

# INVESTIGATION OF FINE-GRAINED CONCRETE PROPERTIES WITH A MIXED BINDER AND VARIOUS FILLERS



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**Abstract:** The goal of this work is to investigate the properties of fine-grained modified concrete using various aggregates and blended binders. Considering that there is a tendency to reduce the use of Portland cement worldwide, the goal was to develop fine-grained concrete compositions with low clinker binders (mixed binders), which would preserve and even improve the physico-mechanical properties of fine-grained concrete. River and lithoid pumice sands were investigated and used as fillers. Superplasticizer, microsilica, and quicklime were used in different quantities to modify fine-grained concrete. The research results show that, depending on the type of fillers used, the compressive strength of the river sand-based mortar increased by 15.33 % after 28 days, and by 6.34 % with lithoid pumice, compared to the reference sample. The use of lime resulted in an increase in the density of cement stone for heavy aggregates but a decrease in density for light aggregates, with no significant increase in strength observed.

**Keywords:** fine-grained concrete, mixed binder, mineral and chemical admixtures, compressive and flexural strengths, carbon dioxide, aggregate activity.

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Received: 28.01.2024

Revised: 25.03.2024

Accepted: 25.04.2024

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## Introduction

New approaches and innovative technologies used to develop modern composite binders aim to increase the quality of the finished product and reduce the cost, but not at the expense of quality. The quality of cement stone, mortar, and concrete can be increased by controlling the structuring processes through the introduction of various mineral and chemical additives [1].

In the modern construction industry, effective plasticizers and microdisperse active mineral additives are required for obtaining concrete with high-quality operational characteristics, that is, mixed binders with complex additives. Another incentive for using various active mineral additives is the problem of reducing carbon dioxide emitted into the atmosphere [2], which occurs in large quantities during the production of Portland cement, which is a co-construction binder [3,4].

Fine-grained concretes based on mixed binders are widely used in construction in different countries: gypsum-cement, cement–lime, and lime cement. Cement-lime mortars are widely used for several reasons. First, lime lowers the cost of the binder and its carbon traces. According to [5-12], the use of large amounts of Portland cement in concrete and construction mortars leads to the emission of greenhouse gases and affects the ecology of the environment.

The cement-lime binders increase the material's eco-friendly qualities, and the constructions based on them are more durable because low-base calcium silicates and aluminates are synthesized in the binding stone. Lime increases the plasticity of the concrete mixture but reduces the curing rate at the initial stage. Over time, lime, as an oily binder, improves the mechanical properties of artificial stone [13,14] because the contact zone, especially in the case of amorphous fillers, is better adhered. If the strength of concrete with dense and inactive fillers is determined by the tensile strength of the bonded surfaces (adhesion) and the strength of the binder

(cohesion), then in concrete with active fillers, in addition to the two factors mentioned, the unique form of adhesion due to the interaction of the filler and the binder plays a significant role.

## Methods and Materials

### Study of the physical and mechanical properties of fine-grained concrete with the same mixed binder and different fillers

The composition and properties of the cement binder greatly influence the structure of the resulting cement stone and concrete. Concrete properties also depend on the type and amount of fillers [15-17]. The effect of a binder with complex additives was studied in this article, with fillers having different origins and chemical activities.

The interaction of the additive with the inorganic binder takes place in the contact zones of the component particles. The optimal content of the mineral additive corresponds to the amount at which its particles will participate in the pozzolanic reaction, as is possible with the calcium hydroxide formed from the clinker minerals [16,17]. In the case of a small amount of the additive, we will have a decrease in the effectiveness of the impact, and in the case of high content, the contact of the particles of the additive with each other will also lead to a decrease in its impact.

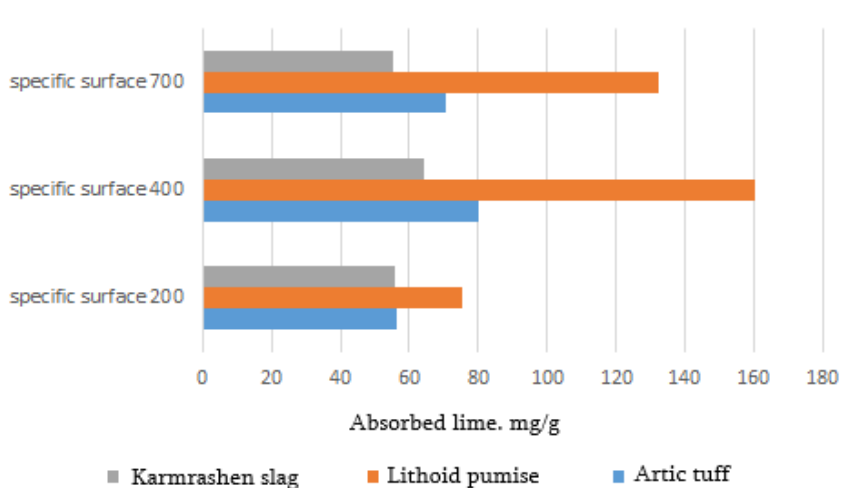
On the other hand, the importance of filler material on the properties of concrete is also known, which is determined by its grain structure, grain porosity, pore shape and size, strength, structure, pozzolanic activity, and strength of adhesion with cement stone [16].

In this study, lime and microsilica were used as mineral additives. Air-setting lime expands several times in volume during lime slaking. In contrast to free super-burnt and very slow lime slaking contained in Portland cement, it slakes quickly, so it does not cause internal stresses during the mortar's hardening process. The import of lime is also due to the activity of vitreous rocks of RA [17].

Lime interacts with the glassy phase of volcanic rocks, determining the mineralogy, phase composition, and structure formation of the resulting artificial conglomerate.

It actively interacts with the vitreous phase of volcanic rocks and determines the mineralogy, phase composition, and structure formation of the resulting artificial conglomerate.

Amorphous volcanic rocks, endowed with energy potential by nature and interacting with lime, produce calcium hydro silicates, hydro aluminates, and other new formations that ensure properties of the artificial stone material. These interactions with different rocks proceed with different intensities because of the difference in the chemical activity of these rocks and the specific surface, which is presented in Figure 1.



**Fig. 1. Activities of volcanic rocks of RA**

RA is rich in effusive rocks, including tuffs, slags, and pumice. Lithoid pumice, the most active rock, was selected as a light filler after considering the most applicable types of these rocks and taking into account the obtained results.

Unlike rocks containing volcanic, porous, and glass phase, quartz, river, quartz-feldspar, carbonate, and other structured fillers used in artificial aggregates, calcium hydroxide practically does not interact with the base of the rock. However, mortars have certain and sufficient strengths.

The preservation of mineral reflexes in rocks (labrador, oligoclase, pyroxene, olivine, quartz, etc.) up to one year of age in limestones examined by X-ray phase means that they do not undergo chemical interaction with lime crystals [16-18].

Therefore, it became interesting to study the behavior of different fillers in concrete with different types of mixed binders: river sand with a crystalline structure from the Ranchpar mine and lithoid pumice from Jraber with the most active vitreous structure in RA.

**Portland cement**

A mixed binder was used in the study, in which M500 or CEM II/A-P 42.5 N (EN 197) class Portland cement produced by the Ararat plant was used. The properties and chemical compositions are given in Table 1 and Table 2.

**Table 1.** Characteristics of Portland cement

Indicator	Results
water requirement, % by mass of cement	31
real density, g/cm <sup>3</sup>	3.1
bulk density, kg/m <sup>3</sup>	1081
fineness of grinding, cm <sup>2</sup> /g	3550
Compressive strength, MPa	
at 3 days	21
at 7 days	38
at 28 days	52
Setting time, minutes	
start	60
end	330

**Table 2.** Chemical composition of Portland cement (oxide content in %)

<i>SiO<sub>2</sub></i>	<i>Al<sub>2</sub>O<sub>3</sub></i>	<i>Fe<sub>2</sub>O<sub>3</sub></i>	<i>MgO</i>	<i>CaO</i>	<i>SO<sub>3</sub></i>	Loss on ignition
21.9	4.5	2.17	1.1	62.2	2.1	3.2

**Micro silica**

Micro silica is the most commonly used active mineral additive, with an average particle size of 0.1 microns. It is approximately 100 times smaller than the average size of cement particles. Owing to the large dispersion and the structure of the amorphous state of the particles, micro silica has high pozzolanic activity and is considered an effective micro filler.

The use of micro silica is appropriate for the introduction of additives and superplasticizers. Being a highly dispersed material, it absorbs a large amount of water, and without the superplasticizer mineral admixture, the effectiveness will be reduced to a minimum, which can sometimes lead to a decrease in the strength characteristics of the concrete. Table 3 lists the characteristics of the micro silica.

**Table 3.** Characteristics of micro silica

Characteristics	Results
particle size, micron	0.1
specific surface, m <sup>2</sup> /g	≈ 20.0
SiO <sub>2</sub> , %	89.1
loss on ignition, %	4.07
bulk density, kg/m <sup>3</sup>	332.5
Cl <sup>-1</sup> , %	< 0.1
pH	5.5 ± 1.0
Color	Grey

**Superplasticizer**

Sika Visco Crete 225P was used as the superplasticizer. It is a powdered organic material of the carboxylate group, has a bulk density of 592 kg/m<sup>3</sup>, and is intended for mortars and concretes.

**Quicklime**

"Effect Group" CJSC lime was used in the work to increase the workability index of the mortar. It is a dust-like material with a bulk density of 703kg/m<sup>3</sup>, average lime slaking rate (12 minutes), and high exothermicity (84°C).

**Fine fillers**

River sand of Ranchpar mine and lithoid pumice sand were used in the study.

The bulk density of river sand is 1765 kg/m<sup>3</sup>, and lithoid pumice sand is 1066 kg/m<sup>3</sup>. The chemical compositions and sieve analysis results are given in Tables 4, 5 and 6.

**Table 4.** Chemical composition of river sand

<i>SiO<sub>2</sub></i>	<i>TiO<sub>2</sub></i>	<i>Al<sub>2</sub>O<sub>3</sub></i>	<i>Fe<sub>2</sub>O<sub>3</sub></i>	<i>MnO</i>	<i>CaO</i>	<i>MgO</i>	<i>SO<sub>3</sub></i>	Loss on ignition
57.26	0.56	14.68	6.22	-	8.33	4.8	trace	4.56

**Table 5.** Chemical composition of lithoid pumice sand

<i>SiO<sub>2</sub></i>	<i>Al<sub>2</sub>O<sub>3</sub></i>	<i>TiO<sub>2</sub></i>	<i>Fe<sub>2</sub>O<sub>3</sub></i>	<i>CaO</i>	<i>MgO</i>	<i>MnO</i>	<i>R<sub>2</sub>O</i>	<i>SO<sub>3</sub></i>	<i>H<sub>2</sub>O</i>	Loss on ignition
71.15	14.64	0.13	1.14	1.46	0.28	0.23	7.22	0.15	0.38	3.70

**Table 6.** Sand residue

Sieve number	2.5	1.25	0.63	0.315	0.16	< 0.16
River sand, partial residue %	12.81	14.56	26.66	16.98	27.6	1.39
River sand full residue, %	12.81	27.37	54.03	71.01	98.61	100
Lithoid pumice sand, partial residue, %	19.75	20.35	12.06	13.02	15.88	18.94
Lithoid pumice sand full residue, %	19.75	40.1	52.16	65.18	81.06	100

**Water**

Water quality meets the requirements of the interstate GOST23732 standard.

**Results and Discussion**

In RA, river sand is widely used for heavy aggregate concrete because the choice of heavy sand is limited, which cannot be said for lightweight filler. Jraber lithoid pumice sand was chosen as an active filler in this study.

The binder was modified by adding varying amounts of microsilica and quicklime. Sika Visco Crete 225P super-plasticizer by 0.3% weight of cement was added to heavy concrete (1.5 kg) and light concrete (1.2 kg). 10 batches of specimens were prepared for testing, with 5 batches containing heavy sand and the other 5 containing light sand.

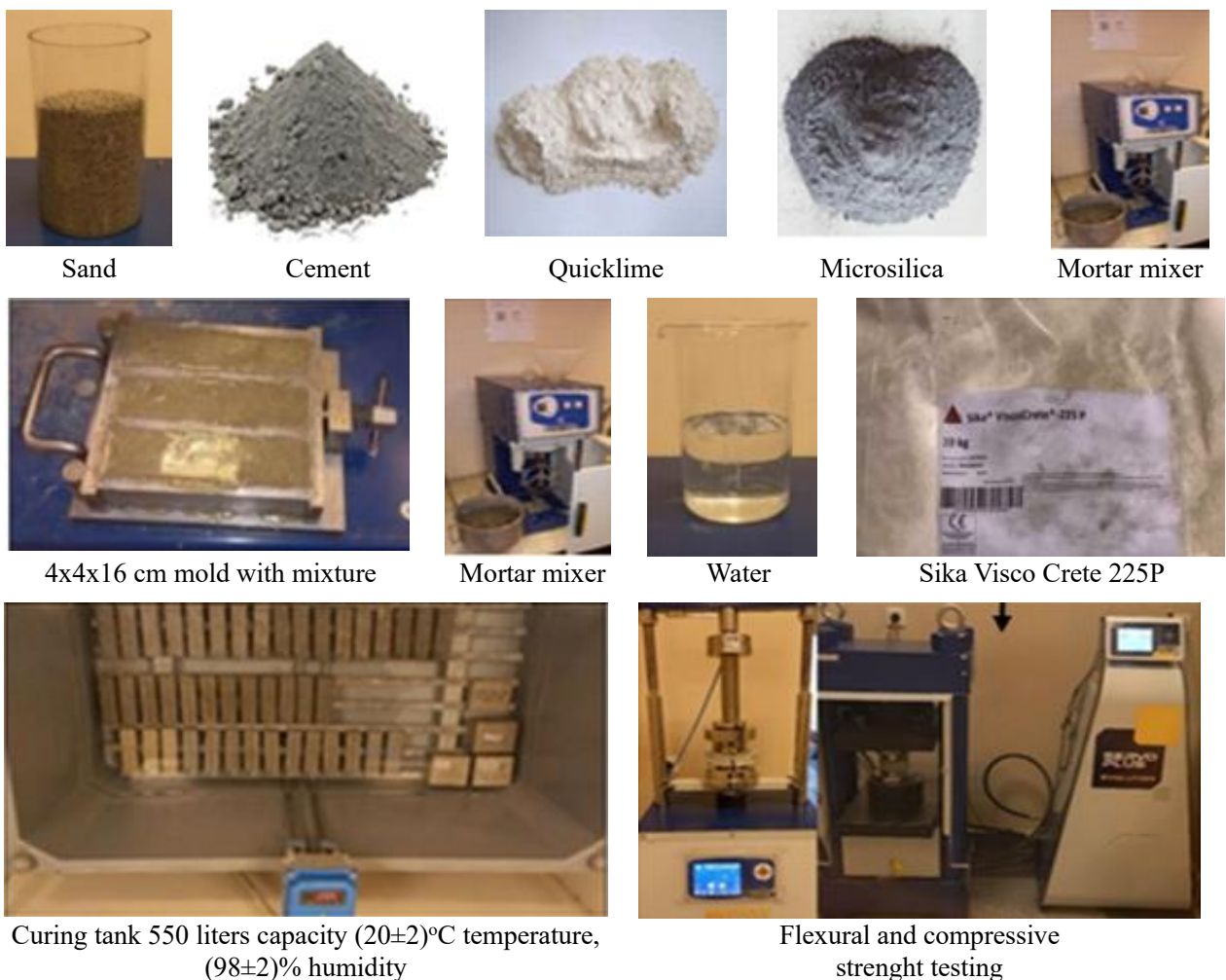
The mortar was prepared with a mixer of MATEST E094 in the following order: cement, micro silica, and lime were mixed for 2 min, sand was added, and mixing was continued for another 2 min. Superplasticizer and water are added to the resulting dry mixture, and the mixing process was continued for another 5 min. In the reference sample, the mass ratio of the binder to sand is 1:3.32. The components of fine-grained concrete with a mixed binder for 1 m<sup>3</sup> are given in Table 7.

40x40x160mm test samples were molded from the obtained homogeneous mixture and compacted on a MATEST vibrator with a frequency of 3000 oscillations/min (Fig. 2).

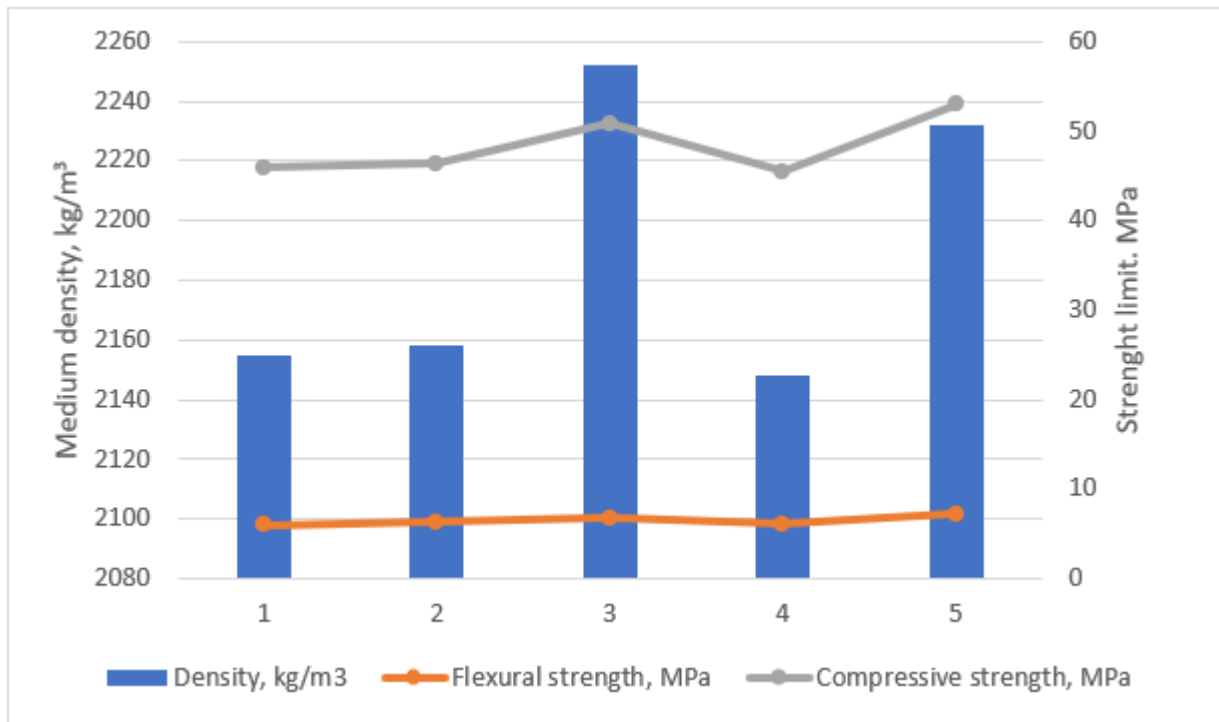
**Table 7.** Compositions of fine-grained concrete

Number	Cement, kg	Superplasticizer, kg	Microsilica, kg	Quicklime, kg	River sand, < 5mm, kg	Lithoid sand, < 5mm, kg
1	500	-	-	-	1660	-
2	500	1.5	-	-	1660	-
3	450	1.5	50	-	1660	-
4	400	1.5	50	50	1660	-
5	350	1.5	100	50	1660	-
6	400	-	-	-	-	1328
7	400	1.2	-	-	-	1328
8	360	1.2	40	-	-	1328
9	320	1.2	40	40	-	1328
10	280	1.2	80	40	-	1328

The peculiarities of the effects of chemical and mineral additives used in the study on the formed stone material are determined by the type of filler used. Mortar made with composite (mixed) binder due to lime slaking were heated during the mixing process. Based on the results obtained, it was observed that the average density and compressive strength of samples made with mixed binder and river sand did not show a significant change when compared to the reference samples (components 1 and 4). However, in the case of flexural strength, a 2.8% increase was recorded which allowed for a saving of 100 kg cement per 1m<sup>3</sup>. Additionally, when the amount of microsilica was increased, there was a 3.6% increase in density and a 15.33% increase in strength which allowed for a saving of 150 kg cement (components 1 and 5) (Fig. 3).

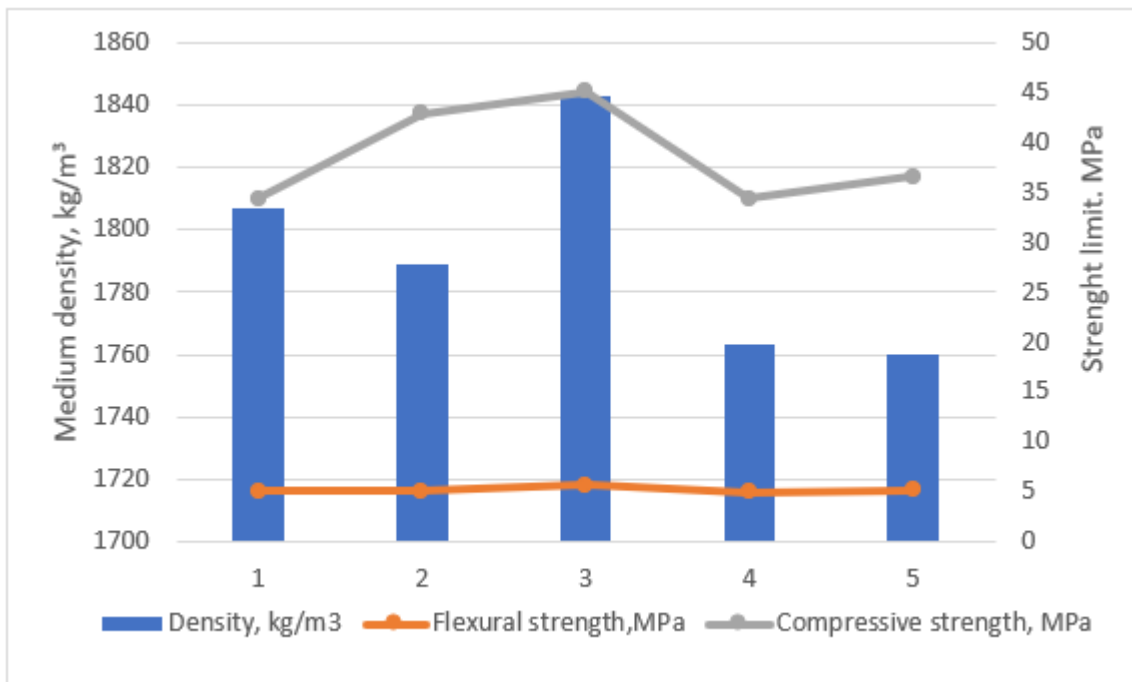


**Fig. 2.** Concrete production technology



**Fig. 3.** The results of the experiment: average density, flexural strength and compressive strength of heavy concrete

For samples with lithoid pumice, with the addition of lime, compared to the reference sample (compositions 6 and 9), a decrease in density of 2.5% is observed, which hardly affected the durability indicators. By increasing the amount of micro silica, the density of concrete decreases by 2.6% compared to the reference sample. By increasing the amount of micro silica, the density of concrete decreases by 2.6% compared to the reference sample, but the strength increases by 6.32% (compositions 6 and 10), which is explained by the formation of a contact layer (crust) on the surface of the light aggregate (Fig. 4).



**Fig. 4.** The results of the experiment: average density, flexural strength and compressive strength of lightweight concrete

In river sand mortar, the increase in volume due to lime slaking leads to the compression of the binder particles, because of which the cement stone becomes dense, creating contact zones with the sand.

The test results of concretes made based on river sand showed that both with using a plasticizing additive (component 2) and microsilica (component 3), an increase in strength was observed compared to the reference sample, but it decreased with the introduction of lime, because of SiO<sub>2</sub> low quantities.

This leads to a significant excess of Ca(OH)<sub>2</sub> (component 4), and with an increase in the amount of silica, pozzolanic reactions between lime and silica again occur, and the strength of the formed stone increases (component 5).

With lithoid pumice, exactly the opposite phenomena occur. The developed specific surface of pumice, which has open and communicating pores, enables the penetration of slaked lime grains into them, which leads to a decrease in the average density of the cement stone, creating a contact layer rather than a contact zone between the cement stone and the aggregates. Because of the decrease in the density of cement stone, the strength of concrete decreases (component 9), which according to [16-18] will continue to increase over time, which is explained by the chemical interaction processes to bind the lime due to the pozzolanic property of pumice, which does not develop quickly, but over tens of years, synthesizing low basic calcium hydro silicates and hydro aluminates (helenite hydrate and hydrogarnet).

The addition of micro silica in this case also leads to an increase in strength, but if it reaches the maximum with a similar composition made of river sand, the result obtained with a composition made of lithoid sand is not the highest strength (the highest: composition 8).

## **Conclusion**

The lime increases the plasticity of the concrete mixture, but reduces the strength at the initial stage of hardening, which is not so convenient in monolithic construction, but the hardening process of the binder, which lasts for tens of years, leads to an increase in the strength and durability of concrete, because low-base calcium hydro silicates and hydro aluminates are synthesized.

Lithoid pumice, which has a vitreous structure and developed surface, when used as a filler, forms a deeper contact zone with the cement stone. Because the grain of slaked lime, which is finer than the grains of Portland cement, penetrates into the smaller pores of the filler and, endowed with activity by nature, it takes place in the structure formation process.

With river sand, the filler is inert, and the strength of concrete increases mainly due to the pozzolanic reactions of Ca(OH)<sub>2</sub> and quicklime with the mineral additive micro silica.

This leads to an increase in the strength of cement stone and, as a result, of concrete. As a result, the strength of concrete with river sand increased by 15.33% compared to the reference sample.

Using lithoid pumice, for modification of the binder with microsilica and quicklime, the strength of concrete increased by 6.3%, but cement consumption per 1 m<sup>3</sup> decreased by 120 kg.

## **Acknowledgement**

The work was carried out with the basic funding of scientific and technical activities from the RA state budget within the framework of the program "Maintenance and Development of the Research Laboratory of Construction and Urban Economy".

## **Conflict of interest**

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

## **Financing**

The study was performed without financial support.

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