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**TEXNIKA FANLARI DOKTORI, PROFESSOR  
MIRAXMEDOV MAXAMADJON MIRAXMEDOVICH  
TAVALLUDINING 80 YILLIGIGA BAG'ISHLANGAN  
“SAMARALI QURILISH MATERIALLARI, KONSTRUKSIYALARI VA  
TEKNOLOGIYALARI”  
MAVZUSIDAGI XALQARO ILMIY-AMALIY KONFERENSIYASI  
ILMIY ISHLARI TO'PLAMI**

Toshkent davlat transport universiteti RAASN akademigi, O'zbekistonda xizmat ko'rsatgan yoshlar murabbiyi, texnika fanlari doktori, professor Miraxmedov Maxamadjon Miraxmedovich tavalludining 80 yilligiga bag'ishlangan, ilmiy ishlar to'plami nashr etilishi ko'zda tutilgan «Samarali qurilish materiallari, konstruksiyalari va texnologiyalari» mavzusidagi Xalqaro ilmiy-amaliy konferensiyani o'tkazishni rejalashtirmoqda.

M.M. Miraxmedov kompozitsion qurilish materiallarining polistruktura nazariyasini rivojlantirishga salmoqli hissa qo'shgan. Uning qurilish materialshunosligi sohasidagi ilmiy hissi e'tirofi sifatida 1995-yilda Rossiya arxitektura va qurilish fanlari akademiyasining (RAASN) xorijiy a'zosi etib saylangan. M.M. Miraxmedov 6 ta monografiya, 200 dan ortiq ilmiy maqolalar va 25 ta ixtiroga mualliflik guvohnomalari muallifidir.

Ushbu konferensiyaning asosiy maqsadi - qurilish materialshunosligi, bino va inshootlarni loyihalash va qurilish sohasidagi ilmiy tadqiqotlar natijalarini, shuningdek, muhandislik ta'limini takomillashtirish yo'llarini muhokama qilishdan iborat.

Konferensiya ishida ishtirok etish uchun oliy o'quv yurtlari va ilmiy tadqiqot institutlari olimlari, O'zbekiston Respublikasi va xorijiy davlatlarning ishlab chiqarish vakillari, ilmiy tadqiqotlarda salmoqli natijalarga ega bo'lgan mutaxassislar taklif etiladi.

**“Samarali qurilish materiallari, konstruksiyalari va texnologiyalari”** mavzusidagi xalqaro ilmiy-amaliy konferensiyaning asosiy yo'nalishlari quyidagilardan iborat:

1. Resurs va energiya tejovchi qurilish materiallari va texnologiyalari.
2. Atrof-muhitning transport infratuzilmasiga ta'siri va uni himoya qilish usullari.
3. Bino va inshootlarning qurilish konstruksiyalari: hisoblash va loyihalashning zamonaviy usullari.
4. Arxitektura, shaharsozlik va shahar muhitini rivojlantirish.
5. Qurilishni tashkil etishning innovatsion usullari va qurilish jarayonlari texnologiyalari.
6. Transport obyektlarini loyihalash va qurishda raqamli texnologiyalar hamda sun'iy intellekt.
7. Temir yo'l transporti infratuzilmasi obyektlarini loyihalash, qurish va ekspluatatsiya qilish.
8. Zamonaviy muhandislik ta'limi tizimini takomillashtirish.

Mazkur konferensiya ilmiy hamjamiyatning turli vakillarini bir joyga jamlab, qurilish materialshunosligi sohasidagi zamonaviy muammolar va istiqbollarni muhokama qilish uchun qulay platforma vazifasini bajardi.

## Modification of the Cementitious System As A Method For Densifying the Inter-Pore Walls of Fiber-Reinforced Foam Concrete

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**Annotation** This study investigates the effect of complex modification of a cementitious system on hardening behavior and strength formation in cement paste designed for the production of fiber-reinforced foam concrete. Microcalcite, microsilica, and a polycarboxylate-based superplasticizer were used as modifying components. The experimental program included a comparison between a reference mixture without additives and a modified mixture incorporating 5% microcalcite, 5% microsilica, and 1% superplasticizer by mass of cement. Compressive strength was evaluated after 3, 7, and 28 days of curing, and the phase composition of the cement matrix was analyzed by X-ray diffraction. The results showed that the complex additive did not lead to a significant increase in early-age strength, but contributed to the development of structure-forming processes by 28 days. X-ray diffraction analysis confirmed the presence of portlandite, calcite, residual clinker minerals, and an amorphous region related to calcium silicate hydrate phases. These findings indicate that the combined use of microcalcite, microsilica, and superplasticizer promotes densification of the cement matrix and can be applied to modify the cementitious binder for fiber-reinforced foam concrete

**Keywords:** Fiber-reinforced Foam Concrete; Cementitious System; Microcalcite; Microsilica; Polycarboxylate Superplasticizer; X-Ray Diffraction; Compressive Strength

### 1. INTRODUCTION

In modern construction, there is an increasing demand for lightweight and energy-efficient materials characterized by reduced density, sufficient strength, and stable performance properties. One of the promising materials in this field is non-autoclaved fiber-reinforced foam concrete, which combines the advantages of a cellular structure and dispersed reinforcement. Due to the presence of artificially formed air pores, this material is characterized by low average density and reduced thermal conductivity, which makes it suitable for use in enclosing, partition, and thermal-insulating structural elements of buildings [1, 2].


However, producing low-density fiber-reinforced foam concrete with sufficiently high strength remains a challenging technological task. As density decreases, the volume of pore space increases, the thickness of the inter-pore walls decreases, and the probability of forming a defective cement matrix increases. As a result, the material may exhibit reduced strength, increased water absorption, shrinkage deformations, and a tendency toward microcracking [3, 4]. Therefore, improving the quality of the cementitious system is one of the key approaches to enhancing the properties of non-autoclaved fiber-reinforced foam concrete.

The condition of the cement matrix forming the inter-pore walls is of particular importance. These structural regions carry the main mechanical load and determine the compressive strength of the material. If the cement matrix is characterized by increased capillary porosity, insufficient density of hydration products, or a large amount of weakly bound phases, the strength of foam concrete decreases even when the pore structure is relatively uniform. In this regard, modification of the cementitious system should be aimed not only at improving the workability of the mixture, but also at controlling the hydration and phase formation processes of cement paste.


A promising approach to increasing the density and strength of the cement matrix is the combined incorporation of mineral and chemical modifiers. In this study, a modifying system consisting of 1% polycarboxylate-based superplasticizer, 5% microcalcite, and 5% microsilica is considered. It is assumed that the superplasticizer ensures dispersion of cement particles and reduces water demand, microcalcite acts as a microfiller and crystallization center, while microsilica contributes to the binding of calcium hydroxide and the formation of additional calcium silicate hydrates.

The aim of this study is to investigate the effect of complex modification of the cementitious system, including 1% polycarboxylate-based superplasticizer,

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5% microcalcite, and 5% microsilica, on phase transformations and the strength of fiber-reinforced foam concrete. To achieve this aim, a reference composition without modifying additives and a modified composition were compared. The effectiveness of modification was evaluated based on the results of compressive strength testing and X-ray diffraction analysis of the cement matrix.

### Literary analysis

The production and application of foam concrete have been widely discussed in the scientific literature. In the work of K. Ramamurthy, E.K. Kunhanandan Nambiar, and G.I.S. Ranjani, studies devoted to the composition, production technology, properties of fresh mixtures, and characteristics of hardened foam concrete are systematized [1]. The authors note that the properties of foam concrete depend on the type of binder, mixture composition, foam stability, water-to-solid ratio, and curing conditions. At the same time, not only the total porosity but also the quality of the formed pore structure plays an important role.

A number of studies show that the strength of foam concrete is closely related to its porosity. E.P. Kearsley and P.J. Wainwright established a relationship between the volume of pore space and the compressive strength of foam concrete [3]. As porosity increases, the strength of the material naturally decreases; however, the nature of this decrease depends on the condition of the cement matrix and the pore distribution. This means that the strength improvement of low-density foam concrete cannot be achieved only by changing the number of pores; it is also necessary to improve the quality of the inter-pore walls.

E.K.K. Nambiar and K. Ramamurthy investigated the influence of pore structure on the permeability and performance properties of foam concrete [4]. The authors emphasize that the size, shape, distribution, and degree of connectivity of pores significantly affect the water absorption and durability of the material. For non-autoclaved fiber-reinforced foam concrete, this conclusion is of particular importance, since instability of the pore system can lead to increased open porosity, reduced strength, and deterioration of performance characteristics.

Fine mineral additives are widely used to improve the structure of the cement matrix. One of the most effective active additives is microsilica. Its effect is associated with its high fineness and high content of amorphous silicon dioxide, which reacts with calcium hydroxide formed during cement hydration. As a result, an additional amount of calcium silicate hydrates is formed, contributing to the densification of cement paste, reduction of porosity, and increase in strength [5, 6]. However, the effectiveness of microsilica depends on its uniform distribution in the cementitious system and on a rational water-to-cement ratio.

Along with active siliceous additives, limestone powder, or microcalcite, is widely used in cement-based materials. According to the review by D. Wang et al., limestone powder can affect cementitious systems through several mechanisms, including the filler effect, nucleation effect, dilution effect, and chemical interaction [7]. When used at a rational dosage, microcalcite contributes to microstructural densification, reduction of porosity, and acceleration of clinker mineral hydration. Under the conditions of fiber-reinforced foam concrete, this may promote the formation of a denser cement matrix and strengthen the inter-pore walls.

An important component of the modified cementitious system is a polycarboxylate-based superplasticizer. Modern polycarboxylate admixtures possess high water-reducing capacity and provide effective dispersion of cement particles. Their action is associated with adsorption on the surface of cement particles, electrostatic repulsion, and steric hindrance between particles [8]. This makes it possible to reduce the water demand of the mixture without impairing its flowability, which is especially important for foam concrete, since an excessive amount of water may cause segregation, settlement, and disruption of the pore structure.

The analysis of literature sources shows that the effects of microsilica, microcalcite, and superplasticizers on cement-based materials have been studied quite extensively. At the same time, most studies consider the action of these components separately or in relation to conventional cement concrete. The complex influence of the combined use of microsilica, microcalcite, and a polycarboxylate-based superplasticizer on phase transformations in the cementitious system and the strength of non-autoclaved fiber-reinforced foam concrete remains insufficiently studied. Therefore, a comparative study of reference and modified compositions using X-ray diffraction analysis is of both scientific and practical interest.

## 2. MATERIALS AND METHODS

The modified cementitious binder was prepared using cement, finely dispersed mineral additives, and a chemical modifier. The main characteristics of the materials used in the study are presented in Table 1.

After the selection of the raw materials, two cementitious system compositions were prepared: the reference composition R and the modified composition M. The reference composition R did not contain mineral or chemical modifying additives and was used for comparative evaluation. The modified composition MK1 included a complex of additives: 5% microcalcite, 5% microsilica, and 1% polycarboxylate-based superplasticizer by mass of cement.



Table 1

## Characteristics of the materials used for the production of fiber-reinforced foam concrete

Material	Origin	Material characteristics	Function in the modified system
Portland cement CEM II/A-K 42.5 N	JSC “Akhangarancement”, Republic of Uzbekistan	Cement containing a mineral carbonate additive; strength class 42.5; used as the main hydraulic binder	Main component of the cementitious system; ensures the formation of cement paste and the strength-bearing matrix of fiber-reinforced foam concrete
Microsilica	By-product of metallurgical production of JSC “Uzmetkombinat”	Highly dispersed siliceous additive with SiO <sub>2</sub> content of more than 92%; particle size less than 1 μm	Active mineral additive; participates in the pozzolanic reaction with Ca(OH) <sub>2</sub> and contributes to the formation of additional C–S–H phases
Microcalcite (CaCO <sub>3</sub> )	Product of carbonate raw material grinding / waste from marble processing	Finely dispersed carbonate filler based on CaCO <sub>3</sub> ; characterized by high fineness, with a specific surface area of 8735 cm <sup>2</sup> /g, and a filler-structuring effect	Acts as a microfiller; improves particle packing, reduces defects in the cement matrix, and promotes nucleation of hydration products
Polycarboxylate superplasticizer “Master Glenium”	Industrial chemical admixture for cementitious systems	New-generation water-reducing admixture; dosage in the modified composition — 1% by mass of cement	Improves the dispersion of cement and mineral particles, reduces the water demand of the mixture, and increases the homogeneity of the cement suspension
Mixing water	Tap water complying with the requirements for water used in concrete mixtures	Used for cement hydration, preparation of the cement suspension, and preparation of the foaming-agent solution	Ensures cement hydration processes and provides the required working consistency of the mixture

Cube specimens with dimensions of 20 × 20 × 20 mm were molded from the prepared mixtures. After molding, the specimens were kept in the molds until demolding and then placed in a standard curing chamber. Curing was carried out at a temperature of 20 ± 2 °C and a relative humidity of not less than 95%. Tests were performed at the ages of 3, 7, and 28 days.

Compressive strength was determined using a hydraulic press in accordance with the requirements of GOST 310.4-81 “Cements. Methods for determination of flexural and compressive strength” and GOST 10180-2012 “Concretes. Methods for strength determination using reference specimens.” At each curing age, specimens of both the reference and modified compositions were tested.

X-ray diffraction analysis of the hardened cement paste was performed at the ages of 3, 7, and 28 days. The analysis was carried out to evaluate the phase changes occurring during the hardening of the reference and modified cementitious systems. The obtained XRD results were compared with the compressive strength test data.

### 3. RESULTS AND DISCUSSION

The experimental results demonstrated that complex modification of the cementitious system significantly influenced the strength development of hardened cement paste. At all curing ages studied, the modified composition M, incorporating 5% microcalcite, 5% microsilica, and 1% polycarboxylate-based superplasticizer by mass of cement, showed higher compressive strength than the reference composition R.



Table 3

Compressive strength of the reference and modified compositions

Composi-tion	Cement content, %	Mineral and chemical additives, wt.% of cement			W/C ratio	Age, days	Compressive strength, MPa
		CaCO <sub>3</sub>	SP «Master Glenium»	Microsilica			
R	100	-	-	-		3	63,4
						7	74,3
						28	74,3
MK1	90	5	1	5		3	63,06
						7	67,73
						28	78,30

As shown in Table 3, at the age of 3 days, the strength values of the reference and modified compositions were almost identical, amounting to 63.40 and 63.06 MPa, respectively. This indicates that the replacement of 10% of cement with microcalcite and microsilica did not cause a noticeable reduction in the early strength of the cementitious system.

At the age of 7 days, the strength of composition MK1 was 67.73 MPa, which was 8.8% lower than that of the reference composition R. This may be attributed to the reduced cement content in the mixture, as well as to the fact that the pozzolanic activity of microsilica does not manifest immediately, but develops gradually as calcium hydroxide accumulates during hardening.

By 28 days, the modified composition reached a compressive strength of 78.30 MPa, whereas the strength of the reference composition remained at 74.30 MPa. Thus, at the design age, MK1 exceeded R in strength by 5.4%. This result indicates the positive effect of complex modification on the strength development of the cementitious system at later curing ages.

The increase in the strength of composition MK1 by 28 days is associated with the combined action of microcalcite, microsilica, and the superplasticizer. Microcalcite contributes to microfilling of the structure, microsilica participates in the pozzolanic reaction with the formation of additional calcium silicate hydrates, and the superplasticizer improves particle dispersion. As a result, a denser cement matrix is formed, which ensures the strength gain of the modified composition.

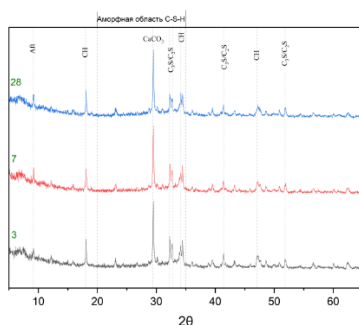


Fig. 1. XRD patterns of the modified composition MK1 at 3, 7, and 28 days

To assess phase changes during hardening, X-ray diffraction analysis of the modified composition MK1 was performed at the ages of 3, 7, and 28 days. The diffraction patterns are presented in Fig. 1.

In the diffraction patterns of composition MK1, reflections of portlandite  $\text{Ca}(\text{OH})_2$ , calcite  $\text{CaCO}_3$ , and residual unhydrated clinker minerals  $\text{C}_3\text{S}$  and  $\text{C}_2\text{S}$  were recorded at all curing ages. The presence of a pronounced  $\text{CaCO}_3$  peak is associated with the incorporation of microcalcite, as well as with the carbonate component present in the cementitious system. The carbonate phase acts as a finely dispersed filler and contributes to the densification of the hardened cement paste structure.

An amorphous region characteristic of poorly crystalline calcium silicate hydrates, C-S-H, is observed in the low-angle range. This phase is the main strength-forming component of hardened cement paste; however, due to its poorly crystalline structure, it does not appear in the diffraction patterns as sharp intense peaks. The formation of the C-S-H phase is associated both with the hydration of cement clinker minerals and with the possible pozzolanic reaction of microsilica with calcium hydroxide.

As the curing age increased from 3 to 28 days, gradual development of the phase composition of the modified cementitious system was observed. The persistence of  $\text{C}_3\text{S}$  and  $\text{C}_2\text{S}$  reflections indicates ongoing hydration processes, while the presence of portlandite confirms the hydration of the silicate phases of cement. At the same time, microsilica may partially bind  $\text{Ca}(\text{OH})_2$  to form additional calcium silicate hydrates, contributing to the densification of the cement matrix.

The obtained XRD data are consistent with the compressive strength test results. Although the strength of composition MK1 at 7 days was lower than that of the reference composition, by 28 days the modified composition reached 78.30 MPa and exceeded the reference composition by 5.4%. This indicates that the main effect of complex modification becomes more pronounced at later curing ages, when the combined action of microcalcite and microsilica contributes to the formation of a denser cementitious structure.



#### 4. CONCLUSION

The conducted studies showed that complex modification of the cementitious system with microcalcite, microsilica, and a polycarboxylate-based superplasticizer changes the hardening behavior of hardened cement paste intended for the production of fiber-reinforced foam concrete.

It was established that the modified composition did not provide a pronounced increase in strength at early curing ages. The main effect of the complex additive became evident by 28 days, which is associated with the gradual development of structure-forming processes in the cementitious system.

The results of X-ray diffraction analysis confirmed the presence of portlandite, calcite, residual clinker minerals, and an amorphous region corresponding to calcium silicate hydrates in the modified composition. The presence of calcite is associated with the incorporation of microcalcite, while the formation of calcium silicate hydrates is caused by cement hydration and the possible participation of microsilica in the pozzolanic reaction.

The combined action of microcalcite, microsilica, and the superplasticizer contributes to the densification of the cement matrix due to microfilling, improved particle dispersion, and the formation of additional hydrate phases. This creates prerequisites for increasing the strength of the inter-pore walls of fiber-reinforced foam concrete.

Thus, the application of the proposed additive system can be considered an effective approach to the targeted modification of cementitious binder for fiber-reinforced foam concrete.

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