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Modified pavement cement concrete

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Abstract. The paper suggests design principles of pavement cement concrete, which covers optimization of compositions and structures at the stage of mixture components selection due to the use of plasticizing agents and air-retaining substances that increase the viability of a concrete mixture. It also demonstrates advisability of using plasticizing agents together with air-retaining substances when developing pavement concrete compositions, which provides for the improvement of physical and mechanical properties of concrete and the reduction of cement binding agent consumption thus preserving strength indicators. The paper shows dependences of the main physical-mechanical parameters of concrete on cement consumption, a type and amount of additives.

1. Introduction

In terms of its structure, properties and requirements, the cement concrete used for road pavement and base significantly differs from other types of concrete intended for industrial, civil, hydraulic engineering and other structures [1]. The structure of pavement concrete and its properties depend on many factors: a type and quality of mother substance, designed concrete mix, applied chemical additives, preparation practices, concrete mix placing and compaction, efficiency of pavement reinforcement, quality of concrete curing [2].

Thus, chemical additives, providing for targeted influence on cement stone and concrete structurization, modification of cement stone and concrete structurization, improvement of technological parameters of concrete mixtures and long-term concrete pavement performance are widely used in the technology of concrete works, particularly in the construction of cement concrete pavements and bases.

The study included calculation and optimization of concrete mix compositions for pavement concrete via mathematical planning. It suggests compositions of road concrete of the B35 class of compression strength index; B_{tb}4.4 bending tensile strength; P1 placeability grade; 4-6% of entrained air; at least 1 hour of concrete mix viability. Besides, there are dependences of the main physical-mechanical properties of concrete on cement consumption, a type and amount of additives.

2. Materials and methods

The following raw materials were used to develop road concrete compositions – cement CEM I 42.5 N, additives of LLC MS-Bauchemie – superplasticizing agent Muraplast FK 88, hyperplasticizing agent Muraplast FK 68, air-retaining substance Centrament Air 202, quartz sand with a 1.43 fineness module, crushed stone of 5-20 and 20-40 fractions.



The selection of tailored compositions for road concrete and the study of influence of separate components on technological and physical-mechanical properties of concrete, obtained on their basis, were performed via mathematical experimental planning. The sample strength was determined according to GOST 10180-90, bending under tension test was carried out in compliance with GOST 10180-90.

3. Development and properties of pavement cement concrete

At present, flexible road pavements are mainly used in Russia. One of the main reasons for this is a relatively simple technology of construction and repair of such flexible pavements. However, they have a fundamental defect, i.e. short-term serviceable life in severe operating conditions. As domestic and international experience shows, only flexible road pavements are able to meet the increasing demand of road traffic, since their service life before overhaul can reach 50 years [3]. They are resistant to aggressive influence of the environment, ensure high wheel adherence and absence of dust. Such roadway is relatively resistant to wear (0.1 mm per year); its thickness does not exceed 16-22 cm.

Stable transport and operational indicators, long-term performance make them advantageous compared to pavements built with organic binding agents; cement concrete pavements are put from newly-laid concrete by pavement layers of the road bed [4].

Concrete pavement is laid on the artificial ground base processed with cement, crushed stone treated with a binding agent or on a base from other strong materials. The required evenness and durability of the road base provides for significant reduction of tension in cement concrete pavement and increase in its operating capacity [5-6]. Full construction mechanization ensures leading positions of concrete pavements among other advanced pavements in the world.

From ecological standpoint, the use of cement in pavement construction instead of organic binding agents is highly favorable. It is known that in course of preparation and laying, hot-mixed asphalt emits toxic polycyclic hydrocarbons. In order to improve adhesive properties of bitumen surface-active additives such as alins and coal, tar products being toxic are added during surface treatment. While in operation, they are partially washed out and evaporate thus causing environmental pollution.

The structure of pavement concrete and its properties depend on many factors: type and quality of mother substance, designed concrete mix, applied chemical additives, preparation practices, concrete mix placing and compaction, efficiency of pavement reinforcement, quality of concrete curing [7].

Pavement concretes are usually classified by coarseness and type of aggregates (fillers). Concrete based on coarse and fine fillers belongs to the category of normal-weight concrete with dense structure, of which the entire space between grains of compact filler (coarse and fine) is filled with set cement stone and pores of entrained air or other gas due to application of air-retaining (gas-forming) additives [8]. When a coarse filler is excluded from the concrete mix composition, the pavement concrete belongs to the category of fine-grained pavement concrete with a dense structure, which space between grains of fine dense fillers is filled with set cement stone and pores of entrained air (or another gas).

The so-called particularly low-crushed-stone concrete at $C_m \approx 0.1 \dots 0.2 \text{ m}^3/\text{m}^3$ serves as a transitional structural type of concrete ranging from a fine-grained to coarse-grained structure, which, in other words, represents fine-grained concrete with an insignificant amount of crushed stone.

The following is typical for road low-crushed-stone mixes: enhanced segregation resistance during technological treatment; high workability; higher stability of edges and sides of newly molded pavement after sliding form construction; high air-retaining and air-holding capacity [9].

Technological features of low-crushed-stone concrete allow using them in pavement construction with track concrete-placing machines with slip forms. Low-crushed-stone concrete is mostly efficient in the construction of cement concrete pavements with high-performance machines with sliding forms [10]. The use of low-crushed-stone concrete allows receiving strong and durable cement concrete pavement at reduced content of crushed stone by 20...30%, which also contributes to the reduction of pavement cost.

At present, fine-grained (sand) concrete becomes ever more important in road construction, which is explained by lower cost of fillers, possibility of radical improvement of technology to manufacture products with specific properties of fine-grained concrete, which causes its wide application and makes it highly efficient [11].

Fine-grained concrete is widely used in road construction, which requires enhanced crack resistance, bending and tensile strength thus making it possible to abandon imported crushed stone and to reduce the road construction cost. The future of fine-grained concrete is connected with their further improvement in relation to various construction technologies (in sliding form, rolling, use of flowing concrete) [12].

Another kind of road concrete is carbonaceous concrete, which uses carbonaceous sedimentary rocks (limestone, dolomite) as fine and coarse fillers. Technical efficiency of carbonaceous concrete is caused by high adhesion of such fillers with cement stone. The cement content of this concrete in comparison with standard equivalent concrete is smaller by 10-15%.

As a rule, lightweight expanded clay aggregates are applied in areas without local stone materials and with production plants located nearby. Such concretes have excessive deformation but lower wear resistance.

Literature sources often refer to the notion of “road high-strength concrete”. Some researchers believe that the strength of this concrete is equal or higher than the cement activity, while others think that the absolute strength of this concrete is higher than a certain minimum value [13]. To produce high-strength road concrete, it is necessary to use highly active (in terms of bending strength) cements. Meso- and macrostructures of such concretes shall be marked by the enhanced extension coefficient in order to completely exclude a coarse filler and shift to highly strong fine-grained structures.

The production of continuously reinforced cement concrete pavements is caused by the desire to eliminate temperature contraction and expansion joints being the most vulnerable in concrete pavements. The fundamental difference of continuously reinforced structures in comparison with standard unreinforced ones is the fact that external influences and available fittings lead to the formation of transverse cracks spaced at 1.5-3.0 m and their openings spaced at 0.2-0.4 mm on a surface. Insignificant crack opening ensures transfer of the shear force between plates and prevents water penetrating into fittings since cracks do not open at the fitting level.

To enhance the competitiveness of cement concrete pavements, there is a need to improve road concrete, construction technology and structures on its basis. At the same time, on the one hand, this requires the increase in long-term pavement performance (service life), and on the other hand, the reduction in material consumption and construction cost.

In recent years, there has been a tendency to make road concrete with enhanced strength and service life [14]. This is achieved by modification of concrete composition with chemical components: plasticizing, air-retaining and gas-forming agents.

The paper studied the possibility of modifying a road cement concrete using plasticizing and air-retaining additives, such as superplasticizing agent Muraplast FK 88 and air-retaining substance Centrament Air 202 by MC Bauchemie.

The study included calculation and optimization of concrete mix compositions using mathematical planning, which established mathematical relation between prescribed properties of concrete and consumption and properties of component materials. The received mathematical dependence is used to select and search the tailored compositions. Mathematical dependences are set via special laboratory tests with their further piloting in production.

To make mathematical planning of experiments simpler and to reduce the number of variability factors, it was established that the following can be used as the most critical parameters of optimization characterizing physical-mechanical properties of road concrete: the amount of plasticizing and air-retaining additives and the amount of water (Table. 1). Then, the necessary levels of factor variations were chosen so that any combination, implied by the plan, was implemented within the designed models and considered real technological conditions.

Table 1. Experimental design conditions

Factors		Variability levels			Variability intervals
Natural form	Code type	-1	0	+1	
Plasticizer content FK 88, %	x_1	0.2	0.5	0.8	0.3
Air-retaining substance content, Air 202, %	x_2	0.1	0.3	0.5	0.2
Cement content	x_3	365.5	430	494.5	64.5

The first stage included assessment tests with various combinations of parameters to compare theoretical and experimental data, define major factors, and choose intervals of their variation.

The second stage included experimental tests with the application of multifactor planning. The results were analyzed via mathematical statistics (Fig. 13).

With an intention to obtain reliable results, each stage of the study implied the analysis of several samples molded and studied in identical conditions and at invariable process parameters.

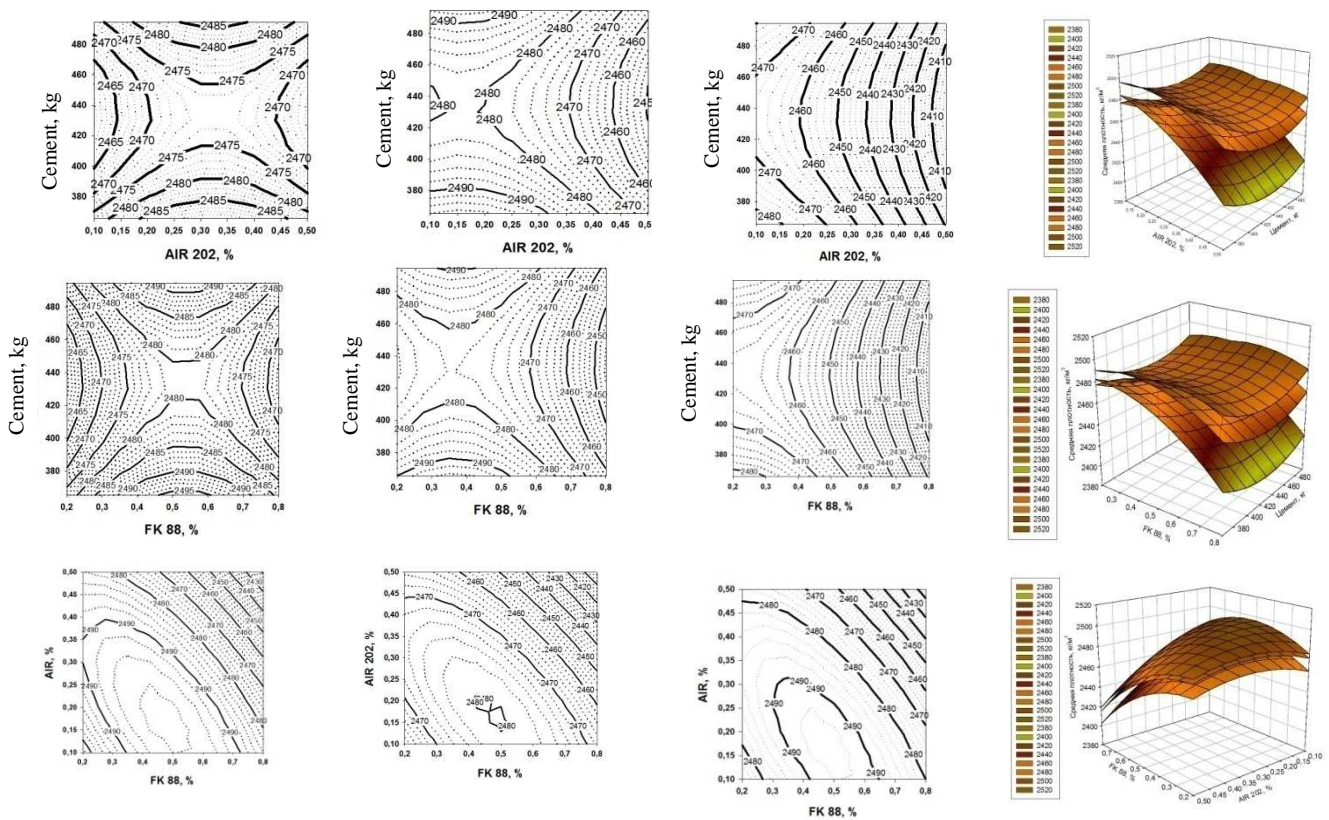


Figure 1. Dependence of concrete density with the use of hyperplasticizing agent MURAPLAST FK 88 on additive content and cement consumption

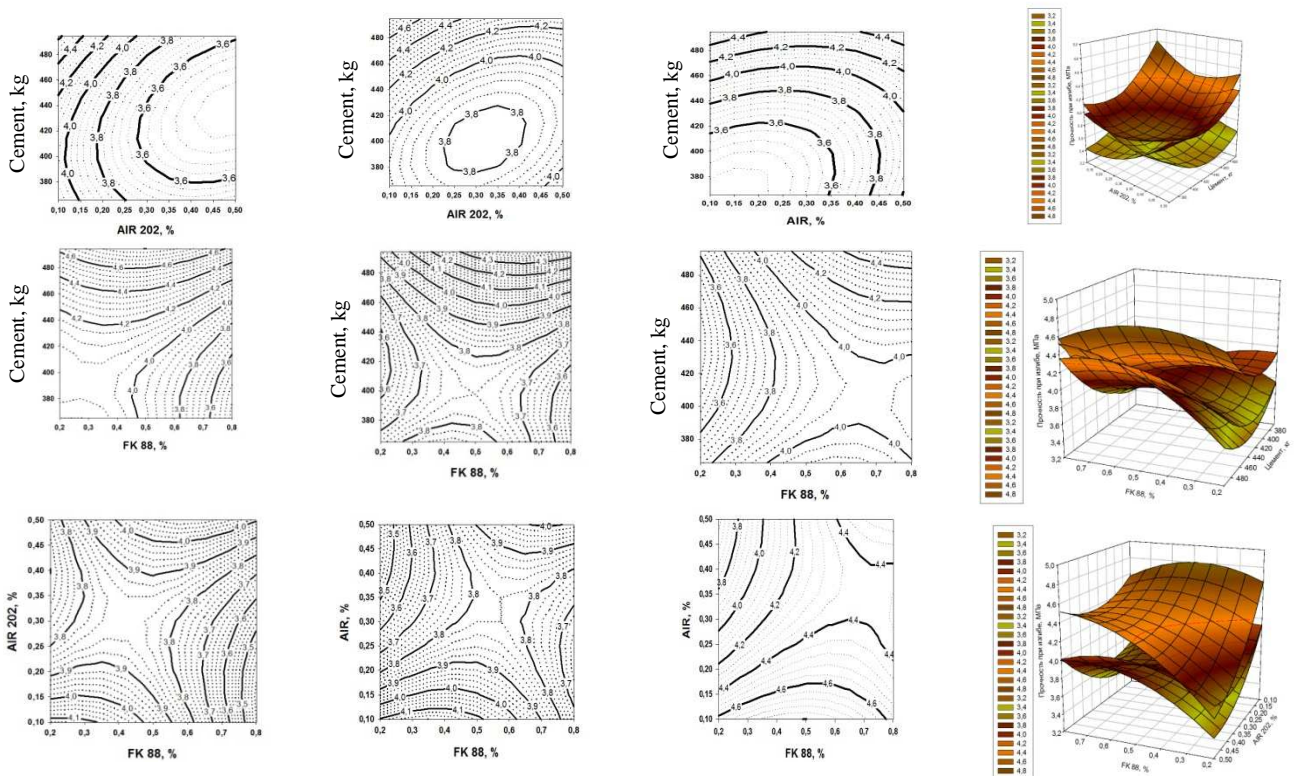


Figure 2. Dependence of concrete bending strength with the use of hyperplasticizing agent MURAPLAST FK 88 on additive content and cement consumption

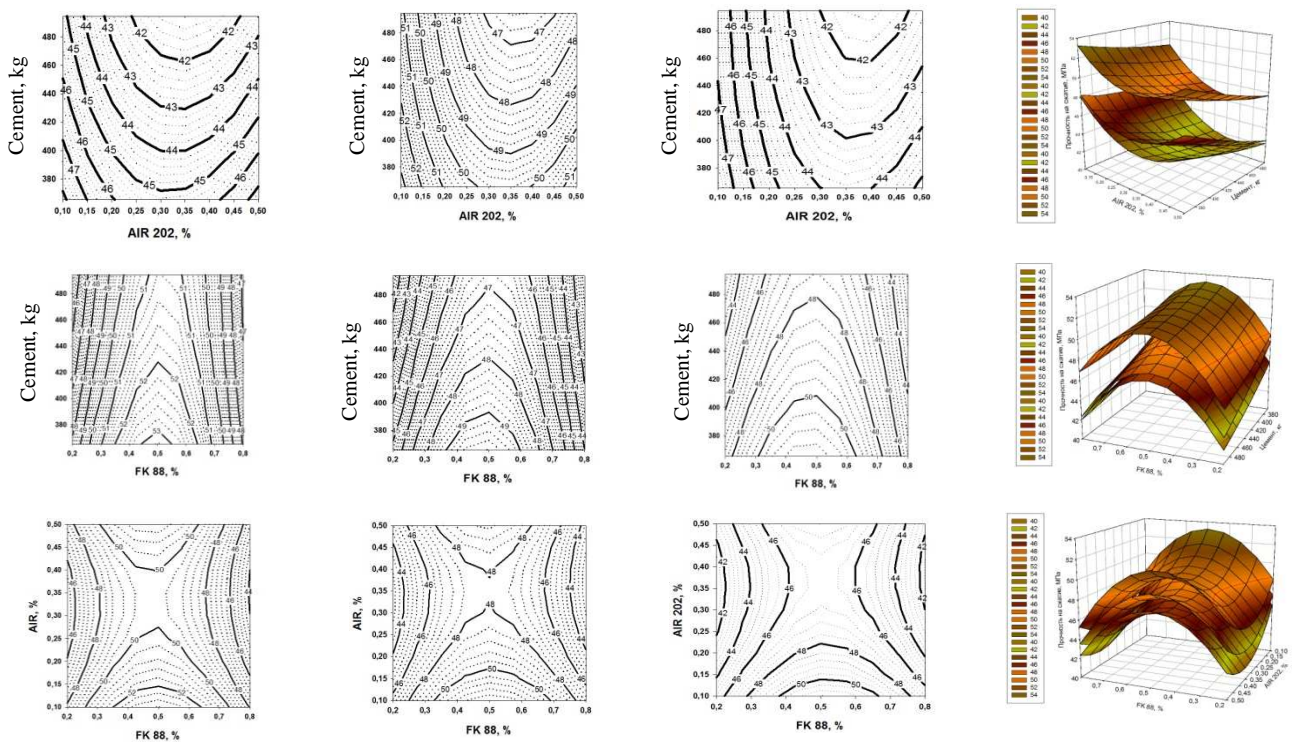


Figure 3. Dependence of concrete compression strength with the use of hyperplasticizing agent MURAPLAST FK 88 on additive content and cement consumption

The obtained three-dimensional diagrams displaying the influence of major factors on concrete parameters are considered; the doubly curved surfaces are oriented towards axes of the content change of plasticizing, air-retaining additives and waters.

Thus, by setting one of the parameters, it is possible to define the composition of concrete and to forecast other physical-mechanical properties.

4. Conclusions

The use of plasticizing additives together with air-retaining agents in the development of road concrete compositions allows improving physical-mechanical properties of concrete and reducing the consumption of cement binding material thus preserving the strength indicators.

The study included calculation and optimization of concrete mix compositions for pavement concrete via mathematical planning. It suggests compositions of road concrete of B35 class of the compression strength index; Bt4.4 bending tensile strength; XF3 operational environment index; F150 frost-resistant grade; P1 placeability grade; 4-6% of entrained air; at least 1 hour of concrete mix viability. Besides, it demonstrates dependences of the main physical-mechanical properties of concrete on cement consumption, a type and amount of additives.

It should be noted that the suggested compositions with additives are cheaper than a traditional heavy road concrete. The use of Muraplast FK 88 and Air 202 additives allows reducing the cost of 1 m³ of concrete mix by 8.22% in relation to nominal content without reducing the grade strength. The use of Muraplast FK 68 and Air 202 additives allows reducing the same cost by 6.6%.

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