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THE INFLUENCE OF A COMPLEX ADDITIVE ON THE STRENGTH CHARACTERISTICS OF CONCRETE FOR ROAD CONSTRUCTION

*Galiya Rakhimova[1], Galina Slavcheva[2], Madina Aisanova[1], Murat Rakhimov[1], Evgeniya Tkach [3]

[1]Department of Construction Materials and Technologies, Karaganda Technical University named after Abylkas Saginov, Kazakhstan; [2] Department of Technology of Building Materials, Products and Structures, Voronezh State Technical University, Russia; [3] Department of Building Materials Science, National Research Moscow State University of Civil Engineering, Russia

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ABSTRACT: Intensive traffic and the rapid growth of the use of motor vehicles necessitate the construction of the most durable roads possible. In this regard, roads made of cement concrete have a number of advantages in comparison with asphalt roads. In the Republic of Kazakhstan, at the moment, it is urgently required to improve the quality of roads. Road concrete works in difficult operating conditions may lead to significant deterioration of its properties (characteristics). To increase the durability of cement concrete coatings and obtain high-strength concrete, there are chemical additives and special-purpose fillers. It is also possible to apply surface treatments to the exposed concrete surfaces. In turn, fillers and additives improve the grain composition, microstructure and reduce the porosity of concrete. In this article, modern additives such as metakaolin, wollastonite and superplasticizer were used to improve the strength of concrete. As a result of the research, it was determined that the use of metakaolin (15% of the cement weight) in combination with a superplasticizer increases the compressive strength of concrete from 40.45 MPa to 54.7 MPa. We also studied the addition of a dispersed filler - wollastonite, which allowed us to achieve an increase in strength up to 40% of the original value. The use of pre-treated water in the electrolyzer was investigated and found to achieve up to 1.5 times increase in strength. Thus, the claimed modified concrete mixture with metakaolin has high strength indicators and has an additional dispersed filler in its composition.

Keywords: Road concrete, Metakaolin, Wollastonite, Compressive strength of concrete

1. INTRODUCTION

The constant increase in the load on the roadway, heavy traffic of motor vehicles, as well as the problem associated with short repair periods undoubtedly affect the wear of road surfaces. In this regard, it is advisable to use cement-concrete road surfaces. These materials typically have increased performance in strength, frost resistance and crack resistance. As a result, concrete road surfaces typically achieve a long service life [1, 2].

In turn, increasing the durability of concrete coatings is one of the important tasks in conditions of a sharply continental climate and increased load from transport. In such climatic conditions, concrete road structures are subjected to a variety of physical and mechanical influences. Such impacts include significant temperature differences (from -40 ^{0}C in the winter to +40 ^{0}C in the summer), moisture (alternating humidification-drying, freezing and thawing of water in the concrete body), dynamic effects of transport, etc. These impacts lead to the destruction of concrete and the loss of its required characteristics [3].

One of the methods of improving the service life of road surfaces is to increase the strength of concrete. It can be achieved by using modern chemical additives, special purpose fillers, impregnation, and processing of finished products with polymer solutions. At the same time, it is necessary to analyze the materials and structures used to apply resource-saving construction technologies [4-11]. The use of additives is mandatory to obtain high-strength concrete. In particular, mineral fillers improve the grain composition and microstructure of cement, stone increases the crack resistance of concrete, while plasticizing additives reduce water demand.

Highly dispersed finely ground mineral additives containing SiO_2 are used in cement concretes for various purposes. Such additives include microsilica, ash, metakaolin, etc. The authors of the article note that metakaolin is a more promising material in comparison with expensive microsilica [12]. Strength experiments using metakaolin have shown an improvement in the mechanical characteristics of concrete, as well as resistance to chemical influences. The authors consider the range from 10% to 15% to be the optimal dosage. While in some articles, the authors use a 15% content of metakaolin when developing the composition of cement concrete. The authors also note a higher rate of development of compressive strength, which is a consequence of a higher rate of hydration [13-14].

The authors of another scientific article also studied the use of metakaolin in the composition of durable concrete. In their article, metakaolin was used in an amount of 5-20% by weight of cement [15]. It is known that additives of mineral origin should be used in combination with water-reducing additives to reduce the water-cement ratio and ensure the necessary mobility of the mixture [16-18].

Also, at the moment, the issue of the use of dispersed reinforcement in concrete is being actively investigated. As a dispersed material, various types of fibers with different sizes and shapes are used. The authors claim that using the various fibers leads to an increase in the strength of concrete [19, 20]. In one of the works, the interaction of metakaolin with steel fiber was investigated, where the authors consider an increase in compressive and tensile strength from 12.5% to 28.6%. It depends on the amount of the additive being injected [21, 22]. We have conducted a search and analysis of information on the use of a cheaper type of fiber. One of these variants is wollastonite fiber, which is a natural material with a fibrous structure.

In the article, the properties of concrete with the addition of wollastonite microfibre were investigated [23]. As a result, the authors obtained high compressive and bending strength. Also, the authors of the article "Durability studies on concrete containing wollastonite" studied the issue of durability of concrete structures with the addition of wollastonite. In this research, when replacing cement with wollastonite, strength and durability increase by up to 15%. At the same time, it leads to a decrease in porosity and compaction of the microstructure of concrete [24]. In one of the works, it was revealed that the addition of wollastonite allows for an increase in the cracking resistance of concrete and also has economic and environmental advantages [25].

The use and effect of electrolyzed water (EV) on improving the strength characteristics of concrete were also studied. Studies have represented that the rapid chemical reaction (hydration) of cement particles in the presence of electrolyzed water leads to the development of a less porous and more compact microstructure [26]. The use of electrolyzed water provides a faster setting of cement and shows higher values of compressive strength compared to a conventional water-based solution at an early stage of curing [27].

2. RESEARCH SIGNIFICANCE

At the moment, there is a problem with the quality of automobile coatings in the Republic of Kazakhstan. This is due to the sharply continental climate and operating conditions. In this regard, it is relevant to improve the mechanical properties of road concrete through the application of modern additives. At the same time, new additives should not lead to an increase in the cost of finished concrete. The purpose of this work is to search for and study effective additives for road concrete available on the territory of Kazakhstan, as well as to analyze their impact on the strength of concrete individually and comprehensively.

Research objectives:

1) Search and analysis of the properties of effective additives for high-strength concrete;
2) Selection of modified concrete composition;
3) Performing studies to determine the strength of concrete;
4) Choosing the optimal composition;
5) Analysis of the obtained research results.

3. MATERIALS AND METHODS

High requirements are placed on the mixture for cement-concrete road surfaces. The formation of the road concrete structure and its properties depends on many factors: the type and quality of the materials, the designed composition of the concrete, the chemical additives used, the technology for preparing, laying and compacting the concrete mixture and the quality of concrete care. According to the recommendations R RK 218-127-2016 [28], Portland cement should be used for concrete road surfaces, which is made on the basis of clinker of normalized composition with a content of tricalcium aluminate (C_3A) in an amount of no more than 7% by weight. Crushed stone and gravel from dense rocks are used as large aggregates. Large aggregates should have an average density of 2000 to 3000 kg/m^3.

As fine aggregates of concrete mixtures, the following are used: sand for construction work, sand from crushing screenings, and mixtures of these sands (sand from crushing screenings of at least 20% by weight). The water used in concrete works should be according to the requirements of the standards. The recommendations also allow the use of additives that improve the properties of concrete and reduce the consumption of cement and the necessary material resources. The materials used in the scientific research satisfy the requirements of regulatory documents.

Table 1 shows the materials used in the work:

Table 1 Materials used in the work

Name of materials	Type (brand, fraction)	Manufacturer
Portland-cement	CEM I 42.5H	LLP "PK "Semey Cement Plant"
Sand		Molodetsky sand quarry
Crushed stone	5-20 fraction	"Techno Industry" LLP, Amansky crushed stone quarry
Crushed stone	20-40 fraction	"Techno Industry" LLP, Amansky crushed stone quarry
Metakaolin additive	Metaver I	NEWCHEM GmbH
Superplasticizer additive	Master Glenium 115	BASF SE
Additive of short-fiber wollastonite		Verkhne-kamskoye field, South Kazakhstan region

Highly active metakaolin, in combination with a superplasticizer and wollastonite, are used as additives. In turn, metakaolin (MTK) is a mineral pozzolan additive that significantly improves the properties of hydraulic cement mortars, concrete and similar products. MTK mixes easily and provides a soft plastic consistency, which is convenient to work with. There are deposits of kaolin ore in Kazakhstan, and therefore, the production of this additive is promising. A feature of MTK is its ability to bind a large amount of free lime in the form of stable crystalline hydrates.

Elemental analysis was performed from different particles of the sample. Figures 1, 2 show the elemental analysis according to the spectrums.

Elemental analysis of the additive has represented the predominance of SiO_2 and Al_2O_3 in its composition in the amounts of 52-54% and 40-43%, respectively. An insignificant content of chemical compounds from 0,1 to 2%, such as Fe_2O_3, TiO_2, CaO, MgO, Na_2O, and K_2O, has also been established. The high content of silicon oxide allows us to conclude that metakaolin has a high chemical activity.

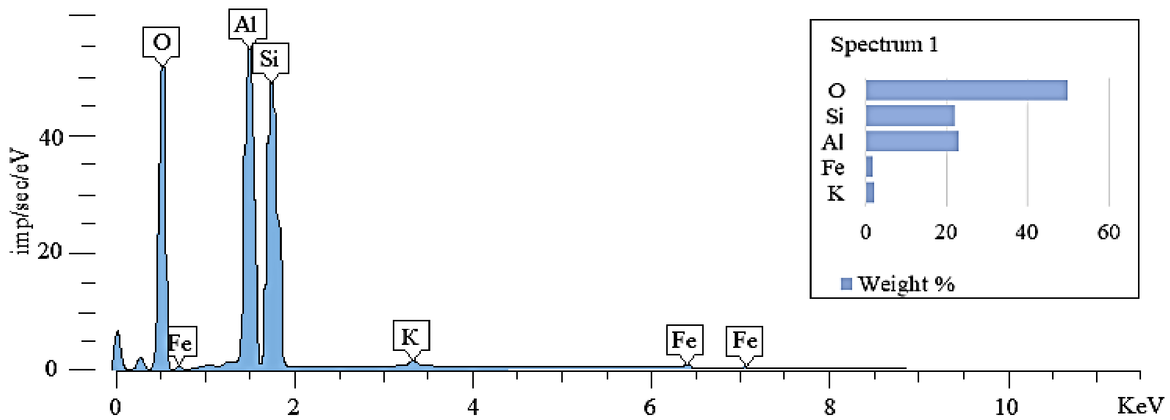

Fig. 1 Spectrum 1. Elemental analysis of metakaolin

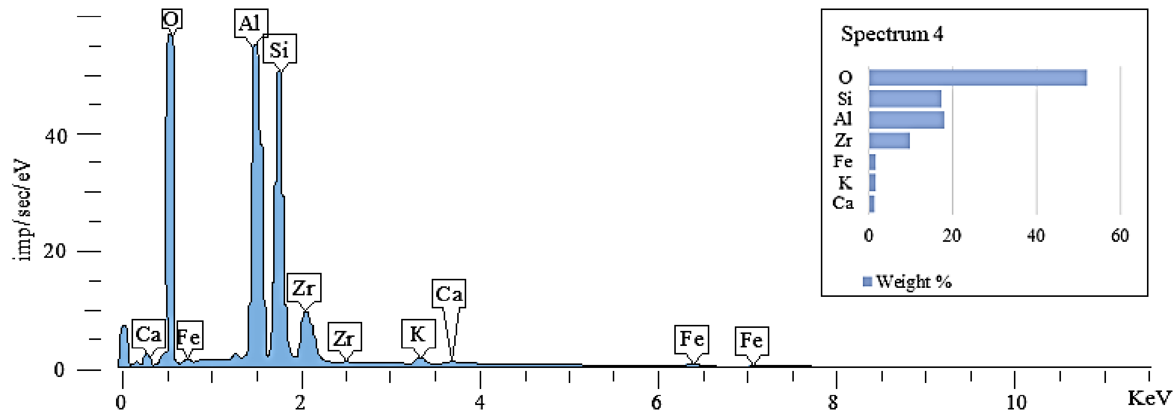

Fig. 2 Spectrum 4. Elemental analysis of metakaolin

Table 2 presents the main physical characteristics of metakaolin.

Table 2 Physical characteristics of metakaolin

Physical characteristics	Indicator
Density	2.6 kg/cm^3
Particle distribution d_{50} d_{95}	 3.4-4.5 mk 12-18 mk
Specific surface area (Blaine)	23000 cm^2/g
Specific surface area (BET)	18 m^2/g
Color	Cream

Studies of the MTK microstructure were carried out. Figures 3 and 4 below show photographs of the MTK microstructure carried out on a Tescan MIRA3 scanning microscope. As the pictures show, the structure of the sample is layered. The layered microstructure gives materials based on it the property of plasticity. The light areas on the right image contain heavier elements compared to the main matrix. As the spectrum of X-ray spectral analysis has shown, in these areas (light), along with the elements, zirconium is detected.

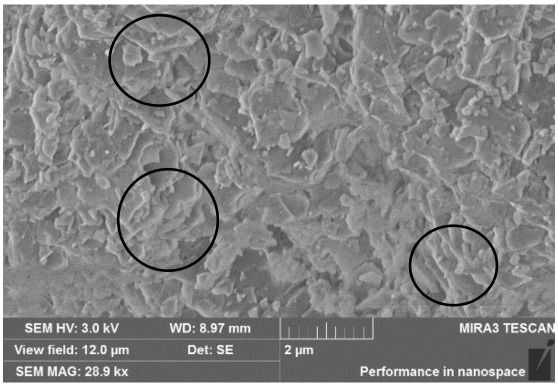

Fig. 3 Microstructure of metakaolin (view field:12.0 μm)

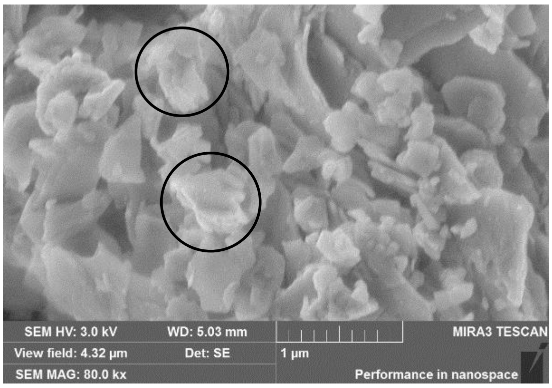

Fig. 4 Microstructure of metakaolin (view field:4.32 μm)

In addition to metakaolin, a superplasticizing additive based on polycarboxylate ether Master Glenium 115 was used. The additive of a plasticizer allows for an increase in the mobility of the concrete mixture, reduces the amount of water, saves the amount of cement without losing the strength of concrete, and increases adhesion. Table 3 shows the main indicators of the MasterGlenium 115 additive.

Table 3 Characteristics of the Master Glenium 115 superplasticizer additive

Characteristic	Indicator
Color	Light brown color
Density, kg/l	1.05-1.09
Chloride content, %	<0,1
Alkali content, %	<3

As a dispersed filler, wollastonite was used, which is a natural calcium silicate of the pyroxenoid subclass with the formula $Ca[SiO_2]$. The color of wollastonite is white with a grayish or brownish tinge. Wollastonite, depending on the length of the fibers, is divided into long- and short-fiber. Wollastonite has a reinforcing effect. This is due to its rough surface, which has chemisorption properties. Figure 5 shows wollastonite acicular microstructure carried out on a S5500 scanning microscope.

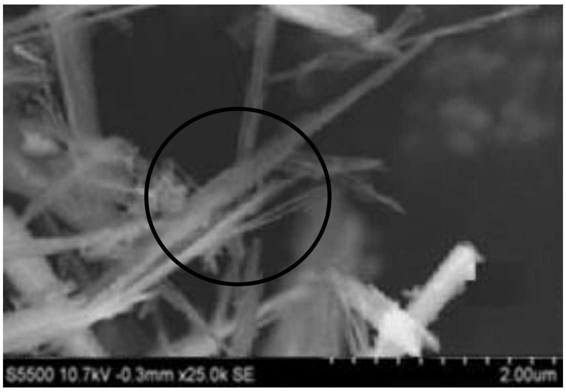

Fig. 5 Wollastonite microstructure (view field:18.1 μm)

4. RESEARCH METHODOLOGY

Research materials were previously investigated according to standards and regulations. According to the regulatory documents, it was necessary to dry the crushed stone and sift the sand through sieves of various diameters. Then there was the distribution of crushed stone by fractions, it was dried to a mass loss of 0%. The first compositions were prepared. We used different combinations of additives in different percentages.

First of all, control composition No. 1 was selected without the use of modifiers and additives. Then composition No. 2 was developed, where highly active metakaolin and a superplasticizer were used. Portland cement, metakaolin and superplasticizer were mixed in a dry state with water. After this, the resulting mixture was added to crushed stone, sand and filled with the rest of the water. Then, composition No. 3 was developed with a changed percentage of metakaolin and superplasticizer. The next option was composition No. 4, which included a dispersed filler – wollastonite. And the final option was composition No. 5, where the water was pre-activated in the electrolyzer.

From the obtained concrete mixes, cubes with a rib size of 10*10*10 and beams for bending tests of 30*10*10 cm were formed. The samples hardened under normal conditions for 28 days, then tests were carried out for compressive and bending strength. The tests were carried out in an accredited laboratory using certified modern equipment.

5. RESULTS

In six series of tests, the preliminary ratio of additives was determined. Initially, 10% and 15% of metakaolin content and a constant value of the superplasticizer were taken. After analyzing the results of the first 2 series, the 3rd series was determined with a change in the percentage of superplasticizers.

Then, we used the additive wollastonite and the preactivated water for compositions 5 and 6, respectively. For each composition, 4 cubes were obtained to investigate the compressive strength. Further, there was checked the mobility of the concrete mixture. The mobility value was 2 cm, it is represented in Figure 6.

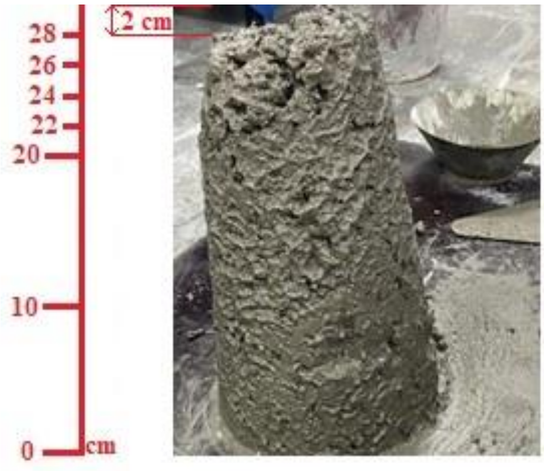

Fig. 6 Measurement of the concrete mixture mobility

Table 4 presents the developed compositions, where the “+” signifies that the materials were used and the “-” signifies that the materials were not used.

Table 4 The developed compositions for concrete

Series No.	Materials used							
	Portland-cement (PC)	Sand	Crushed stone 5-20 fr.	Crushed stone 20-40 fr.	Meta-kaolin	Superplas-ticizer	Wollas-tonite	Activated water («+» - Yes, «-» - No)
1	+	+	+	+	-	-	-	-
2	+	+	+	+	+ (10% of PC)	+ (0.9% of PC)	-	-
3	+	+	+	+	+ (15% of PC)	+ (0.9% of PC)	-	-
4	+	+	+	+	+ (10% of PC)	+ (1.2% of PC)	-	-
5	+	+	+	+	+ (10% of PC)	+ (1.2% of PC)	+ (1% of PC)	-
6	+	+	+	+	+ (10% of PC)	+ (1.2% of PC)	+ (1% of PC)	+

There are concrete samples of Series 1 and 2, respectively, after vibration treatment in Figure 7. At the same frequency and duration of vibration treatment, series 2 with additives in Figure 7 has a denser structure of the concrete mixture.

Fig. 7 Samples after vibration treatment

Further on, Figures 8 and 9 show the results of the compressive strength tests. The tests were carried out on the 28th day after hardening under normal conditions. The Series 6 has represented the highest value of compressive strength for concrete cubes with preactivated water.

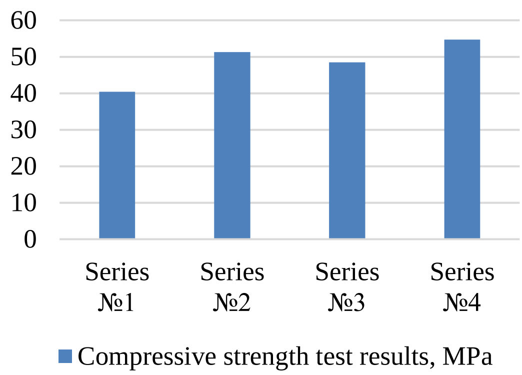

Fig. 8 Results of tests for compressive strength of concrete series 1, 2, 3, 4

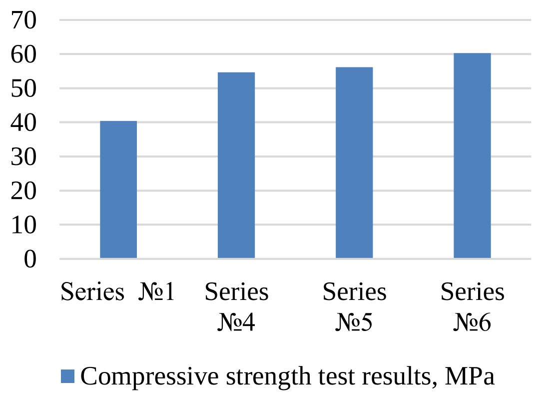

Fig. 9 Results of tests for compressive strength of concrete series 1, 4, 5, 6.

It should be noted that the water was activated in the Melesta electrolyzer, which allowed an increase in the pH of the water from 7.1 to 10 pH. There is an equal of the alkaline medium. We assume that the processes of hydrolysis and hydration occur more intensively due to the application of pre-activated water.

6. CONCLUSIONS AND DISCUSSIONS

According to the test results, we conclude that the application of activated metakaolin into the concrete mixture in combination with a plasticizing additive significantly increases the compressive strength indicator. In particular, when metakaolin was added in an amount of 15% by weight of cement in combination with a superplasticizer (Series 4). The compressive strength of concrete has increased from 40.45 MPa to 54.7 MPa. The rise of the strength index is 35% compared with the control series. The addition of a dispersed filler - wollastonite, also led to a rapid increase in the strength index by 40% of the original value. During the pretreatment of water in the electrolyzer, the compressive strength index increased by 1.5 times in comparison with the control sample. That is why we consider that it is necessary to use such water in the production of high-strength concrete. The optimal composition is composition No. 6 (series 6). Thus, the claimed modified concrete mixture with metakaolin has high strength indicators and has an additional dispersed filler in its composition.

The research results have shown that the use of metakaolin additive with a superplasticizer is more effective when it is mixed with previously activated water in the electrolyzer. Previously, in scientific research, the authors used a dispersed filler separately in an amount of up to 30% of cement and the increase in strength was approximately 30%. While in our research, wollastonite works in conjunction with metakaolin and superplasticizer, and at the same time the strength of concrete increases to 50% of the original value. This is due to the fact that the used additives have good adhesion to the cement stone, reducing the porosity of the cement stone and thereby providing effective micro-reinforcement of concrete. It should also be noted that Kazakhstan has sufficient reserves of kaolin clays and wollastonite ore, which significantly reduces the cost of finished concrete.

The obtained results lead to the possibility of designing high-strength road concrete, including for special structures, where one of the main indicators is the strength of concrete. At the moment, scientific research is being conducted to determine the tensile strength during bending, as well as the frost resistance of the road concrete.

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