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EFFECTIVE WATERPROOFING OF RAILWAY CULVERT PIPES

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Abstract. The composition material for waterproofing of the railway infrastructure objects, in particular, culvert pipes is suggested in the article. The waterproof composition contains an acrylic polymer and a filler. The comparison of the composition properties with two kinds of the fillers (silica sand and Portland cement) is carried out. The following properties are defined – water absorption, corrosion stability, stability in an aggressive environment, frost resistance to evaluating the suitability of the proposed

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composition for waterproofing. These properties are determined for three batches: an acrylic polymer without a filler, an acrylic polymer with silica sand, and an acrylic polymer with Portland cement. The test results show that the composition with silica sand possesses the best waterproofing properties. Wherein the quantity of silica sand is 1.5 mass parts to the quantity of polymer. Compared to the non-filled acrylic polymer the offered composition is characterised less water absorption, more significant corrosion stability and stability in an aggressive environment, better frost resistance. The mix with Portland cement shows a bit worse results at a higher cost of the material in whole.

Keywords: acrylic polymer, corrosion stability, filler, frost resistance, stability in an aggressive environment, water absorption, waterproofing.

Introduction

The culvert pipes in the railway embankments are an essential element of the infrastructure. More often, the load on them is by far fewer than the strength limit of the material that they are made of from that they are made. Nevertheless, pipes and structures similar to them (bridges, tunnels, overpasses) are subject to demolishing external effects – cyclic wetting-drying, freezing-thawing, the impact of aggressive medium (groundwater, acid rains, fuel materials). To prolong service time and defence concrete and reinforced concrete constructions the various kinds of waterproofing are used: monolayer and multilayer ones, for cold and heating surfaces, with filler and without, as membrane or plaster. For each particular case, it is necessary to come to choose the most effective method for construct protection (Kwak, Ma, Choi, & Oh, 2015; Margaryan, 2016).

The concrete permeability becomes a serious problem for the durability of hydraulic and water-retaining constructions since concrete is directly subjected to the influence of water or humid medium in such structures. Therefore, the waterproof compounds are used for both the improving of the porous concrete composition and the water permeability concrete reducing. Remya & Koshy (2016) study the impact of the waterproofing natural polymer compound on the durability and concrete mechanical properties. As waterproofing the natural rubber, latex is used with the different kinds of fillers. It possesses good binding properties and excellent adhesion to concrete. The latex molecules have a long-chain structure that helps in developing structure bonds far from the solid surfaces.

In contrast, cement materials provide short-range structure of bonding. As a result, polymer materials usually provide superior compressive, tensile and flexural strength of the concrete compared to Portland cement (Remya & Koshy, 2016). Polymer-modified cement waterproofing coating and cementations capillary crystalline waterproofing materials are considered by Yu & Sun (2017). In this investigation, the ones are presented as some of the waterproofing materials, which are widely used for the industrial and civil buildings.

The polymer coatings are the most suitable to repair and carry out waterproofing works. They improve the reliability and strength of the waterproofing layer. Also, these coatings are characterised by excellent strength properties and corrosion stability. However, having comparatively little strength, the main advantage of such coverings is elasticity – the ability to withstand alternating loads without brittle fracture. It is shown by Jun & Xiao (2017) that the silicone or polyurethane sealants possess high resistance to ultraviolet, but they poorly oppose to the vibrations under high-speed trains moving. It is proposed to use asphalt that is layered by spraying to seal railway slab seams.

It needs to note that asphalt should be heated for spraying, but it makes difficult the technological process. Besides, asphalt is softened and melted in the summer period. Due to this phenomenon, the integrity of the waterproofing is violated.

To eliminate these disadvantages, some authors propose to modify asphalt. The most popular asphalt modifier is the styrene-butadiene-styrene. This thermoplastic elastomer increases the thermal resistance of bitumen, widens the range of plasticity and amends rheological properties (Ratajczak, 2017).

Nevertheless, its disadvantages became the stimuli for the search of other modifiers. The research results of oleic imidazoline – the new generation bitumen modifier – are presented in (Zieliński & Babiak, 2016). It is demonstrated that such type modifier that is developed by Zieliński & Babiak (2016) affects much the bitumen physical characteristics. Its usage leads to the significant increase of the bitumen plasticity range and substantial rising of the ageing resistance. For further growth of the neoprene, latex and stabiliser are used in the paper (Zhou, Zhao, Lu, Guo, & He, 2015). Therefore, the bitumen mastics require additional expenses for its usage.

It is notified by Uebelhoer (2016) that the modern bitumen-based systems satisfy are dissatisfactory for the increasing demands to the modern bridges under conditions of the rising service life and the stability under significant loads. That is why the main aim of the research is the developing of such resin-based systems that provide longer service term, shorten the downtime in case of the maintaining works, and reduce the repair costs. The key study results are summarised in a paper of Pasetto & Giacomello (2014) that is devoted to the mechanical characteristics of the resin and aggregate mixtures for the bridge waterproofing and paving slabs. The comparison demonstrates that the polymer suspensions with fillers possess better deformation steadiness than polymer multilayer and bitumen mixtures under the much higher temperatures (40–60 °C). However, they display some disadvantages in the adhesion properties. Besides these coverings possess the low technological indicators (a high viscosity, a need for heating, a long hardening term, a complexity). The acrylic-based polymer mortar that is the powder-liquid type compound of cold curing does is devoid of these disadvantages.

The great state and the durability of the bridges, tunnels and culvert pipes, as well as the maintenance costs most depend on the quality of the applied materials. During the operation process, the used acrylic compound is subjected to the daily and season temperature fluctuations, an effect of the atmospheric precipitation in combination with the temperature changes, wind action and sometimes-harmful precipitation that is emitted by industrial enterprises. The concrete and reinforced concrete construction strength reduce due to the influence of the cyclic freezing-thawing underwater contact condition. Because of this, it is necessary to evaluate the corrosion steadiness and water permeability of the acrylic compositions to provide the effective waterproofing of the infrastructure objects. Besides, it needs to determine the frost-resistance of the waterproof coverings of the mentioned acryl-based compounds. The filler addition significantly changes the physical and mechanical characteristics of the polymer systems. The fillers strengthen the polymer compounds, reduce the tangential stresses and the volumetric expansion coefficient, increase viscosity and heat-resistance, give polymers the thixotropic properties, and provide the minimum shrinkage during curing. The powdered silica, quartz flour, graphite, chalk, soot and aluminium powder belong to the fillers that are often found in practice. The main requirement to these compounds is fineness, which allows providing the filler ability to absorb the destruct products of the adhesive components that are formed during glueing under high temperatures. The filler addition allows both decreasing the adhesive cost and imparting them the unique properties, for example, electrical conductivity due to application of the metal powders. The fibreglass plastics that are wrapped around pipes great give them more significant strength and corrosion resistance (Trykoz, Kamchatnaya, Pustovoitova, & Atynian, 2018).

The overview shows that the applied material range is quite extensive. Among such materials, the acryl polymers possess the most advantages due to first the resistance to the exterior influences. They are the objects of this investigation. The purpose of this research is the suitability assessment of the acryl-based waterproofing for culvert pipe constructions under the railway embankments. To achieve the aim, it needs to determine the kind of the filler and its rational quantity, establish the dependencies of water absorption, water resistance and corrosion resistance of the acrylic composition on the filler kind and quantity, define the frost-resistance of the developed mixture.

1. Materials and methods

The main composition of waterproofing substance is the mix of the polymer binder and filler. As the binder, the acrylic powder-liquid type plastic of cold curing is applied. The acrylic powder-liquid type plastic of cold curing is applied as the binder. Powdered component (polymer) is a high-molecular methyl methacrylate-based substance. Liquid component (hardener) of acrylic plastic is methacrylic methyl ester (methyl methacrylate monomer). The curing of acrylic plastic is occurred spontaneously under normal temperature due to the polymerisation process, which is based on the oxidation-reduction reaction. The waterproof composition has been prepared by the mixing of the components. Three sample batches of acryl mortar have been tested. The first sample batch is made of acryl plastic without filler, the second one – with quartz sand as a filler, the third one – with Portland cement as a filler.

For water absorption testing the composition samples monomer : polymer : sand = 1.0 : 1.0 : 1.5 were prepared. The sample preparation and test carrying were conducted compare, as stated into *ASTM C140-01:2002 Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units*. The water absorption was defined with the usage of the samples that were previously dried in the drying cabinet under temperature 105 °C ± 5 °C to a constant mass. The dried samples after the mass determination were placed in a vessel with water under temperature 20 °C ± 5 °C so that the water level in the vessel was higher than the sample top by at least 20 mm. In this position, the samples were kept during different periods. After that they were taken out from the vessel, the surface moisture was removed with a humid cloth, and weighed.

The water absorption (W_i) in mass per cent is calculated by Eq. (1):

$$W_i = \frac{m_1 - m}{m} \cdot 100, \tag{1}$$

where m_1 – a mass of a sample that is saturated with water, g; m – a mass of a sample that is dried to a constant mass, g.

The water absorption (W_i) was determined as the arithmetic mean of absorption test results of the entire sample batch, which was calculated with the accuracy to 0.1%.

The steadiness assessment of the samples is carried out considering the reducing of their strength after an exposition in various mediums. The preparation of the above-described samples and their testing were conducted conforming to *ASTM C140-01:2002*. To determine the corrosion steadiness in agreement to *ASTM C267-01:2012 Standard Test Methods for Chemical Resistance of Mortars, Grouts, and Monolithic Surfacings and Polymer Concretes* the dried samples (monomer : polymer : sand = 1.0 : 1.0 : 1.5) were placed in the corrosive mediums: 5% nitric acid solution, 10% hydrochloric acid solution, 10% sulphuric acid solution, 10% sodium hydroxide solution, used machine oil. In this position, the samples were kept during different periods. After that, they were taken out from the vessel, removed from the surface solution with a humid cloth, and weighed.

The corrosion steadiness has estimated the allowance for the increment of their masses that is calculated by Eq. (2):

$$\Delta M = \frac{m_2 - m}{m} \cdot 100, \quad (2)$$

where m_2 – a mass of a sample that is saturated with aggressive medium, g; m – a mass of a sample that is dried to a constant mass, g.

For frost-resistant testing, three batches of samples were made of concrete class C12/15 in the cube form with the rib size 150 mm, as stated in *ASTM C666/C666M-15:2015 Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*. The first batch had the thin-layered covering with the thickness of 0.8–1.2 mm that is made of acrylic plastic, the second and third ones – thick-layered covering with the thickness of 5–7 mm that was made of acrylic polymer mortar. In the second batch quartz sand with a grain size up to 0.14 mm was used as filler, in the third one – Portland cement. Before the frost-resistance testing the concrete sample, batches were saturated with water under temperature 18 °C ± 2 °C. The saturation of the samples was carried out by its immersion into water up to 1/3 of the sample height and held for 24 hours. Next, the water level rose to 2/3 of the sample height, and the samples were held for the subsequent 24 hours. After that, the samples were immersed completely and held for subsequent 48 hours. Wherein the samples have been surrounded by water in all sides with the layer at least 20 mm. After complete saturation, the samples were subjected to freezing under temperature minus 18 °C ± 2 °C for 2.5 hours. After that, thawing was carried out in water under temperature 18 °C ± 2 °C for 2.5 hours. Two-four hours later after the respective number of freezing-thawing cycles, the samples were examined to establish the destruction signs in the form of splinters, cracks and mass loss.

2. Results and discussion

This chapter presents the details of the experimental investigation carried out to study the water absorption, corrosion steadiness, aggressive medium steadiness, and frost resistance of concrete with acryl polymer as waterproofing.

2.1. Water absorption

At the first day, the W_i that is calculated by Eq. (1), was 0.039%–0.089%. It is explained by the presence of the small pores on the sample surfaces. During the subsequent six days, it is observed that the water absorption percentage increased insignificantly. On the 8th day (in the mass stabilisation moment of the samples of the acryl polymer mortar), the water absorption was 0.015%–0.330%. It testifies the little water absorption. After the mass stabilisation, the samples of the acryl polymer mortar were tested to determine the water saturation by boiling. The average of the water saturation was 0.62%.

2.2. Corrosion stability

The observations show the lack of change in the exterior and size samples after water action, acid medium (5% nitric acid solution, 10% hydrochloric acid solution, and 10% sulphuric acid solution), alkaline medium (10% sodium hydroxide solution), used machine oil. The mass change is demonstrated in Figure 1. For the 70–80 days the sample

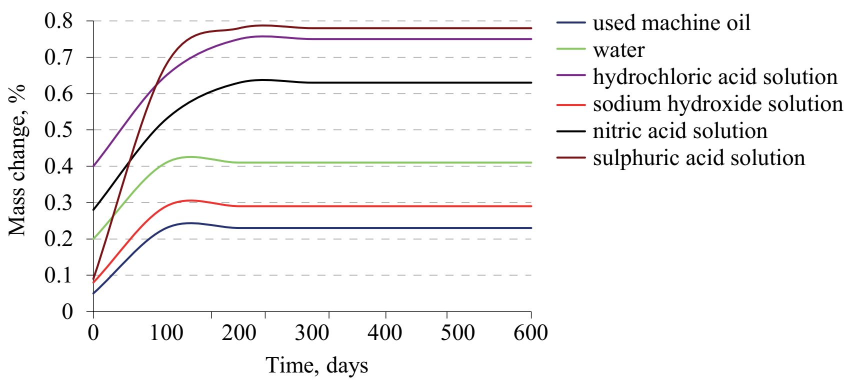

Figure 1. The mass change of the acryl composition samples under the aggressive medium action

mass grew sharply after keeping the samples in the chemical reagents. For instance, the mass rose by 0.78% after holding in sulphuric acid solution, after holding in nitric acid solution – by 0.67%, after holding in sodium hydroxide solution – by 0.42%. After 180 days of the aggressive medium influence, the mass of the sample remains stable. The research had been continuing for 600 days to make sure that this trend is long-term. It is important for the evaluation of the cover durability.

2.3. Aggressive medium stability

The compressive strength of the acryl composition samples increased by 11.80% in water, by 9.20% in hydrochloric acid solution, by 8.50% in sulphuric acid solution, by 6.80% in sodium hydroxide solution, by 6.00% in used machine oil at the 60th day (Figure 2). During succeeding 400 days, the strength decline was: for water – by 14.70%; for the hydrochloric acid solution – by 1.48%, for sulphuric acid solution – by 1.80%, for sodium hydroxide solution – by 3.60%. The samples strength stays changeless in the used machine oil. Under the action of the nitric acid solution, the compressive strength fell by 13.40%. Subsequently the compressive strength remained steady. The corrosion stability study of the acrylic composition shows that long-term action of the aggressive mediums does little for its physical-mechanical properties. The strength decrease is fewer than 4.70%, and the sample mass increase is just 0.87%.

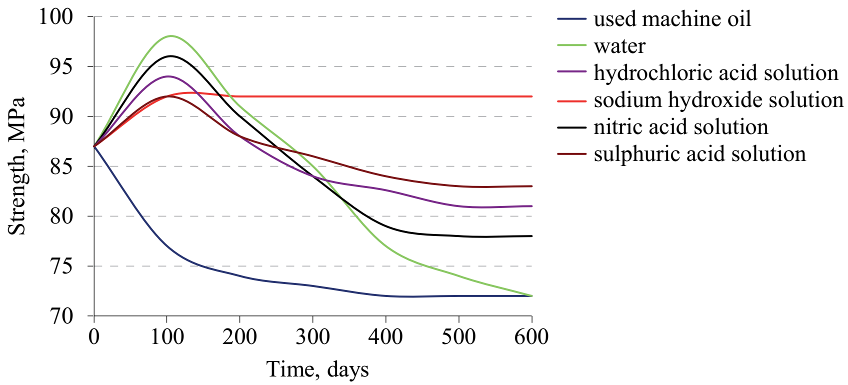

Figure 2. The strength change of the acryl composition samples under the aggressive medium action

2.4. Frost resistance

The waterproof covering compound was chosen due to its water impermeability because the frost resistance depends on this parameter. The samples of the first batch began to destruct after 7–14 freezing-thawing cycles. The first sign of destruction in most specimens was the appearance of cracks in the ribs. Next, the cracks were growing, and the covering exfoliated from the concrete surface. The thin-layer covering of the first batch samples is destroyed due to the different temperature coefficients of linear expansion of the non-filled polymer mortar and concrete. For example, the concrete temperature coefficient of linear expansion is α_{tc} = $10 \cdot 10^{-6}$ grad^{-1}, the acryl polymer one is α_{tp} = $80 \cdot 10^{-6}$ grad^{-1}. Consequently, the deformation difference of concrete and the covering achieves the significant value during sample freezing. It leads to the internal stresses appearance that by far larger than the adhesion strength of covering-concrete connection under shear. As a result, the covering is destructed. It is confirmed by the kind of sample destruction in the exfoliation form from concrete surface.

The second batch samples withstand 100 freezing-thawing cycles as reported by State Building Regulations of Ukraine. The minimum concrete frost resistance grade is 100 freezing-thawing cycles for the massive concrete constructions. After that, both covering destruction and mass decrease were absent. The hairline cracks appeared after 87–89 freezing-thawing cycles in the third batch samples. These cracks grew to 100th cycle, and the sample masses reduced by 2.0%–4.5%. In agreement to the National Standard of Ukraine, the mass loss of the basic samples must be less than 3.0% for concrete of road and aerodrome coatings. The experiments demonstrated that the thick-layer coverings are frost-hardy, which are made of the acryl polymer mortar in which the filler is quartz sand. The thin-layer coverings made of acryl polymer are recommended for the concrete and reinforced concrete construction protection under the normal temperature and humid operation conditions without freezing possibility.

Conclusion

Thus, the acrylic compositions possess sufficient strength, chemical resistance, and they are recommended for the usage as the material for the culvert railway pipe waterproofing. As a filler quartz sand is preferably used to decrease the polymer consumption and improve the adhesion properties. The addition 1.5 mass parts of sand reduce the water adsorption of the waterproof composition to 0.33%. The waterproof covering demonstrates the most corrosion resistance to used machine oil (the mass increment is 0.25%), the smallest one to the sulphuric acid solution (0.78%). The most significant strength decline is for the samples after holding in water and nitric acid solution (14.70%). The best result is demonstrated by the samples that are placed in used machine oil. Their compressive strength remains constant. The frost resistance of the developed waterproof composition is 100 freezing-thawing cycles without the destruction signs. Therefore, this acrylic-based polymer composition is recommended for the usage for the concrete and protection of the concrete and reinforced concrete constructions of the railway infrastructure – pipes, bridges, and tunnels.

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