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# The Modified Composite Binder For Cement-Concrete Road Surfaces\*

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**Abstract.** The comparative analysis of motor road surfaces made of cement concrete and asphalt concrete has been carried out. The advantages of cement-concrete road surfaces as compared to the traditionally used asphalt concrete have been shown. The necessity of using cement-concrete road surfaces has been substantiated, with the purpose of meeting the up-to-date requirements of transport safety, service reliability, comfort and environmental compatibility. The factors, which influence the strength and frost resistance of road surfaces, have been noted. A factory-fabricated modified binder based on a new polyfunctional modifier has been suggested, which would allow considerably increasing the strength of cement-concrete road surfaces, and especially their frost-resistance. The experimental data of studying the colloid-chemical properties of the obtained modifier and the technological and performance properties of the binder and the cement concrete based on this modifier have been presented. It has been shown that the presence of individual components with various hydrophilic groups results in the combined plasticizing and air-entraining effects. The resulting modified binder allows obtaining concrete with frost-resistance 800-1000 cycles, which would significantly increase the durability of cement-concrete road surfaces.

## 1. Introduction

Nowadays a special role in the national economy growth is assigned to the building and development of the extensive road networks of local and regional significance with connection to federal highways [1].

The accomplishment of this objective implies the transition to using up-to-date high-efficient polyfunctional materials and structures of roadway surfacing, which would provide the high transportation and performance characteristics of motorways, their increased service life and ride comfort.

Over the course of decades the asphalt concrete has been preferred at making road surfaces. This was explained by its low cost, simplicity of its production technology and asphalt-concrete road surface making, availability of materials, low traffic flows.

Nowadays the motor roads, especially the street and road networks, should meet the heightened requirements in both the performance reliability and riding comfort, and in environmental friendliness. The increase of road traffic density and of the environmental temperature (up to +40°C and more in the shade in summer) results in the intensive evaporation of the asphalt concrete components and the ecological problems of the urban environment. As the international and domestic experience shows,



these heightened requirements conditioned by the road traffic and ecological situation are the most efficiently met by cement-concrete road surfaces. In this regard, the purpose of this work is carrying out the comparative analysis of the asphalt-concrete and cement-concrete road surfaces' characteristics in accordance with [2-4], as well as studying the colloid and chemical properties of a new polyfunctional modifier (PFM), aimed for obtaining a composite binder, and studying the physical and mechanical properties of the modified binder and the cement concretes based on this binder.

## 2. Methodology

To study the influence of modifiers on the properties of concretes and cement concrete mixes the integrated research methods, standardized by GOST, were used.

The flowability of modified cement suspensions was researched by mini-cone method, according to the Gosstroy's Concrete and Reinforced Concrete Research Institute (CRCRI) methodology [5], which consists in determining the spread diameter of a cement suspension under the action of gravity.

The rheological properties of cement grouts and mortars were researched and the batching of cement concrete was carried out according to the methodology, developed in CRCRI, concerning the application of admixtures of various kinds in pre-cast and mass concrete technology [6].

The rheological properties of cement suspensions were studied by using a rotation viscometer. In the course of the research the dependence between shear stress value and shearing rate was determined. On the basis of the obtained findings the rheological curves were plotted, by means of which the yield value and the plastic viscosity were found.

The flowability of cement-concrete mix was determined by means of standard cone according to GOST. The strength and frost-resistance of concretes were studied on cubical concrete samples  $10 \times 10 \times 10$  cm and  $7.07 \times 7.07 \times 7.07$  cm on edge according to standard procedures.

To study the modifiers' mechanism of action the physical and chemical research methods were used. The water solutions of modifiers, the hardening kinetics of cement paste, the alteration of phase composition of cement stone samples with additives, the phase transformations in models systems and in clinker minerals at the hydration and hardening were studied.

## 3. The main part

In highway construction the road surfacing should be especially distinguished with high strength, frost resistance, abrasion resistance and thermal stability, it should be smooth and provide the good grip of wheels with the road. Apart from having the required strength, stress-strain and performance properties, as well as the environmental specifications, road surfaces must meet the required service life terms under given conditions, i.e. they should be durable. At present, due to the increasing vehicle-to-population ratio, freight traffic and passenger traffic, the problem of building and maintenance of the reliable, comfortable, environmentally friendly and safe motor roads is of primary importance in creating the urban infrastructure, optimal for the human life. Due to the fact that the conventional cement concrete not always meets these requirements, the authors have carried out the experimental research of a new modified composite binder for high-strength and frost-resistant cement-concrete road surfaces.

According to the statistical data of State Motor Vehicle Inspectorate of the Interior Ministry of the Russian Federation, about 40% of the annual number of road accidents occurs due to the poor state of roads [7].

These showings require from the relevant organizations such technical and technological solutions at building, maintaining and reconstructing motorways, which would allow cutting these figures to a minimum.

The high porosity of asphalt concrete contributes to the quick destruction of roadway surfacing in the autumn-winter period. The moisture, accumulating in the pores of asphalt concrete and freezing, disrupts its structure and creates the stress concentration inside the body of the road. The deterioration processes are catalyzed by the reagents, used by road services to remove snow and ice (magnesium chloride, bio-nord, thawing salt, sand-salt mixture). The asphalt concrete, imbued with salt solutions, is prone to the quicker and deeper frost deterioration.

The abovementioned problems can be solved by reducing the porosity of the asphalt-concrete surfacing, but as experience shows, it only slows down the deterioration of the road and doesn't solve the problem in full.

Application of cement-concrete road surfaces allows removing the above-mentioned shortcomings almost completely. One of the most important advantages of cement concrete is the stability of its transportation and performance characteristics, high durability and environmental compatibility as compared to asphalt concrete. The up-to-date motorways should meet the heightened transportation, performance and ecological requirements and should be comfortable and durable. The usage of asphalt concrete doesn't allow achieving the required results.

The modern cement concrete is a composite building material, which can be produced with the specified characteristics for certain service conditions by modifying its structure and properties with various admixtures [8-11]. This provides the material with durability, performance reliability, ecological safety and applicability in any service conditions [12]. Besides, it simplifies carrying out the repair operations in any season of the year.

A large number of various repair compositions for maintaining cement-concrete road surfaces have been designed nowadays, based either on inorganic binders, or on polymer binders [13,14]. These compositions have quick setting time and strength-gain time, good compatibility and adhesion with the repaired road surfaces, high strength, frost-resistance and abrasion resistance. All this allows providing the road with the required transportation-performance characteristics within a short time.

The cement-concrete motorway surfaces have a number of substantial advantages as compared to the conventional asphalt-concrete surfaces, which determine the reliability, safety and durability: the high strength of cement concrete and the total hardness of roads with cement-concrete surfacing, able to carry considerable loads, exceeding manifold the design loads for asphalt concrete at the equal conditions and requirements; longer service life (1.5–2.0 times longer, than that of asphalt concrete surfaces); the strength enhancement of cement concrete in the course of time, which allows preserving the high transportation-performance characteristics of the road without costly and prolonged repairs for a long time. This, in its turn, cuts expenses for the roads usage and maintenance.

The cement-concrete road surfaces should comply with a set of requirements, including: the grade of Portland cement, the strength and frost-resistance of concrete, the W/C ratio and flowability of cement-concrete mix, the special requirements for aggregates, and the volume of the entrained air during the cement-concrete placing.

So, the usage of general-purpose cements in cement-concrete production for road surfaces doesn't prove efficient. Besides, as it was mentioned earlier, the achievement of the required purposes has been hindered lately by natural and climatic changes, which make it necessary to carry out additional activities at concrete casting both at the stage of preparation and laying of concrete mixes and during the service of concrete structures.

For this purpose the authors have carried out the research concerning the possibility of obtaining a modified composite binder for cement-concrete road surfaces. In accordance with the service requirements, the application of such binder would allow obtaining road cement concretes, having high strength, frost-resistance, water impermeability and abrasion resistance. One of the most important properties, which influence the transportation-performance characteristics and the service life of the road, is the freeze-thaw resistance of cement-concrete road surface [15].

The alternating freezing and thawing of concrete and reinforced concrete structures, operating outdoors, result in destructive processes, which reduce their durability. The deterioration of the wet material under the action of negative temperatures is caused by the internal stresses, resulting from crystallization pressure of the ice, hydraulic pressure of the water, osmotic forces, the wedging pressure of thin water films, the absorption phenomena and the difference between the expansion coefficients of the ice and crystalline splice. The most significant influence is exerted by the phase transitions of moisture within the concrete [16].

Due to this, the frost-resistance of concrete is determined by the initial water-cement ratio, the type of the used binder, the type of coarse aggregate, the cement properties, the structural density of the

newly-laid concrete mix, the curing conditions and other factors, which determine the concrete structure, on which its frost resistance depends. The crucial role here is played by all the structure elements, presented by the solid phase, the pore space, and the gas or liquid, filling the pores.

The dispersity of the solid phase, in its turn, forms the parameters of the pore space. The pores in the structure of the concrete are divided into three types: pores of the cement stone, pores of the aggregate and the contact (sedimentative) pores at the boundary surface between the cement stone and aggregate [17].

Therefore, the freeze-thaw resistance of concrete can be improved by increasing the concrete density by means of reducing the macropores volume and their water permeability, by creating in the concrete a system of redundant air pores, not filled with water at the regular water saturation.

Until recently various chemical admixtures have been used to improve the frost resistance of concrete: superplasticizers (SP), air-entraining agents and others. Their application allowed achieving the required result in terms of frost resistance, but impaired the other technological properties of concretes and concrete mixes, which didn't meet the requirements to these materials.

The appearance of polyfunctional modifiers of the mixed type has allowed eliminating the above-mentioned shortcomings, but their application runs into a number of difficulties due to the need for the additional batch-weighing equipment and tanks for preparation and storage of admixtures and the compatibility of components.

The development of surface-active substances synergism theory in designing polyfunctional modifiers has allowed solving the problem of individual components compatibility, while the issue of the modified concretes production technology still remains topical [18].

According to the theory of frost deterioration mechanism of the concrete, in order to achieve high frost resistance the concrete should have fine-crystalline structure, the interaction of clinker phases with water should occur quicker and simultaneously in order to fix its structure, the pore space should have as many relatively-closed fine spherical pores as possible, uniformly distributed around the whole volume, and as few open capillary pores as possible. For this purpose the binder should contain the Portland cement clinker, superplasticizer, accelerating agent, air-entraining agent and should be factory-fabricated. As the research has shown, the combined introduction of components in order to achieve the above-mentioned properties doesn't allow obtaining the concrete with high frost resistance due to their incompatibility. Moreover, the positive effect of adding one component is neutralized by the negative effect of another.

Besides, the combined introduction of the above-mentioned components into the composition of the binder is hindered by the conditions of production. If the superplasticizer and the accelerating agent can be added to the mix in the dry state when milling, the air-entraining agents are usually presented with the liquid phase.

A polyfunctional modifier has been designed, which possesses the combined plasticizing and air-entraining ability and allows accelerating the concrete hardening processes. The binder on the basis of this modifier is obtained by means of mechanochemical treatment of Portland cement clinker and the dry modifier up to specific surface  $450\text{-}550\text{ m}^2/\text{g}$ . The suggested polyfunctional modifier contains individual components with hydrophilic groups, different by their nature [19].

The carried-out research has shown that along with plasticizing properties, the adsorption of the polyfunctional modifier on the surface of Portland cement phases and new formations' crystals reduces the surface tension at the solid-liquid interface, which contributes to the additional air-entraining [20].

The study of the colloid-chemical properties of the polyfunctional modifier has shown that the plasticizing component in its composition allows increasing the flowability of concrete mix to the optimal value, at which the best pores fixation is achieved. The peptizing effect provides the simultaneous hydration of clinker phases and the formation of microcrystalline structure [21]. It also reduces the initial water-cement ratio, which results in the decrease of open capillary porosity and the increase of the concrete strength.

The air-entraining ability of the admixture's components reduces the size of air bubbles and provides their staying in the concrete. These components stabilize the air bubbles, which are formed in the concrete during its mixing. The stabilizing effect of the air-entraining component is provided due to its adsorption on the surface of air bubbles. The molecules of the admixture are oriented with their polar functional groups towards water, and with nonpolar functional groups – towards the air bubbles, which, being like-charged, repel one another, which prevents their coalescence [22]. Another way to stabilize the bubbles system is the adsorption of admixtures on the hydrate phases' particles. The products of cement hydration are positively charged and due to electrostatic attraction forces the air bubbles are attracted to the particles, making them hydrophobic. As the particles size is considerably smaller than the size of air bubbles, they shield the bubbles, preventing their coalescence. Taking into account the pore space structure of the mortar phase and its influence on the strength and frost resistance, the adding of polyfunctional modifier changes the character of pore distribution. The volume of relatively-closed fine spherical pores is increased, while the volume of the open capillary porosity is reduced, which improves the frost resistance of the concrete.

#### 4. Conclusions

The carried-out research has shown that the presence of individual components with various hydrophilic groups in the modifiers' composition results in the combined plasticizing and air-entraining effects. The resulting modified binder allows obtaining concrete with the frost resistance 800-1000 cycles, which would significantly increase the durability of cement-concrete road surfaces.

The development of cement-concrete roads construction in Russia is a promising area, which would combine the economic, social and ecological efficiency, as well as provide the high level of safety of the street and road network maintenance in any season of the year and in any climatic conditions.

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