.
24. **Treece R. A., Jirsa J. O**. Bond strength of epoxy-coated reinforcing bars. ACI Materials Journal, III-IV. 1989.
25. **Tuller W. N.** The nature of sulphur. Data Book, New York. 1954.
26. **Wieczorek G.** Pore solution properties in concrete with chlorides, Kurdowski Symposium “Science of cement and concrete”, Kraków. 2001.
27. **Wieczorek G.** Korozja zbrojenia inicjowana przez chlorki lub karbonatyzację otuliny, Dolnośląskie Wydawnictwo Edukacyjne, Wrocław. 2002.
28. **Zybura A.** Modelling of the reinforcement corrosion of the scratching concrete cover. Corrosion of Cement Paste, Kraków. 1994.
29. **Zybura A.** Zabezpieczenie konstrukcji żelbetowych metodami elektrochemicznymi, Wydawnictwo Politechniki Śląskiej, Gliwice. 2003.
30. **Zybura A.** Electrochemical corrosion protection of concrete structure reinforcements, “Ochrona przed Korozją” No. 1/2007.

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Eksperimentiniai ir inovatyvūs polimeriniais sieros kompozitais padengtų įtemptų strypų poliarizacijos tyrimai

Reziumė

Pateiktieji eksperimentinių tyrimų rezultatai rodo, kad apsaugai nuo korozijos sustiprinti tikslinga naudoti polimerinius sieros kompozitus. Pateikiama duomenų apie korozijos spartą įtemptuose plieniniuose armatūros strypuose, dengtuose polimerine danga ir pamerktuose į tirpalą, imituojantį betoną. Nustatyta, kad plieno strypuose, dengtuose apsaugine danga, korozijos sparta sumažėja viena eile.

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