

Self-compacting concrete made with the use of local raw materials and industrial wastes

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Abstract. The subject matter of the research: fine-dispersed mineral additives based on raw materials and industrial wastes for the production of self-compacting concrete with prescribed high physical and mechanical characteristics, the use of which will be economically more justified by reducing energy consumption, evaluating their contact with superplasticizers.

The aim: the analysis of mineral additives based on local raw materials and industrial wastes combined with a superplasticizer for the production of self-compacting concrete with high physical and mechanical properties.

Materials and methods: scanning electron microscope JEOL JSM-6490 LV, X-ray fluorescence spectrometer for elemental analysis ARL OPTIM, X, ThermoTehno, Switzerland; gas analyzer Gank - 4. The parameters to study are as follows: sedimentative and chemical composition of mineral additives, molding properties of a concrete mixture, mechanical properties of concrete.

The result: mineral additives with the use of local raw materials and industrial wastes have been analyzed, optimal costs have been selected for the optimal hydration reaction behavior and the formation of a denser structure of self-compacting concrete.

Conclusions: studies of finely dispersed mineral additives in combination with a superplasticizer have been carried out in order to obtain self-compacting concrete with specified high physical and mechanical properties.

1 Introduction

Currently, a rapid development in the production and the use of construction materials have been observed. There are new technologies and methods of constructing the buildings. In its turn, it results in increasing requirements for construction materials, mostly to concrete. Concrete is a typical building resource. It is a material that allows to put into practice the most ambitious projects.

Nowadays there is a huge variety of the types of concrete. Due to them it is possible to achieve the tasks. We can produce concrete of the required functionality while controlling the properties, creating the necessary structure of the material of a certain composition by means of technological impact on raw materials and predicting the results.

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All these factors have contributed to the development of a new concrete technology, the so-called self-compacting concrete (SCC). As it was made not long ago, it relates to a new generation of technology [1].

SCCs are characterized by a specific granulometry of fillers - the consumption of crushed stone does not exceed the consumption of sand, the sieving of fillers, if it is possible, approximates the “ideal” curve - and the obligatory availability of a mixture of modifying agents including fine mineral fillers and an increased consumption of a superplasticizer. The search for new mineral additives based on local raw materials and industrial wastes, which can improve the physical and mechanical properties of self-compacting concrete, is a relevant task.

2 Literature review

The idea of self-compacting concrete originated in Japan in 1990, when Professor H. Okamura introduced a new generation of high-performance additives based on polyacrylate and polycarboxylate to improve viscosity. K. Maekawa and K. Ozawa have also contributed to the development of SCC properties. As a result, high-ductility concrete with a low water-cement ratio was obtained [2].

Further development of the study of SCC refers to Germany. Properties of self-compacting concrete were studied at the Institute of Construction Research in Aachen (Germany) in 2000-2001 under the charge of Professor V. Brahmshuber commissioned by the firm “DyckerhoffBetonGmbH”, which created the first preconditions for the official distribution of this material throughout the Europe. According to the research, compressive strength of such concrete is higher than that of “vibrating concrete”. In addition, the material has increased water permeability properties. As a result, the SCC was formally recommended for constructing the buildings with tough requirements for water permeability [3-4].

The regulatory document containing both detailed terms, methods for diagnosing SCCs and references with other standards connected with concrete was published in Berlin by the German Reinforced Concrete Committee in November, 2003. It contributed to the wider distribution of self-compacting concrete in Europe [5]. After the release of this document, self-compacting concrete was officially authorized in Europe.

Nowadays SCC study is still relevant. The Faculty of Engineering of the Technical University in Berlin under the guidance of professors Hillemeier and . Buchenau still deals with the research of methods of defining mixture properties.

Now in Russia there are also scientific research results aimed at designing compositions of high-strength self-compacting concretes [6]. In the works [7] binding composites used for fine-grained self-compacting concretes were considered. The mechanism of increasing the strength of concrete with the use of microfillers has been studied [8-9].

Both European and Russian specialists are involved in research connected with development of raw material base used for production of self-compacting concrete.

3 Materials and methods

The implementation in modern construction of complex projects and modern rates of production of concrete works require the use of special concretes, such as SCC. It has some specific properties and cannot do without a complex of additives. The complex of modifiers, such as fine mineral fillers and super-plasticizers in the composition of self-compacting concretes was investigated.

The set of most polymer and mineral additives is formed empirically. So, the study and integral assessment of the interaction mechanisms of microfillers and hydrate phases of cement systems in the process of hardening is one of the most important tasks in the development of concrete science. It is impossible to characterize this mechanism unambiguously, since a complex and multicomponent hydrating cement system has a number of factors that affect the nature and kinetics of chemical and crystallization processes.

Nowadays, the most common mineral additive used in the technology of concretes with high operating properties, including self-sealing, is microsilica. However, it is necessary to expand the raw material base of mineral additives at the expense of local raw materials and associated products of the industry. For this purpose it is necessary to study other fine materials (fineness of grinding close to cement), since the volume of the fine filler introduced into the SCC is higher than in vibrating high-strength concrete.

In the mining and processing industries a huge amount of waste production of natural and man-made origin is accumulated. They contain silica, alumina, carbonate and other components and the use of them in the concrete technology is economically and environmentally beneficial.

As finely dispersed mineral additives the study applied: ground limestone from overburden Mazul Deposit, jadeite cutting waste of Kashkarakskiy Deposit, ash of the Krasnoyarsk thermal power plants in comparison with nanocrystallization Centrilite of NCproduction MS-Bauchemie. Some of them, along with high rheological ability in relation to superplasticizers, may have chemical activity in the hydrating cement system. The optimal dosage for inert fine additives can be both the volume comparable to the volume of capillary pores and necessary to fill the corresponding voids and the structure sealing and the rheological properties ensuring of the mixture [10]. The chemical composition of the products used as mineral additives is given in table 1.

Table 1. The chemical composition of the mineral additives

Mineral additive	Content of Oxides, %									
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	SO ₃	Na ₂ O	K ₂ O	TiO ₂	C. L.
Ground limestone of Mazul Deposit	2,88	1,6	1,19	7,9	76,56	0,67	-	-	-	9,2
Jadeite cutting waste of Kashkarakskiy Deposit	57,6	20,3	2	1,2	2,1	-	11,7	-	0,2	4,9
Ash of the Krasnoyarsk Thermal Power Plant 1	68,8	6,22	3,57	3,82	15,2	0,93	0,18	0,45	-	< 0,1

Ash of the Krasnoyarsk Thermal Power Plant 2	35,6	8,21	8,8	3,44	28,73	3,9	0,6	0,4	-	1,12
Ash of the Krasnoyarsk Thermal Power Plant 3	48,8	8,2	9,3	4,1	23,0	0,7	0,3	0,6	-	0,7
Note: C. L. - Calcination Losses										

The initial rock of jadeite cutting waste of Kashkarakskiy Deposit looks like crystals of light greenish-gray color with coarse-grained massive texture of granoblastic structure. The percentage of rock-forming minerals is jadeite corresponds to 95%, albite corresponds to 4%, analcim corresponds to 1%.

A liquid plasticizing additive based on polycarboxylate esters - MC-Powerflow-7951 was used as a superplasticizer. The system action mechanism of the mineral additives in combination with a modifier based on the ethers of polycarboxylates in concrete mixtures results from an increase in the specific surface area of the cement paste components. Thus, the volume of firmly held adsorption water increases as well. It leads to obtaining the necessary amount of fine fraction paste, which, in its turn, provides the formation of a sufficiently thick coating on the surface of the filler grains, and finally contributes to obtaining a self - compacting mixture.

4 The results of the research

“The microfiller effect” cannot be explained only by the formation of additional centers of crystallization, since their direct effect is to accelerate the initial stage of chemical hardening [8-9]. It is necessary to estimate the particle size of the mineral additive, which should be in the same area with the cement grain, i.e. a specific surface area of at least 3500-4000 cm²/g.

In order to assess the dispersion of the studied products, a sedimentation analysis was performed. The results of the analysis are presented in the table 2.

Table 2. The dispersion of the mineral additives

Name	d _{min} , μm	d _H , μm	d _{max} , μm	S _{sp} , cm ² /g
Jadeite cutting waste	2,15	13,49	90,71	3733
Ground limestone of Mazul Deposit	7,20	25,95	174,38	1651
Ash of the Krasnoyarsk Thermal Power Plant 1	8,00	28,42	193,81	1835
Ash of the Krasnoyarsk Thermal Power Plant 2	1,98	12,41	83,44	3434
Ash of the Krasnoyarsk Thermal Power Plant 3	11,45	41,26	277,25	2625

According to the results, the products used as mineral additives are polydispersed and the particle sizes of some products correspond to the cement ones, others exceed. Thus, the specific surface area of the additives makes it possible to use them in self-compacting concrete. They affect positively both on the distribution of binder particles in the microstructure of the formed artificial stone and on the rheological properties of the SCC. It should be noted that the ground limestone, despite the lowest specific surface area, had high water demand. The dispersion of jadeite cutting waste allows it to be used without additional processing, so it is an energy-efficient resource.

In addition, there were significant fluctuations in the chemical composition and structure of ash, it results in the use of special technological methods for stabilization. The surface microstructure of the ash samples from the Krasnoyarsk Thermal Power Plant 2 is in Fig.1.

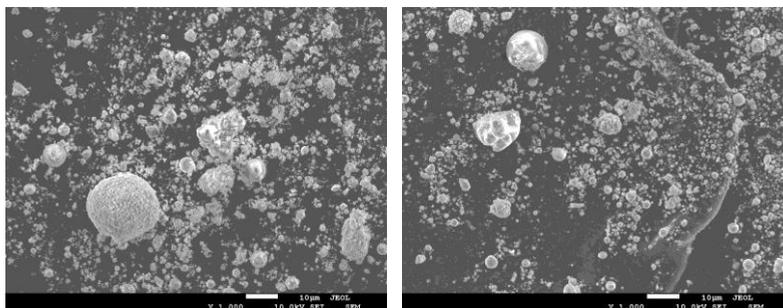


Fig.1. Microstructure of the ash samples surface

The use of the studied mineral fillers will make it possible to exert a structure-forming effect for oriented crystallization of new formations, to obtain an artificial stone of high density, promotes the hydration of clinker minerals, thereby changing the nature and rate of hydration processes, which leads to the formation of stable, high-strength structures in the cement stone.

The first stage included the assessment of the cement paste quality, water-cement ratio and the optimal consumption of the plasticizer. Water demand was calculated by linear regression and extrapolation.

The second stage was devoted to the determination of the self-compacting concrete mixture properties. A limited amount of large filler was added to the solution and the final compositions were calculated: fine composition (cement + filler), large filler, water and sand. A large number of compositions were investigated and only some of them were allocated. They had the most satisfactory physical and mechanical characteristics. Further they are given as the main laboratory.

The composition with ground limestone was rejected due to the fact that an abundant gas release and stratification of self-compacting concrete mixture were observed when introducing superplasticizer (Fig. 2)



Fig.2 Self-compacting concrete mixture with ground limestone

The released gases were collected and their preliminary analysis was performed. It showed the presence of the ammonia form of calcium nitrate $\text{Ca}_5\text{NH}_4(\text{NO}_3)_{11}$ (0.01 ml/dm³) and ammonium hydroxide NH_4OH (0.3 ml/dm³). This effect requires further research, but it should be taken into account that if the composition of the concretes include limestone and plasticizing additive together, the volume of the mixture should be noted: the greater the volume the greater the concentration of the gases. After hardening, the conditions of high humidity in the room will provoke catalytic isolation and decomposition of these substances.

In order to determine the physical and mechanical concrete characteristics, cube samples with an edge of 10 cm. were made. They were equal to the cement consumption and different products as fine-dispersed mineral fillers. In the process of laboratory mixing compositions were correlated to ensure the stability of the SCC. The test results are shown in table 3.

Table 3. Properties of self-compacting concrete

Index	Compositions of self-compacting concrete on the basis of			
	Centrlit NC	Jadeite cutting waste	Ash of the Krasnoyarsk Thermal Power Plant 2	
	1	2	3	
Consumption of mineral additives, kg / m ³	53	136	136	
W/c	0,31	0,27	0,28	
Concrete density, kg / m ³	2560	2526	2504	
Strength of samples, MPa (%)	days	57,4 (81,5)	65,4 (92,9)	68,4(97,2)
	8 days	81,5 (117,2)	89,3(126,8)	72,7 (103)
Note: percentages are based on required strength for the class B55				

The compositions with mineral additives Centrlit NC and jadeite cutting waste provide a compressive strength class W55. However, for obtaining optimal strength the consumption of Centrlit NC was 53 kg/m³, which is 2.5 times lower than the jadeite cutting waste. It is explained by high dispersion and nanocrystallizer activity, which, in its turn, is characterized by an increased water-cement ratio.

The consumption of ash and jadeite cutting waste are the same, but the 28 days strength is higher in composition 2. Probably it results from the reduced water-cement ratio because of the increased porous phase of ash.

All highly functional concretes require special modes of care, the lack of them leads to a decrease in strength at different hardening periods. So, samples of composition 2, for 14 days showed strength of 89.1 MPa, and left without leaving for 28 days - 79.3 MPa, the samples of the composition 3 also showed a decrease in strength from 71.5 to 57.7 MPa, respectively.

Since the concrete mixtures of SCC have a low water-cement ratio (less than 0.4), the decrease in strength can be explained by the autogenous shrinkage. It occurs due to the so-called “self-drying” of concrete, as the cement continues to absorb water for hydration from the pores.

5 Conclusion

A number of fine mineral additives in combination with a superplasticizer in the production of self-compacting concrete with some prescribed high physical and mechanical characteristics have been studied. The best physical and mechanical properties were achieved in the

samples of SCC with the use of jadeite cutting waste. Their strength is equal to the nanocrystallization concrete. It is possible to use jadeite cutting waste as a mineral additive without any technological refinement. According to sedimentation analysis, we came to the conclusion that its specific surface area, as well as the ash of the Krasnoyarsk Thermal Power Plant 2, is comparable to the cement dispersion. The use of them as mineral additives makes it possible to obtain a high density cement matrix and increases the strength at the age of 28 days. The best costs of the mineral fillers for the optimal behavior of hydration reaction and the formation of a denser concrete structure are selected.

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