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Original Empirical Research

Innovative Technology of Preparation of Concrete Mixtures

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Abstract

Introduction. Using the example of the production of road concrete in the Rostov region, the article looks at the issues of increasing the efficiency of the technology for preparation of concrete mixtures to ensure the normative indicators of the physical and mechanical properties of concrete without increasing cement consumption and additional costs for reconstruction of existing enterprises in the construction industry.

The aim of the study is to develop a set of prescription and technological measures to ensure regulatory requirements for strength characteristics of concrete produced with the use of local raw materials with no technical re-equipment of existing concrete mixing plants.

Materials and Methods. To this end, while conducting the experimental research, a local raw material base was used that is widely available in the construction industry. The study aimed at developing prescription and technological measures for improving the production efficiency of the road concrete under study was performed using standard methods for assessing the normalized properties of similar materials, concrete mixtures and hardened concrete. In order to optimize the parameters of the developed formulation and technological solutions, mathematical modeling methods of the stochastic system under study based on the theory of experimental planning were applied.

Research Results. The developed innovative technology for preparing concrete mixtures enables an increase in the strength of the concrete under study by 15–20%, or reduce cement consumption by 10–12% without a reduction in the strength of the resulting material.

The results were achieved by means of developing a set of prescription and technological measures including introduction of the suggested carbonate micronutrient and polycarboxylate superplasticizer into the concrete mixture in combination with the developed two-stage method for preparing the concrete mixture.

Discussion and Conclusion. The novelty of the developed technology for preparing concrete mixtures is protected by an invention patent. The results were achieved by means of the combined introduction of the developed limestone-shell filler and superplasticizer ST 5.0 into the concrete mixture in combination with an innovative two-stage technology for preparing concrete mixtures.

Based on the general theoretical understanding of the structure formation of cement concretes as well as of their strength properties, it is possible to extend the results of these studies to production of a broad range of monolithic and prefabricated products as well as structures that are to comply with the regulatory requirements for not only compressive strength, but also for tensile strength. Naturally, in each specific case, additional research will be required that would take into consideration the specifics of the regional raw material base as well as the specifics of a particular enterprise in the construction industry and its product range.

Keywords: road cement concrete, technology of concrete mix preparation, carbonate microfiller, superplasticizer

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Инновационная технология приготовления бетонных смесей

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Аннотация

Введение. В статье на примере производства дорожного бетона в Ростовской области рассмотрены вопросы повышения эффективности технологии приготовления бетонных смесей, обеспечивающей нормативные показатели физико-механических свойств бетона без увеличения расхода цемента и дополнительных затрат на реконструкцию действующих предприятий строительной индустрии.

Цель проведенных исследований — разработка эффективных рецептурно-технологических мероприятий, обеспечивающих нормативные требования к прочностным показателям бетона, изготавливаемого на основе местной сырьевой базы без технического перевооружения действующих бетоносмесительных заводов.

Материалы и методы. Для достижения поставленной в работе цели при проведении экспериментальных исследований использована местная сырьевая база, доступная для широкого применения на предприятиях строительной индустрии. Исследования, направленные на разработку рецептурно-технологических мероприятий по повышению эффективности производства исследуемого дорожного бетона, выполнены с применением стандартных методик оценки нормируемых показателей свойств сходных материалов, бетонных смесей и затвердевшего бетона. Для оптимизации параметров разработанных рецептурно-технологических решений применены методы математического моделирования исследуемой стохастической системы на основе теории планирования эксперимента.

Результаты исследования. Разработанная инновационная технология приготовления бетонных смесей обеспечивает возможность на 15–20 % повысить прочностные показатели исследуемого бетона, либо на 10–12 % уменьшить расход цемента без снижения прочности получаемого материала.

Полученные результаты достигнуты за счет разработки комплекса рецептурно-технологических мероприятий, включающего введение в бетонную смесь предложенного карбонатного микронаполнителя и поликарбоксилатного суперпластификатора в сочетании с разработанным двухстадийным способом приготовления бетонной смеси.

Обсуждение и заключение. Инновационная новизна разработанной технологии приготовления бетонных смесей защищена патентом на изобретение. Полученные результаты достигнуты за счет совместного введения в бетонную смесь разработанного микронаполнителя на основе известняка-ракушечника и суперпластификатора ST 5.0 в сочетании с инновационной двухстадийной технологией приготовления бетонной смеси.

Исходя из общетеоретического представления о структурообразовании цементных бетонов и формировании их прочностных свойств, можно распространить результаты данных исследований на производство широкого круга монолитных и сборных изделий и конструкций, которые должны удовлетворять нормативным требованиям по прочности не только на сжатие, но и на растяжение. Естественно, в каждом конкретном случае потребуются дополнительные исследования с учетом специфики региональной сырьевой базы и специфики того или иного предприятия строительной индустрии и номенклатуры выпускаемой продукции.

Ключевые слова: дорожный бетон, технология приготовления бетонной смеси, карбонатный микронаполнитель, суперпластификатор

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Introduction. The article deals with the current issues of improving the efficiency of the technology for preparing concrete mixtures to ensure the normative indicators of the physical and mechanical properties of concrete without an increase in cement consumption and investment costs for renovation of existing construction industry enterprises in the context of the conditions of road concrete production. The relevance of the issues is due to concrete road surfaces becoming more broadly used in most developed countries. The trend is due to the annual increase in the number of vehicles on roadways, an increase in their load-bearing capacity and speed of cargo flows in motorways.

Given all of the above, the issues of the quality of raw materials for road concrete production with the appropriate physical and mechanical properties are gaining momentum [1].

At the same time, deposits of fine sands dominate in lots of regions, with their use in the concrete composition causing increased cement consumption. As a result of numerous previous studies [2–5], methods have been developed to reduce cement

consumption in concretes on fine sands by means of introducing micro-fillers into the concrete mixture, such as finely ground sand, ground metallurgical slags and other natural or man-made mineral components. However, the process of grinding these raw materials to produce a micron filler is highly energy-intensive, which ultimately increases concrete costs.

There are also known methods for reducing cement consumption by intensifying the process of mixing concrete mixture [6–9], however, these methods require replacing existing concrete mixers with high-speed ones in most cases, which requires large investment costs.

The aim of these studies was to develop comprehensive formulation and technological solutions to ensure production of concrete mixtures for road concrete at existing enterprises in the construction industry with no additional investments needed for modernization and technical re-equipment or an increase in cement consumption.

Based on the analysis of previous studies [10–15], a working hypothesis was set forth that this aim can be achieved by using micro-filler additives in road concrete composition in combination with optimizing the method of preparing concrete mixtures for road concrete at existing concrete mixing plants. The following tasks were thus solved in stages:

1. Selecting modifying additives of domestic production in the concrete mix.
2. Searching for an effective micro-filler based on a local raw material base.
3. Developing an innovative technology for preparing concrete mixtures with no technical re-equipment of existing concrete mixing units.

Materials and Methods. The road concrete of the design class in terms of compressive strength B35 and flexural tensile strength was adopted as the object of research B_{fb} 4.0.

The following materials were used in the study.

Portland cement produced by Sebyakovcement CEM I 42.5 N with a normal NG density of 26.75 and an actual activity of 29.2 MPa at the age of 2 days, 54.8 MPa at the age of 28 days was used as a binder.

Sandstone crushed stone with a fraction size of 5–20 mm produced by Donskoy Kamen LLC in compliance with the requirements of GOST 26633-2015 was used as a coarse aggregate for manufacturing the road concrete under study.

According to the regulatory documents, sands with a modulus of size $M_k = 1.5–3.0$ should be used for road concrete. High-modulus sands are not produced in the Rostov region. The delivery of such sands from other regions leads to a significant increase in the cost of concrete mixtures. The most suitable local sand in terms of characteristics is the sand of the Kayalsky quarry with a M_k equal to 1.57 used as a fine aggregate.

A polycarboxylate-based superplasticizer ST 5.0 manufactured by BSR LLC, St. Petersburg, was selected for plasticization of the concrete mixture based on previous information. According to the manufacturer, the specified superplasticizer is characterized by the data in Table 1.

Table 1

Characteristics of the additive ST 5.0

Indices, measurement units	Values
Appearance	Brown liquid
Smell	Weak
Total content of the solid phase, %	25
Density of the solution, g/cm ³	1.070 ± 0.03
pH (undiluted product)	9 ± 1.5

The developed micro-filler for the road concrete under study was obtained using pontic limestone-shell rock from the Kamenskoye deposit in the Rostov region, crushed to a powdery state.

The original limestone-shell rock is a yellow-brown rock, mostly consisting of slightly cemented fragments of shells of various sizes. The content of calcium carbonate in the rock ranges from 87 to 97%. The average density of rock pieces is in the range of 1.5–2.2 t/m³, depending on the deposit depth. Compressive strength is up to 25 MPa, rock porosity is 15–40% by volume.

Methodological studies aimed at achieving this aim were performed in stages in compliance with the working hypothesis and the suggested research aims. At the same time, use of standard methods for identifying the normalized properties of the original materials, characteristics of the resulting concrete mixtures as well as strength parameters of the hardened concrete were combined by means of mathematical methods of experimental planning theory, polynomial modeling and interpretation of the resulting response functions.



Fig. 1. Appearance of shell limestone

At the first stage of the experimental studies, the effect of the degree of crushing of powdered limestone-shell and its content in the mixture on the strength properties of the mortar part of concrete was examined. The experiments were performed on cement-sand samples — beams measuring 40×40×160 mm with its material compositions modelling the mortar part of the concrete under study.

After the samples had hardened under normal conditions at the age of 28 days, they were subjected to strength tests by means of conventional bending and compression methods.

Based on the results of the strength tests and corresponding mathematical processing of the experimental data using methods of planning theory [16], polynomial models were obtained that adequately describe the dependencies under study at a 5% significance level that were used to identify the rational dosage ranges of the resulting carbonate micron filler based on crushed limestone-shell.

At the second stage of the study, considering the results at the first stage, in order to optimize the technological parameters of preparing the concrete mixtures, experiments were performed on concrete samples-prisms measuring 100×100×400 mm tested at specified times by means of the standard methods for identifying the compressive and flexural strength of the concrete under study.

Research Results. At the first stage of the study conducted on a cement-sand mortar with a ratio of C:S = 1:1.7 corresponding to the mortar part of the road concrete, quadratic polynomial models of the effect of the degree of crushing of the carbonate filler and its quantitative content in the mixture on the flexural and compressive strength of the resulting material were obtained by means of the methods of experimental planning theory. As a result of interpreting the obtained models, it was found that the optimal dosage of the micron filler under study ranges from 60 to 100 kg/m³ while grinding the original limestone shell to a specific surface area of at least 2000 cm²/g.

As a result of further studies, an innovative two-stage technology for preparing concrete mixtures with a limestone-shell filler was developed. The priority novelty of this development is protected by the patent of the Russian Federation for invention [17].

The essence of the developed two-stage technology is as follows. At the first stage of the preparation of the concrete mixture, small and large aggregates, as well as micro-fillers, were loaded into the concrete mixer at specified dosages.

The above components were mixed in a dry state until a homogeneous dry mixture was obtained.

At the second stage, Portland cement, water, and a superplasticizer were added to the resulting dry mixture, after which all of the components were mixed until a concrete mixture of the required workability was obtained.

The composition of the concrete mix with a consumption of 420 kg/m³ of Portland cement with the following ratio between the components (by weight) was adopted as the original one C:N:L = 1:1.69:2.71.

The consumption of the superplasticizer additive ST 5.0 (an aqueous solution of 25% concentration) was 1% by weight of Portland cement. The consumption of the filler additive varied from 40 to 120 kg/m³ and was introduced into the mixture due to a corresponding reduction in sand consumption. The amount of mixing water in each case was selected from the conditions for obtaining equally mobile mixtures of grade P2 (5–9 cm).

The compositions of the concrete mixtures, methods of preparing them as well as the results of the strength tests of concrete at the age of 28 days of normal hardening are shown in Table 2.

Table 2

Compositions of the concrete mixtures, technology of preparing them and the concrete strength at the age of 28 days of normal hardening

No. of a test	Mixture preparation method	Material consumption, kg/m ³						Concrete strength, MPa	
		cement	water	limestone	sand	ST 5.0	microfiller	R_{tb}	R_b
1	Single-stage	420	168	1140	710	4.2	0	5.1	45.2
2	Two-stage	420	172	1140	650	4.2	60	6.0	51.8
3		420	174	1140	630	4.2	80	6.3	53.9
4		420	176	1140	610	4.2	100	5.8	49.7
5	Two-stage with reduced cement consumption	370	170	1140	680	3.7	80	5.2	45.6

В результате проведенных исследований установлено, что разработанная инновационная технология приготовления бетонных смесей повышает прочность бетона на 15–20% (составы No 2, 3, 4) или позволяет на 12% снизить расход цемента (состав No. 5) по сравнению с одностадийной технологией (состав No. 1) без ухудшения прочностных свойств дорожного бетона. Наглядно эти результаты представлены на рис. 2.

As a result of the study, it was found that the developed innovative technology for preparing concrete mixtures increases concrete strength of by 15–20% (compositions No. 2, 3, 4) or reduces cement consumption by 12% (composition No. 5) compared with the single-stage technology (composition No. 1) without compromising the strength properties of road concrete. These results are clearly shown in Fig. 2.

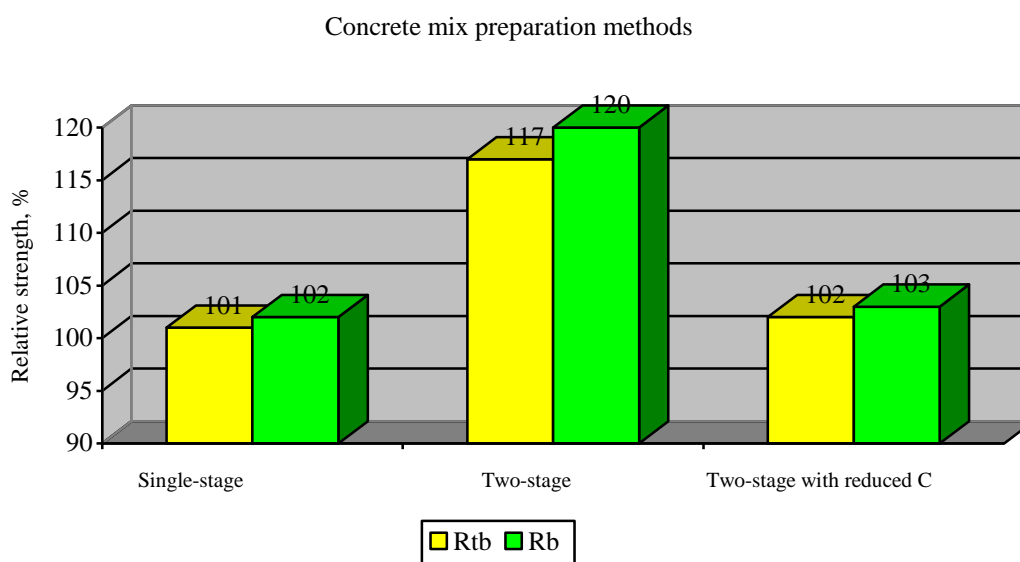


Fig. 2. Dependence of concrete strength parameters on the technology of concrete mix preparation

Discussion and Conclusion. The study results ensure road concrete production in compliance with the regulatory requirements for its strength characteristics, with no additional costs for technical re-equipment of existing concrete mixing units and based on a local raw material base.

The results were achieved by means of a combined use of a micro-filler developed using crushed limestone-shell and superplasticizer ST 5.0 in combination with an innovative two-stage technology for concrete mixture preparation.

The innovative technology of manufacturing concrete mixes for road concrete developed in compliance with the study aims enables a reduction in cement and superplasticizer consumption at existing enterprises of the construction industry with no additional costs for reconstruction and technical re-equipment or compromising product quality.

The suggested set of prescription and technological measures to improve the efficiency of concrete mix production technology can be extended to mass production of concrete mixtures for general construction purposes. At the same time, for them to be introduced into production, technological solutions should be adjusted taking into account the requirements for products, local raw material base as well as specifics of existing enterprise, which can be attained at the factory laboratory.

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