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PROTECTION OF REINFORCEMENT OF ARMORED CEMENT STRUCTURES AGAINST CORROSION

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ABSTRACT

This article discusses composition and protective properties of powdered anticorrosion coating for protection of woven reinforcement of armored cement structures against corrosion. It is demonstrated that the developed anticorrosion coatings on the basis of powdered polyphenylene sulfide, grade PFS-L, epoxy paint, grade EK-201, powdered corrosion inhibitor, grade VNKh-L-20, filled with cement, reliably protect reinforcement against corrosion in 3% NaCl solution even at crack opening of 0.1-0.3 μm, which evidences reliable passivation of reinforcement, hence, high lifetime of armored cement structures with reinforcement protected by the recommended anticorrosion coating. Increased lifetime of these structures is achieved by protection of reinforcement prestressed by electric thermal method and application of powdered anticorrosion coating on its surface. The composition of anticorrosion coating, modes of application of the powdered coating onto reinforcement on electrostatic fields are developed.

Keywords: corrosion, steel reinforcement, armored cement structure, thermal treatment, reinforced concrete.

INTRODUCTION

Possible mechanisms of steel corrosion in concrete are discussed in [1] as well as the issue of application of two dominant concepts: impressed current cathodic protection system and the system with galvanic cathodes. The first system has better performances and is proposed as very efficient protection. In practice, for insuring significant saving in supply of electrical energy from distribution network, the application of solar energy system as support for impressed current cathodic protection system has been proposed.

Corrosion of steel reinforcement in concrete due to chloride penetration is a known issue. Several approaches were adopted for protection of reinforced concrete, additional protection for specific coating by treatment with silane and siloxane. These products react with cement matrix and form hydrophobic layer on pore walls in concrete preventing penetration of water and salts [2].

Studies by Lobanov and Sobakina [3] of corrosion resistance of reinforcement of armored cement structures in cracking areas demonstrated that reinforcement corrosion can occur in the case of cracking opening from 0.005 μm and above. In addition, it is mentioned that thermal treatment increases reinforcement corrosion in cracks.

Among existing coatings for surface protection of armored cement structures it is reasonable to apply elastic crack resisting coatings. Such coatings on the basis of chlorosulfonated polyethylene were developed in NIIZhB (Research Institute of Concrete and Reinforced Concrete named after A. A.Gvozdev) by Shneiderova *et al.* [4, 5, 6]. Highly efficient method of improvement of protective properties of concrete with regard to reinforcement is increase in its density [7, 8, 9].

Defects occurring due to operational reasons are comprised of cracks in the vicinity of reinforcement caused by corrosion damage of reinforcement under the impact of various aggressive mediums, sulfuric acid vapors in particular. This leads to concrete corrosion, type 3 according to Moskvin. As a consequence of such processes, basicity of concrete liquid phase decreases (below critical value determined by Prof. Alekseev and equaling to pH = 11.8), and hence, decreases passivating action of concrete with regard to steel reinforcement [10].

Respective investigations were performed by Lobanov and Sobakina [3, 11, 12], who determined corrosion resistance of wore reinforcement in armored cement samples of fine concrete of various hardness at different thickness of protective layer. Testing of samples in 3% NaCl solutions demonstrated that at appropriate selection of mixture compaction, it is possible to achieve multiple resistance increase of reinforcement in fine concrete.

On the basis of laboratory experiments the authors concluded that without existence of cracks it is possible to expect long lifetime of armored cement structures with protective concrete layer of 3-4 mm without protection against environmental impacts. Herewith, the fine concrete should have sufficiently high density (0.88-0.90). It should be cured under natural conditions or under mild thermal treatment [13].

Among existing methods of formation of armored cement items, the layer-by-layer method developed by Panarin attracts attention. This method permits item formation of low-slump mixes with high compaction degree; it provides the most accurate fixation of reinforcement mesh [14].

Field observations of structures [15] fabricated by later-by-layer formation demonstrated that after 4 years of operation in ambient environment concrete carbonization was mainly characterized by film pattern.

Another engineering approach, which facilitates obtaining of concrete region of increased density near

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reinforcement, is the use of electrokinetic processes running in freshly laid concrete upon its treatment of direct electric current [16, 17, 18].

The data of accelerated testing of armored cement samples in [19] demonstrated good protective properties of phosphate coating with satisfactory cohesion between reinforcement and fine concrete. However, it should be mentioned that the necessity to apply a layer of lacquer coating on phosphate film makes the overall procedure more complicated and time consuming.

Experimental results demonstrate possibility to obtain coatings on the basis of powdered materials with good protective properties with regard to reinforcement at its sufficiently high cohesion with cellular concrete.

However, armored cement structures have low thickness of concrete protective layers, hence, operation conditions of such structures require for improvement of protection both of concrete itself and of woven reinforcement against corrosion.

Therefore, we decided to increase the concrete resistance by means of primary protection, that is, by addition of hydrophobic agents on the basis of drill muds into concrete. It allowed us to obtain volumetric hydrophobicity of concrete structure.

Among existing protective coatings of reinforcement, the most efficient are powdered polymer coatings. No reliable data are available on behavior of such coatings on reinforcement in concrete. Powdered coatings for protection of reinforcement of armored cement structures against corrosion have not been proposed yet. It necessitates further studying of protection efficiency of woven reinforcement of armored cement structures by powdered polymer coatings; this work is based on this necessity, which determines its urgency.

METHODS AND MATERIALS

The following raw materials were used for experiments.

Binder: Portland cement, Volsk-cement, SSPTs 400-D20, and Novotroitsk Portland cement, SSPTs 400-D20. Chemical and mineralogical compositions of the cements are summarized in Tables 1 and 2.

Table-1. Chemical analysis of the cements.

Cements	Oxides, %							
	SiO_2	CaO	MgO	Al_2O_3	Fe_2O_3	R_2O	SO_3	LOI
Volsk-cement	22.73	65.89	2.27	4.33	2.80	0.60	0.33	1.05
Novotroitsk	23.69	63.72	2.37	2.48	3.25	0.78	2.51	1.20

Table-2. Mineralogical compositions of the considered cements.

Cements	Minerals, %			
	$3CaO·SiO_2$ (C_3S)	$2CaO·SiO_2$ (C_2S)	$3CaO·Al_2O_3$ (C_3A)	$4CaO·Al_2O_3·Fe_2O_3$ (C_4AF)
Volsk-cement	56.35	18.06	6.75	13.55
Novotroitsk	55.96	17.54	7.05	14.43

Physicomechanical properties of the considered cements are summarized in Table-3.

Table-3. Physicomechanical properties of the considered cements.

Cements	Specific surface area, cm^2/g	Cement dough normal consistence, %	Matrix W/C 1 : 3	Setting time, h - min		Ultimate strength after 28 days, MPa	
				initial set	final set	bend	compression
Volsk-cement	3200	26.7	0.43	2-30	6-35	5.8	42.1
Novotroitsk	3215	27.1	0.42	2-27	7-15	5.9	43.2

Fine filler for fabrication of armored cement structures was obtained from quartz–feldspar sand from Melovye Gorki deposit, West Kazakhstan, in 1.5-2 km south-eastward from Uralsk, size modulus of 1,53.

Oil portion of the mud was comprised mainly of paraffin-naphthene hydrocarbons with oil content of 5.5-7.2%.

In order to obtain powdered anticorrosion coatings and study of their main protective properties epoxy compositions were used: EK-201 (Specifications TU 2329-354-02068474-95); polyphenylene sulfide, grade PFS-L (Specifications TU 6-05-231-234-82), powdered corrosion inhibitor, grade VNKH-L-20, produced by OOO Ekolon, St. Petersburg, and PO Lakokraska, Yaroslavl, aimed at protection of various metal items against corrosion.

Fine cements with cement to sand ratio 1:2 were used in the experiments, both with and without addition of oil drilling mud.

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The concrete mix was compacted in 10 s using laboratory vibratory bench with additional weight; oscillation frequency was 2800-2950 per minute.

Water met the requirements of Russian Standard GOST 23732- for concrete and mortars.

Protective properties of the powdered polymer coatings with regard to steel reinforcement were tested in simulated chloride aggressive medium.

Chloride medium (causes pitting corrosion) was made of 3% NaCl solution [6], since the solutions of low concentration (3-5%) are especially aggressive to steel reinforcement in concrete. Tests were performed according to accelerated procedure (4 h for soaking of reinforced concrete samples, 20 h drying at 18-20 °C).

Such testing mode is considered to be the most severe.

In order to determine polarization curves reinforced concrete samples with coated reinforcement (working electrodes), silver chloride reference electrode, auxiliary electrode were placed into a dielectric reservoir with aggressive solution (electrochemical cell) and connected to a P-5827M potentiostat. Potentials and currents were recorded using a PDP-004 two-coordinate potentiometer and a M2020 microammeter.

Prior to the study the concrete samples were saturated with water in vacuum until their complete saturation. The curves were detected at constant rate of potential variation (2 V in 10 min) starting from the stationary potential of metal in the considered medium.

The powdered polymer coatings were applied onto metal surface as follows:

Protected reinforcement was placed into ionized fluidized bed, where charged particles under the action of electric forces were deposited onto metal surface forming powdered layer. The required coating thickness was controlled with high accuracy by voltage applied onto electrodes and holding time of sample in ionized fluidized bed.

The sample with deposited layer of powdered particles was placed into thermo-irradiation furnace, where it was held at certain temperature during certain time. Fusion mode was determined by properties of initial powdered polymers, that is, by temperature and time of its film formation. Molten coating was hardened upon subsequent cooling in air. The applied procedure allowed to readily obtain coatings on all metal samples used as reinforcement: rods, wires, woven meshes.

RESULTS AND DISCUSSIONS

Experimental results of armored cement samples with mesh reinforcement demonstrated that in the reference samples rust strains on surface of concrete protective layer appear already after 10-15 cycles of corrosion tests.

When the developed coating with the thickness of 70-80 μm was applied onto the mesh, single rust strains (not more than 1-3 pieces on the surface of armored cement sample) appeared only after 150-200 testing cycles.

The influence of protective coating on corrosion resistance of reinforcement was studied on armored cement samples with meshes installed in their top area, and the bottom area was reinforced with single wires with the diameter of 0.55 mm. For convenience of resistance measurements, the wire ends were protruded from the sample, their edges were subsequently insulated by epoxy resin. Corrosion tests were performed with batches of samples with various thickness of protective polymer cement layer on reinforcement surface equaling to 25 μm, 50 μm, 75 μm and 100 μm. The amount of controlled wires in each batch was 80 pieces. The experimental results are summarized in Table-4.

Table-4. Corrosion tests of armored cement samples without cracks.

Number of cycles of corrosion tests	100	150	200	250	300	350	400	450
Number of damaged wires, % of total	Reference samples							
	17	30	50	60	68	70	83	100
	Coating thickness, 25 μm							
	–	–	–	–	5	10	18	35
	Coating thickness, 50 μm							
	–	–	–	–	–	7	12	23
	Coating thickness, 75 μm							
	–	–	–	–	–	2	5	9
	Coating thickness, 100 μm							
	–	–	–	–	–	–	3	6

It follows from Table-4 that after 200 cycles of corrosion tests 50% of monitored reinforcement in reference samples were damaged; when testing cycles were increased to 350, 70% of reinforcement were damaged.

First damages of reinforcement coated by polymer cement were observed only after 350 testing

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cycles in samples with the thickness of protective coating equaling to 25 μm.

After 450 cycles of corrosion tests the percentage of damaged reinforcement as a function of thickness of protective polymer cement coating amounted to 35% for the samples with the thickness of 25 μm, to 23% for the samples with the thickness of 50 μm, *to* 9% for the samples with the thickness of 75 μm, to 6% for the samples with the thickness of 100 μm.

Therefore, it is possible to conclude that application of protective polymer cement coating on reinforcement makes it possible to increase significantly corrosion resistance of wire reinforcement, moreover, the protective effect increases with the increase in the thickness of protective polymer cement coating.

Taking this into account, corrosion tests of armored cement samples with cracks were performed. Composition of concrete samples, procedure of their fabrication remained the same. Wire with the diameter of 0.55 mm was used as reinforcement. The thickness of protective polymer cement coating on reinforcement was 70 μm and 90 μm.

Cracks in the samples were obtained by bending of two plates of armored cement with a steel rod underneath (in the center of the samples); the samples were fixed by yokes at the edges. The crack opening was measured by microscope. Aiming at more complete determination of influence of proactive coating on corrosion resistance of reinforcement in cracks, the crack opening was set equal to 0.1 mm, 0.2 mm, and 0.3 mm, that is, with maximum allowed for armored cement, and exceeding it by two and three times.

The results of corrosion tests are summarized in Tables 5 and 6.

Table-5. Corrosion tests of reference armored cement samples with cracks.

Number of cycles of corrosion tests	**50**	**100**	**150**	**200**	**250**	**300**
Number of damaged wires, % of total	**Crack opening in samples, 0.1 mm**					
	5	30	50	70	91	99
	Crack opening in samples, 0.2 mm					
	23	44	68	80	98	
	Crack opening in samples, 0.3 mm					
	40	65	80	98		

Table-6. Corrosion tests of armored cement samples with cracks. Reinforcement is protected with polymer cement coating.

Number of cycles of corrosion tests	**150**	**200**	**250**	**300**	**350**	**400**	**450**
Number of damaged wires, % of total (numerator - samples with the thickness of polymer cement coating on reinforcement δ=70 μm, denominator - with the thickness δ = 90 μm).	**Crack opening in samples, 0.1 mm**						
	–	–	–	$\frac{4}{3}$	$\frac{11}{9}$	$\frac{15}{13}$	$\frac{18}{15}$
	Crack opening in samples, 0.2 mm						
	–	–	$\frac{6}{5}$	$\frac{12}{10}$	$\frac{20}{17}$	$\frac{29}{24}$	$\frac{34}{28}$
	Crack opening in samples, 0.3 mm						
	–	$\frac{8}{6}$	$\frac{12}{10}$	$\frac{18}{15}$	$\frac{27}{23}$	$\frac{38}{32}$	$\frac{49}{41}$

The data in Tables 5 and 6 show that reinforcement protected with polymer cement coating is characterized by minor corrosion damages upon testing of samples with cracks. For instance, in reference samples with maximum crack opening equaling to 0.3 mm after 150 cycles of corrosion tests the number of damaged wires was 80%.

Similar samples with protected reinforcement after 450 cycles of corrosion tests had only 43% of damaged reinforcement at thickness of polymer cement coating of 70 μm and 41% at coating thickens of 90 μm.

Reference samples with crack opening, maximum allowed according to valid for armored cement norms (0.1 mm), after 250 cycles of corrosion tests had 90% of damaged reinforcement. In similar samples with protected reinforcement the percentage of damages after 450 cycles of corrosion tests equaled to 18% at 70 μm of polymer cement coating and 15% at 90 μm of coating thickness.

Hence, the proposed protection significantly improves corrosion resistance of reinforcement in the vicinity of cracks in armored cement.

CONCLUSIONS

The developed powdered anticorrosion coatings protect reliably reinforcement against corrosion in 3% NaCl solution even at crack opening of 0.1-0.3 μm, evidencing reliable passivation of reinforcement and long lifetime of armored cement structures with reinforcement protected with the recommended anticorrosion coating.

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