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Fine-grained concrete for repair and restoration based on complex modifiers

Sarsenbek Kozhasov[1], Aigul Kozhas[2,*]

[1]Kazakhstan Institute for Reconstruction and Development, Karaganda, Kazakhstan
[2]Department of Technology of Industrial and Civil Engineering, L.N. Gumilyov Eurasian National University, Astana, Kazakhstan
*Correspondence: kozhas@bk.ru

Abstract. Nowadays ensuring normal operation of buildings made of monolithic reinforced concrete is of great relevance. Bearing building structures in the process of operation or erection can have defects and damages of various origins. There is a need to develop repair compositions to ensure the durability and reliability of monolithic reinforced concrete buildings. In this paper we have conducted research and developed a repair composition of fine-grained concrete (FGC) on the basis of modification and improvement of its structure. In the composition of complex modifier on the basis of analysis were chosen: microsilica MCU-95 as a highly active pozzolanic mineral admixture; superplasticizer C-3, hydrophobizing component – soapstock. Cements of Novo-Karaganda, Ust-Kamenogorsk, Shymkent cement plants M400 were chosen as binders. In order to study the influence of modifiers on the setting time of cement dough and concrete structure, several concrete compositions were developed. The performance of the developed FGC was improved in terms of basic physical and mechanical parameters. Cement consumption was reduced by 15% (from 450 kg to 382.5 kg). The influence of the main factors and dependence of performance indicators on physical and mechanical properties of cement stone and the studied FGC has been established. Production waste and local construction materials were used to save binder.
Keywords: microsilica, concrete, repair, repair, composition, defects, damage.

1. Introduction

Currently, construction in Kazakhstan is developing rapidly. There is an increase in the construction of low-rise and high-rise residential buildings, various commercial and cultural centers. Monolithic construction of higher storey with load-bearing stone structures or reinforced concrete space frames has been widely used. In the monolithic buildings constructed in recent years, there is a significant number of defects of load-bearing structures [1–3] (Figure 1). The nature of defects and damages in buildings made of monolithic reinforced concrete depends on many factors and reasons: the quality of engineering surveys and design documentation, the quality of materials and products, compliance with the quality control system during construction, as well as violation of the technology of construction works, including the use of poor-quality formwork [4]. Physical deterioration of reinforced concrete structures under the factor of time: creep and shrinkage of concrete, exposure to aggressive external environments, mechanical loads lead to cracking of concrete, corrosion of steel, peeling of concrete coating, and, as a consequence, loss of serviceability and safety of the structure [5]. This has caused a huge need to improve the performance of existing reinforced concrete structures by repairing and reinforcing them in order to extend their service life. According to the results of the authors' research [6] – the main cause of defects in buildings and structures is the inability to ensure the necessary characteristics of concrete, both at the stage of concrete mixture preparation and at the stage of erection of the finished monolithic structure.

Ensuring reliability, durability and increasing the service life of buildings made of monolithic and prefabricated reinforced concrete structures is an urgent issue in the construction industry not only in Kazakhstan, but also in the whole world. The construction industry of all industrially developed countries spends about 42 % of financial injections for repair and operating costs on objects built of reinforced concrete. In [7], a repair cost analysis using PSLF (probabilistic service life function) is proposed, where changes in initial and extended service life due to repair are considered.

In view of the relevance of the use of concrete mortars for the repair of concrete and reinforced concrete structures, the works and research work of many researchers have been studied. Since concrete on coarse aggregate is not quite acceptable for its application in thin layers, it was decided to use crushed stone of 5...10 mm size as an aggregate. The concrete obtained on such aggregate is classified as fine-grained concrete.

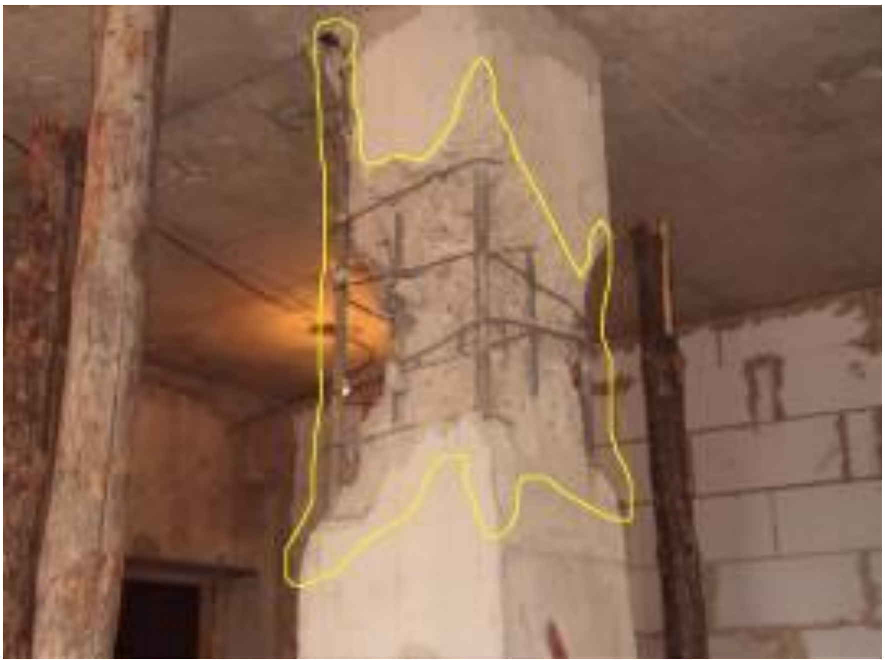

Figure 1 – Column concrete failure with bare and corroded reinforcement

In the present work, the research and development of repair composition of fine-grained concrete (FGC) based on modification and improvement of its structure, which consists in improving its physical-technical and hydraulic properties. To obtain FGC with high repair properties, the existing materials were reviewed and compared.

It is well known that the repair mortars used are made from ordinary Portland cement (OPC), which were developed to repair old concrete to achieve better compatibility with concrete bases [5]. To obtain concrete with improved technical and performance characteristics, one of the most promising directions in construction is to modify concrete with a complex of modifying additives and production wastes, which is economically feasible and develops domestic house building. The paper [8] presents the results of research work on the development of fine-grained polymer concrete modified with microsilica. The authors of [9] used 5%, 7.5% and 10% (by weight) of microsilica to improve the mechanical properties of mixtures as a partial replacement of cement, and the results show that the mixture with 25% recycled aggregates and 5% microsilica showed characteristics comparable to conventional concrete, while the use of a higher content of microsilica negatively affected the rheological properties.

In order to obtain concrete with enhanced performance characteristics under the condition of minimizing raw material, energy and labor costs in the present work, studies on the development of the optimal composition of FGC were carried out. The following materials were used: microsilica MCU-95, superplasticizer - C-3, hydrophobizer - Soapstock and curing gas pedal - sodium sulfate.

The purpose of the work is to study and develop an effective composition of concrete FGC for repair and restoration of reinforced concrete structures in the construction and operation of residential buildings.

The purpose of the work should be achieved by solving the following tasks:

– introduction of microsilica, hydrophobizer and curing gas pedal in addition to superplasticizer into the concrete composition to obtain an effective FGC composition;

– to find out the optimal ratio of components to obtain FGC with high performance characteristics, effectively used in the repair of residential buildings made of concrete and reinforced concrete;

– to establish the influence of the main factors and dependence of performance indicators on physical and mechanical properties of cement stone and the studied FGC.

2. Methods

In the course of research and practical work the following materials were used.

Cements of Novo-Karaganda, Ust-Kamenogorsk, Shymkent cement plants M400 were chosen as a binding material. Characteristics on mineralogical and chemical composition of cements are given in Tables 1 and 2.

Table 1 – Mineralogical composition of cements

Name of manufacturing plant	Mineral content, %			
	C_3S	C_2S	C_3A	C_4AF
Karaganda	58.16	18.92	8.61	13.52
Ust-Kamenogorsk	54.88	22.96	9.70	12.31
Shymkent	51.92	15.06	8.18	13.96

Table 2 – Chemical composition of cements

Name of manufacturing plant	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	$CaO_{св}$
Karaganda	19.87	6.09	4.48	61.53	1.50	1.26	0.58
Ust-Kamenogorsk	21.68	6.29	4.02	67.60	0.80	0.44	0.67
Shymkent	19.42	6.05	4.83	61.67	1.63	1.74	0.71

The cements used in the work were tested in accordance with [10] and [11]. The results are attached in Table 3.

Table 3 – Cement test results

Name of plant, type and grade of cement	Bulk density, kg/m^3	Specific surface area, cm^2/g	Grinding fineness by residue on sieve No. 008, %	Normal density of cement dough, %	Ultimate strength at the age of 28 days, MPa	
					Compressive	Flexural
Karaganda Portland cement M400	1095	3100	8.4	27.0	43.0	5.9
Ust-Kamenogorsk Portland cement M400	1100	3200	8.2	27.0	42.0	6.0
Shymkent Portland cement M400	1100	3200	8.2	26.0	41.0	5.8

The tested cements, according to the obtained results, meet the requirements of [12].

Water for testing of cements and concretes corresponded to [13]. The analysis of total hardness of water used in the technology showed 12.8...100 mg-eq/l, from slightly brackish (dry residue up to 2.3 g/l) to strongly brackish (dry residue 3.0+19.5 g/l) and by acidity from slightly alkaline to slightly acidic (pH - 6.7...7.3).

Sand and crushed stone used in concrete mixtures meet the requirements of [14-15]. Characteristics of the used sand are given in Table 4.

Table 4 – Sand test results

Sand mine	Characteristics of sand		
	Coarseness modulus	Bulk density, kg/m^3	Impurity, %
Karagandanerud, JSC	2.6	1450	2…3
Gauhartas, LLP	2.2	1420	0.5…1
SBS Group, LLP	2.4	1480	1.5

The characteristics of the coarse aggregate used are given in Table 5.

Table 5 – Test results of coarse aggregate

Fraction of aggregate, mine	Name of indicators			
	Density, kg/m^3	Water absorption, %	Sparseness, %	Impurity, %
5-10 mm, Karagandanerud, JSC	1400	0.85	8.06	0.75
5-20 mm, Bektas Group, LLP	1420	0.96	9.24	2.06
5-10 mm, TechnoIndustry, LLP	1370	0.41	3.1	1.86

The composition of organomineral admixture of fine-grained concrete (FGC) for repair was developed on the basis of the following materials. In the composition of the complex modifier were chosen: microsilica MCU-95 as a highly active pozzolanic mineral admixture; superplasticizer C-3, contributing to the effective liquefaction of concrete mixtures [16], hydrophobizing component - soapstock [17-18], obtained by refining oils; curing gas pedal sodium sulfate (Na_2SO_4), meeting the requirements of TS 38.10742-84.

Requirements for superplasticizer C-3 and composition are given in Table 6.

Table 6 – Requirements for superplasticizer C-3

Name of indicators	Normal value
Appearance	The liquid is brown in color. A precipitate is allowed.
Active substance content in terms of dry product, % at least	69
Water content, % not exceeding	68
Ash content in terms of dry product, % exceeding	38
pH of 2.5 % aqueous solution	7-9

Superplasticizer C-3 is 20...40 % water concentrate and is supplied in tanks or drums. Percentage of water in the solution is regulated by passport data.

Soapstock is a production waste obtained during processing of vegetable oils, consisting of 41 % of fatty acids and 50 % of inactive inclusions (Table 7). Soapstock has the consistency of viscous dark brown paste, well and stable emulsifying with water.

Table 7 – Characteristics of soapstock (in accordance with TS-10-04-0280-91)

Name of indicators	Characterization		
	Light oil soapstock	Cottonseed oil	Animal fat soapstock

		soapstock	
Color	Light to light brown with a tinge of the color of the original oil	Brown to dark brown	Yellow to dark yellow with a grayish tint
Consistency at 20°C	Liquid or ointment	Ointment	Ointment
Smell	specific, characteristic of soapstock from various oils and fats fats and greases, a slight odor of decomposition products of organic substances is allowed, no odor of petroleum products is allowed, odor of decomposition products of organic substances is allowed, petroleum product odor is not allowed		
External solid impurities	Absence	Absence	Absence

Sodium sulfate (SN) is a powdered or granular product supplied in packaged form. According to the known method of concreting, its main application was to accelerate the processes of setting and hardening of concrete [19–22]. In the developed composition of FGC with modifying additives SN, stabilizing the action of soapstock, is simultaneously a reagent that actively hardens the components of the liquid structure on the surface areas of mineral particles.

The International Union of Experts and Laboratories for Testing of Building Materials, Systems and Structures RILEM proposes to classify mineral additives from industrial waste by assessing their best applicability, primarily in terms of pozzolanic and hydraulic activity.

Microsilica is an ultradisperse material consisting of spherical-shaped particles, obtained in the process of gas cleaning of furnaces in the production of silicon. The main component of the material is amorphous silicon dioxide.

Microsilica is supplied in saleable forms and is labeled accordingly: compacted, MCU-90, MCU-95.

The numerical index in the labeling indicates the minimum allowable amount of silica (SiO_2). Technical specifications TS 5743-048-02495332-96 for condensed condensed microsilica are presented in Table 9.

Table 9 – Specifications for condensed microsilica

Name of indicators	Standards for grades of condensed compacted microsilica	
	MCU-90	MCU-95
Appearance	Fine-grained powdery material of gray color with aggregate size up to 0.5 mm	
Mass fraction of water, %, not exceeding	5	5
Mass fraction of loss on ignition, %, not exceeding	5	5
Mass fraction of silicon dioxide (SiO_2), %, at least	90	95
Mass fraction of sulfur dioxide, %, not exceeding	0.6	0.6
Grinding fineness (specific surface area), m/g, at least	12	12
Bulk density of microsilica dry forms, kg/m^3	80-500	280-500

The chemical composition of microsilica is presented in Table 10.

Table 10 – Chemical composition of microsilica

Manufacturer	Content, %						
	SiO_2	C	Fe_2O_3	Al_2O_3	CaO	Impurities	other
Tau-Ken Temir, LLP	96.9	1.82	0.05	0.16	0.22	2.84	0.78

3. Results and Discussion

In order to study the effect of modifiers on the setting time of cement batter and structure of concrete, several concrete formulations were developed as shown in Table 11.

Table 11 – Experimental compositions of concrete mixtures

No.	Composition, kg/m^3							
	Portland cement	Sand	Crushed stone	Water	Superplastisizer C-3	Microsilica	Hydrophobicizer of vegetable oil soapstock	Hardening accelerant sodium sulphate
1 (Reference)	450	660	1060	167	3.6 (0.8%)	-	-	
2	455.5	650	1060	167	3.6 (0.8%)	4.5 (5%)	-	5.4 (1.2%)
3	382.5	650	1060	167	3.6 (0.8%)	67.5 (15%)	-	6 (1.3%)
4	382.5	650	1060	167	3.6 (0.8%)	67.5 (15%)	2.1 (0.46%)	9 (2%)

In the course of laboratory studies it was possible to obtain the most optimal ratio of aggregates, filler and modifiers in relation to the mass of binder, the distribution of which is as follows: Portland cement – 382.5 kg/m^3, Crushed stone – 1060 kg/m^3, Sand – 650 kg/m^3, Water – 167 kg/m^3 at W/C of 0.43; Microsilica – 67.5 kg/m^3 (15%); Superplastisizer C-3 – 0.5…0.9% (in fact – 0.8%); Soapstock – 0.2…0.5% (in fact – 0.46%); Sodium sulphate – 1…2% (in fact – 2%).

To determine the effect of the complex of modifying additives on the processes of structure formation, the influence of their dosage on setting time was studied.

Table 12 shows the results of cement dough tests to determine the normal density and setting time.

Table 12 – Effect of complex modifiers on normal density and setting time of cement dough

No.	Composition	Quantity by weight of cement, %	Normal consistency, %	Setting time, h	
				Start	End
1	Superplastisizer	0.8	22.2	4.1	6.1
2	Superplastisizer +Sodium sulphate	2 (0.8+1,2)	21	3.8	5.6
3	Superplastisizer +Sodium sulphate	2.1 (0.8+1.3)	20	2.6	3.5
4	Superplastisizer + Soapstock+Sodium sulphate	3.26 (0.8+0.46+2)	18.5	2.3	3.1

From the data obtained, it can be seen that the normal density of cement dough decreased from 22.2 % to 18.5 % when the dosage in composition No. 4 was changed. It is also observed that the onset of setting time decreased from 4.1 hours to 2.3 hours and the completion accelerated from 6.1 hours to 3.1 hours. Based on the results obtained, it is assumed that the optimum balance in dosage of superplasticizer C-3 and curing gas pedal sodium sulfate has been found. Applying only Superplastisizer (C-3) separately, it is impossible to simultaneously correct and comprehensively affect the normal cement dough density and setting time.

It should be noted that the acceleration of the beginning and end of setting time is of great importance for the use of complex modifiers of concrete during repair works.

According to the results of the experiments shown in Table 13 and Figure 2, it can be observed that the densest structure is characterized by the composition No. 4 containing Microsilica, Superplastisizer, Soapstock and Sodium sulphate with an open porosity of 6.1% and corresponding water absorption of 2.2%.

Also, from the obtained experimental results it can be concluded that Superplastisizer more densely packs different-sized grains, and in the process of cement hydration mineral additives and Microsilica react with other materials. All these processes lead to the fact that the surfaces of particles are enveloped by a thin layer of hydration products and the whole structure is united into a single whole.

Table 13 – Main microstructure indicators

No. of compositions	Age of concrete, day	Average density, kg/m^3	Water absorption of concrete, % by weight	Overall porosity (P_o), %	Volume of open pores, P_{op},%	Average size index of capillary pores, λ_2	Uniformity dimensions index of open capillary pores, α
1	28	2140	4.2	16.8	9.0	0.74	0.61
2		2188	3.8	16.3	7.4	0.60	0.68
3		2260	2.9	13.2	6.4	0.54	0.76
4		2272	2.2	12.8	6.1	0.56	0.77

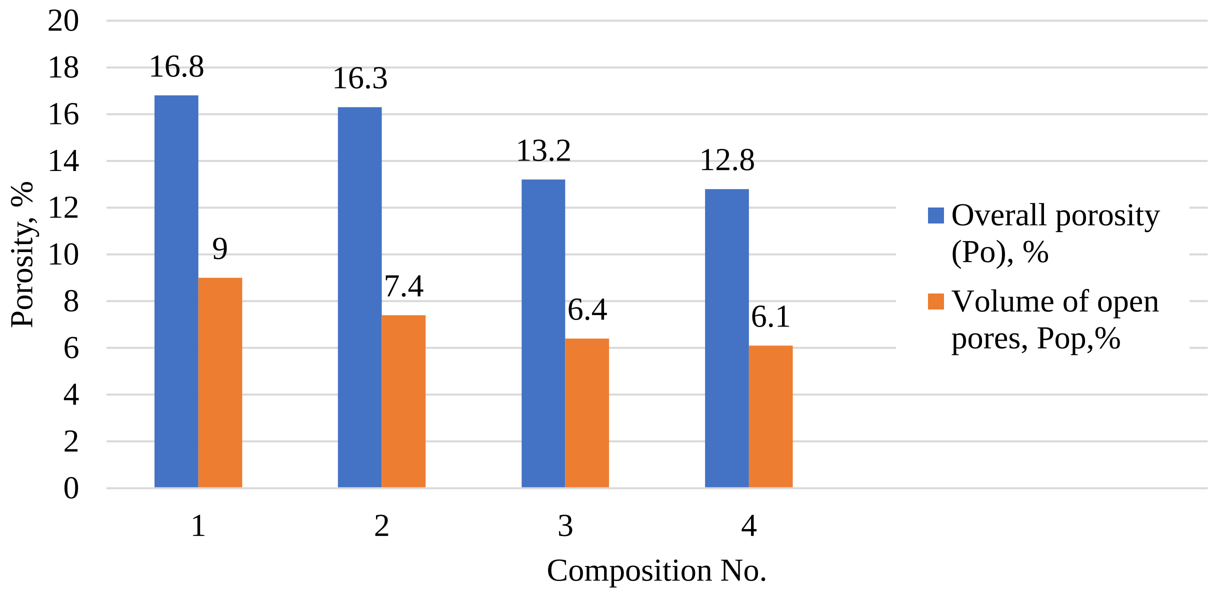

Figure 2 – Effect of modifying additives on density indices of repair concrete structure

It should be noted that the composition modified by the complex of additives has a lower capillary porosity in relation to the control composition, and, therefore, has less shrinkage, which is also an important property for repair mortars.

Determination of shrinkage deformation and corrosion resistance of the developed modified MZB formulation.

Before the developed modified concrete composition is the task of using it mainly in the repair of structures, which means that the prepared concrete mortar will need to be applied in layers with a thickness of 10 ... 40 mm. Due to the relative thinness of the layers there is a high probability of formation of shrinkage cracks in them. Repairs made in this way will be short-lived and will not provide proper protection of the structure from corrosion and destruction. In order to determine the shrinkage performance of concrete, the compositions below were tested:

– the reference composition - plasticized concrete of class B40 on coarse aggregate (crushed stone 5-20 mm), without additional modifiers;

– composition No. 1 – plasticized FGC class B40, without additional modifiers;

– composition No. 4 – developed by FGC for repair, with a modified composition (Microsilica + Superplastisizer C-3 + Soapstock + Sodium sulphate).

The results obtained are shown in Table 14.

Table 14 – Shrinkage strain values of compositions

Curing age, days	Reference composition		Composition No. 1		Composition No. 4	
	Shrinkage		Shrinkage		Shrinkage	
	Absolute, mm	Relative, %	Absolute, mm	Relative, %	Absolute, mm	Relative, %
1	0.119	0.09	0.108	0.08	0.064	0.03
2	0.169	0.10	0.153	0.10	0.085	0.04
3	0.200	0.14	0.178	0.12	0.094	0.05
5	0.210	0.17	0.184	0.12	0.097	0.05
7	0.210	0.17	0.188	0.13	0.097	0.05
14	0.220	0.17	0.194	0.13	0.100	0.05
28	0.220	0.17	0.205	0.14	0.100	0.05
42	0.220	0.17	0.205	0.14	0.100	0.05

The results in Table 14 show that compared to the samples of the control mortar and mortar No. 1, the developed mortar No. 4 is the least subject to shrinkage, which allows this concrete to be placed in relatively thin layers. This means that the developed composition can be recommended for use as a repair mortar or even for cladding, since shrinkage cracking is minimized.

As a fine-dispersed mineral additive in the developed composition of FGC is used microsilica from Karaganda plant of Tau-Ken Temir, LLP, which is, in fact, a waste product of ferrosilicon production. Soapstock is also a waste product of Karaganda margarine plant, obtained during processing of vegetable oils. Cement, sand and crushed stone are supplied by local Karaganda producers. All this gives grounds for significant savings on raw materials and transportation costs.

4. Conclusions

The conducted research allows us to conclude that a composition of fine-grained concrete with high performance characteristics has been developed, which is recommended to be used for repair and facing works of residential structures made of concrete and reinforced concrete.

The experimental results confirm that:

– Improvement of characteristics of the developed FGC on the basic physical and mechanical indicators at application in its composition of additives-modifiers of concrete, such as: superplasticizer C-3 on a naphthalene formaldehyde basis, highly active microsilica as a fine-dispersed pozzolanic mineral admixture, hydrophobizing component – soapstock, i.e., a by-product of oil refining and gas pedal of hardening sodium sulfate (Na_2SO4);

– Reduction of cement consumption by 15% (from 450 kg to 382.5 kg);

– The influence of the main factors and the dependence of performance indicators on the physical and mechanical properties of cement stone and the studied FGC was established.

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Information about authors:

Sarsenbek Kozhasov – MSc, Researcher, Kazakhstan Institute for Reconstruction and Development, Karaganda, Kazakhstan, sarsenbek@yandex.kz

Aigul Kozhas – Candidate of Technical Sciences, Senior Lecturer, Department of Technology of Industrial and Civil Engineering, L.N. Gumilyov Eurasian National University, Astana, Kazakhstan, kozhas@bk.ru

Author Contributions:

Sarsenbek Kozhasov – resources, testing, modeling, interpretation, editing, funding acquisition.
Aigul Kozhas – concept, methodology, data collection, analysis, visualization, drafting.

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