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RESEARCH ON THE INFLUENCE OF MICROSILICA ON THE STRENGTH OF CONCRETE USED IN THE COMPOSITION OF A TWO-COMPONENT MODIFIED ADDITIVE

Abstract. In modern construction, considerable attention is paid to the search for environmentally safe and cost-effective methods to improve the performance of concrete. This paper investigates the potential of a complex admixture developed on the basis of industrial wastes, in particular microsilica, phosphogypsum, soapstock and post-alcoholic bard for concrete modification. The aim of the study is to evaluate the effect of each component of the admixture on the transformation processes of concrete, especially on its strength characteristics. Laboratory tests were carried out on specimens with different microsilica content and the results showed that the maximum strength increase was achieved at a microsilica content of 20 % in relation to the cement mass. Further analysis revealed a decrease in strength performance when the microsilica content increased above 20 %, which may be due to the overabundance of silica in the binder composition.

Keywords: microsilica, phosphogypsum, soapstock, post-alcoholic bard, concrete modification, two-component modified additive.

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Introduction. In the modern world, construction stands as one of the most pivotal sectors of the economy. Concrete, being the primary construction material, plays a key role in the erection of buildings and structures. However, concrete production is associated with several issues, such as:

1. High energy consumption. Cement production, the main component of concrete, is an energy-intensive process leading to significant greenhouse gas emissions.

2. Depletion of natural resources. Extraction and processing of raw materials for cement production negatively impact the environment.

3. Generation of waste. Concrete production generates a considerable amount of waste that needs to be disposed of [1].

In light of these challenges, the quest for environmentally friendly and economically viable solutions for concrete modification is a pressing issue. One promising approach to addressing this issue is the utilization of industrial by-products as additives to concrete [2].

This study proposes a comprehensive additive developed from industrial by-products:

- Microsilica (Ms) – by-product of metallurgical production;
- Phosphogypsum (PhG) – waste generated during phosphoric acid production;
- Soapstock (Sp) – residue from refined oil production;
- Distillery slop (PaB) – waste from alcohol production.

Utilizing industrial by-products as concrete additives offers several advantages:

1. Environmental sustainability: utilizing waste helps reduce the environmental burden.
2. Economic efficiency: waste utilization helps decrease the cost of concrete production.
3. Enhancement of concrete strength characteristics: additives can improve concrete properties such as compressive strength, flexural strength, and modulus of elasticity.

The research aims to evaluate the influence of each component of the additive on the transformative processes of concrete, particularly its strength characteristics [3]. In the first stage of the study, the influence of microsilica on the following aspects will be examined:

Compressive strength of concrete. The effect of microsilica on concrete compressive strength will be studied across various additive content ranges.

Flexural strength of concrete. The impact of microsilica on concrete flexural strength will be investigated across various additive content ranges.

Modulus of elasticity of concrete. The influence of microsilica on concrete modulus of elasticity will be explored across various additive content ranges.

Subsequent stages of the research will involve studying the influence of other additive components on concrete properties [4].

This work holds both theoretical and practical significance:

Theoretical significance. It involves studying the mechanisms through which the comprehensive additive affects the transformative processes of concrete.

Practical significance: It entails the development of a new type of additive that can be used to enhance concrete strength characteristics.

In the scope of this study, it is proposed to employ a comprehensive additive formulated from industrial by-products.

Composition of the additive:

Microsilica (Ms) – a by-product of metallurgical production; Phosphogypsum (PhG) – waste generated during phosphoric acid production; Soapstock (Sp) – residue from refined oil production; Distillery slop (PaB) – waste from alcohol production; Caustic soda (NaOH) – stabilizer. Microsilica, comprising a finely dispersed medium of active minerals, is incorporated into concrete to enhance its strength properties.

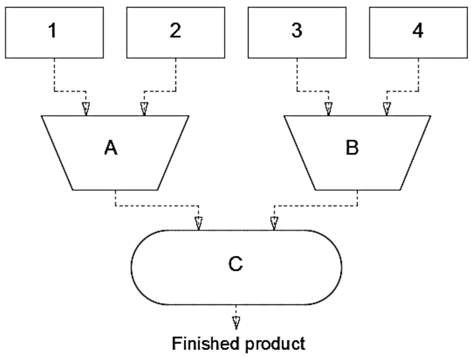
To improve workability and plasticity, distillery slop is added, which essentially acts as a surfactant [5]. In order to ensure mineralogical balance, phosphogypsum is introduced into the concrete mix, considering that microsilica contains up to 95% silica oxide. The application of soapstock, possessing a fatty acid composition, promotes volumetric hydrophobization of concrete [6]. A small amount of caustic soda is also added to the additive to alkalize the soapstock and retard its oxidation. As a result of employing this comprehensive additive, hydrophobic concrete with enhanced strength is obtained.

The objective of the research is to assess the influence of each component of the additive. This article presents the results of only the first stage of the study, which focuses on examining the effect of microsilica on the transformative processes of concrete, particularly its strength characteristics [7].

Materials and methods. The proposed additive consists of a composite mixture of industrial by-products, comprising liquid and solid phases. The solid phase (Component 1, C1) is represented by a dry mixture of microsilica, phosphogypsum, and neutralized soapstock, while the liquid phase (Component 2, C2) consists of distillery slop.

To enhance the strength properties of concrete, microsilica is introduced into its composition, which is a finely dispersed medium of active minerals. For better workability and plasticity, distillery slop, essentially serving as a surfactant, is added. To maintain mineralogical balance due to the addition of microsilica, which contains up to 95 % silica oxide, phosphogypsum is incorporated into the concrete mix. The inclusion of soapstock in the concrete composition contributes to its volumetric hydrophobization due to its fatty acid composition. Additionally, a small amount of caustic soda is added to the additive to alkalinize the soapstock and slow down its oxidation process. Ultimately, hydrophobic concrete with enhanced strength is obtained [8].

Figure 1 depicts the technological scheme of modified additive production.



1 – Microsilica, 2 – Phosphogypsum, 3 – Soapstock and Caustic Soda, 4 – Post-Alcohol Stillage, A, B – Mixer, C – Rotary Disperse.

Fig. 1. Technological stage of additive production

The production process involves two subsequent stages. In the first stage, preparation of the dry component of the additive is carried out, involving grinding, drying, and mixing of microsilica and phosphogypsum. Grinding of the components is necessary to obtain a homogeneous finely dispersed medium, maximizing their activity during concrete hydration. Drying is essential for precise component mass selection and exclusion of unaccounted water in the additive composition. In the second stage, preparation of the liquid component of the additive is performed, involving precise mixing of soapstock with distillery slop and subsequent neutralization based on acidity [9].

Stage 1: (Preparation of the dry component): Mixing of microsilica and phosphogypsum in mixer A.

Stage 2: (Preparation of the liquid component): Mixing of soapstock, caustic soda, and stillage in mixer B.

Table 1 shows the variable compositions of the mixtures of the first stage of the study, exactly the compositions with different content of microsilica (Ms).

Table 1

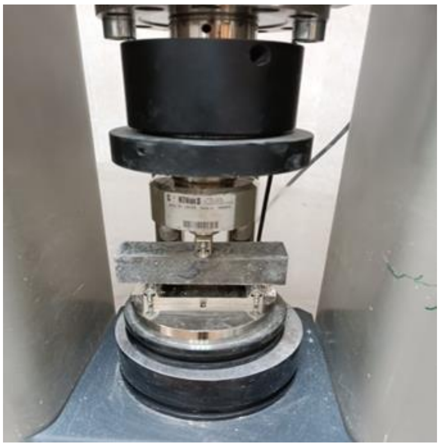
Variant compositions of the studied mixtures

Type	Component content by weight, g							
	Sand	Cement	Ms	PhG	Sp	NaOH	PaB	Whater
Reference	1500	500	0	-	-	-	-	200
Ms=10%	1500	450	50	-	-	-	-	200
Ms=15%	1500	425	75	-	-	-	-	200
Ms=20%	1500	400	100	-	-	-	-	200
Ms=25%	1500	375	125	-	-	-	-	200

Variational substitution of microsilica from 10 to 25 % (multiples of 5 %) by mass of cement.

Evaluation of the strength properties of specimens under compression and bending was carried out according to the standard methodology of GOST 310.4 (Fig. 2). A comparison of the strength of specimens with a variable composition was performed to assess the optimal composition of the modified additive and evaluate its effectiveness. Comparing the strength properties of specimens with and without the additive will provide an assessment of the influence of additive components on concrete modification and its transformation in terms of strength improvement.

In compression

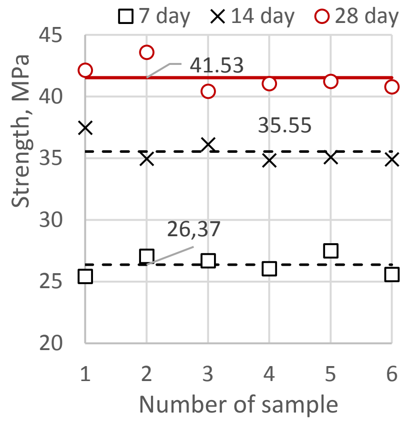


In bending

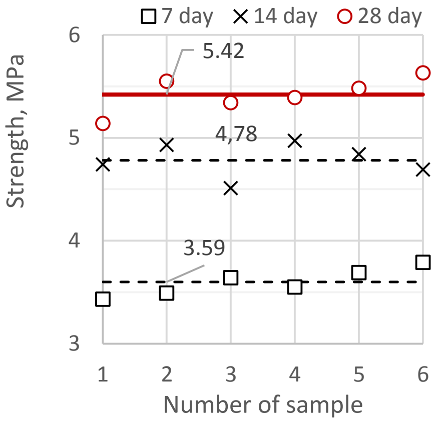
Fig. 2. Conducting laboratory tests

Research results. Figure 3 shows the test results of beam specimens for compressive strength (A) and flexural strength (B). Figure 4 and 5 show the same values for samples with different microsilica content Ms from 10 to 25 % (A-D).

The results are represented by the data points of strength indices as well as their average values (straight line).

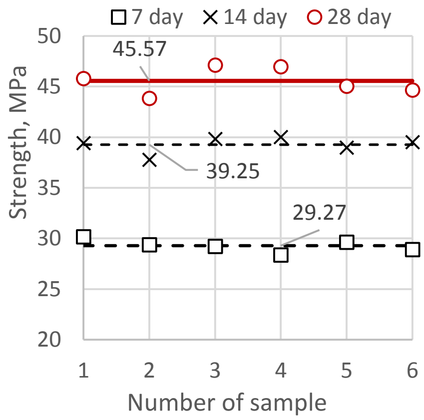


A.Compression

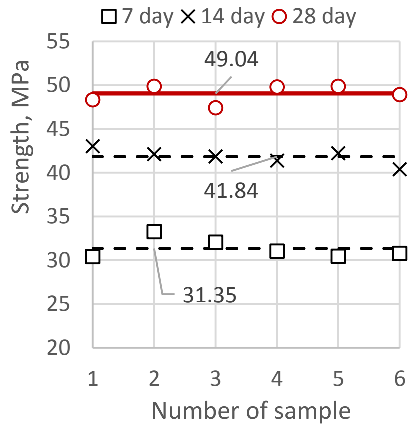


B.Bending

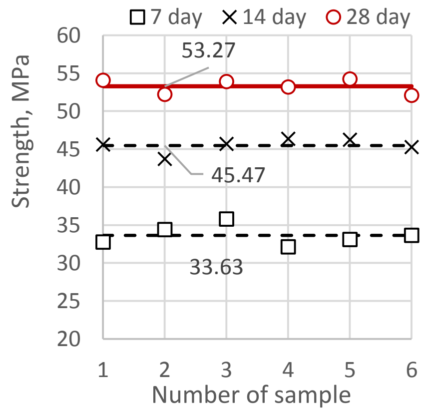
Fig. 3. Reference sample



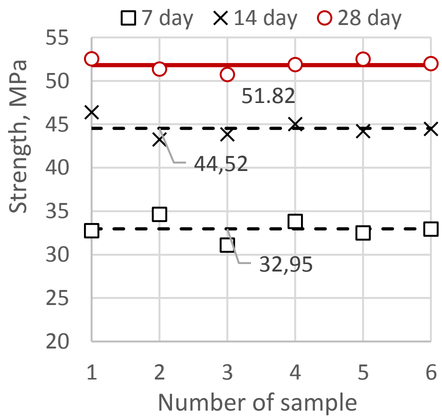
A.Ms = 10 %



B.Ms = 15 %



C.Ms = 20 %



D.Ms = 25 %

Fig. 4. Test results of beam specimens under compression

The compressive strength of the reference sample (without additive) beam specimens averages: at 7 days old, 26.37 MPa; at 14 days old, 35.55 MPa; at 28 days old, 41.53 MPa. The flexural strength of the reference sample is: at 7 days old, 3.59 MPa; at 14 days old, 4.78 MPa; at 28 days old, 5.42 MPa.

The compressive strength for specimens with 10% microsilica (Ms) content was: at 7 days old, 29.27 MPa, exceeding the reference sample strength by 11.0 %; at 14 days old, exceeding the reference sample by 10.4 %, reaching 39.26 MPa; at 28 days old, 41.53 MPa, exceeding the reference sample by 9.7 %. Samples with 15 % Ms content showed the following strength characteristics: at 7 days old, 31.35 MPa, already exceeding the reference sample strength by 18.9 %; at 14 days old, exceeding the reference sample by 17.7 %, reaching 41.84 MPa; at 28 days old, 49.04 MPa, exceeding the reference sample by 18.1 %. For specimens with 20 % Ms content, the strength was: at 7 days old, 33.63 MPa, exceeding the reference sample strength by 27.5 %; at 14 days old, exceeding the reference sample by 27.9 %, reaching 45.47 MPa; at 28 days old, 53.27 MPa, exceeding the reference sample by 28.3 %. For specimens with 25 % Ms content: at 7 days old, 32.95 MPa, exceeding the reference sample strength by 24.9 %; at 14 days old, exceeding the reference sample by 25.2 %, reaching 44.52 MPa; at 28 days old, 51.83 MPa, exceeding the reference sample by 24.8 %.

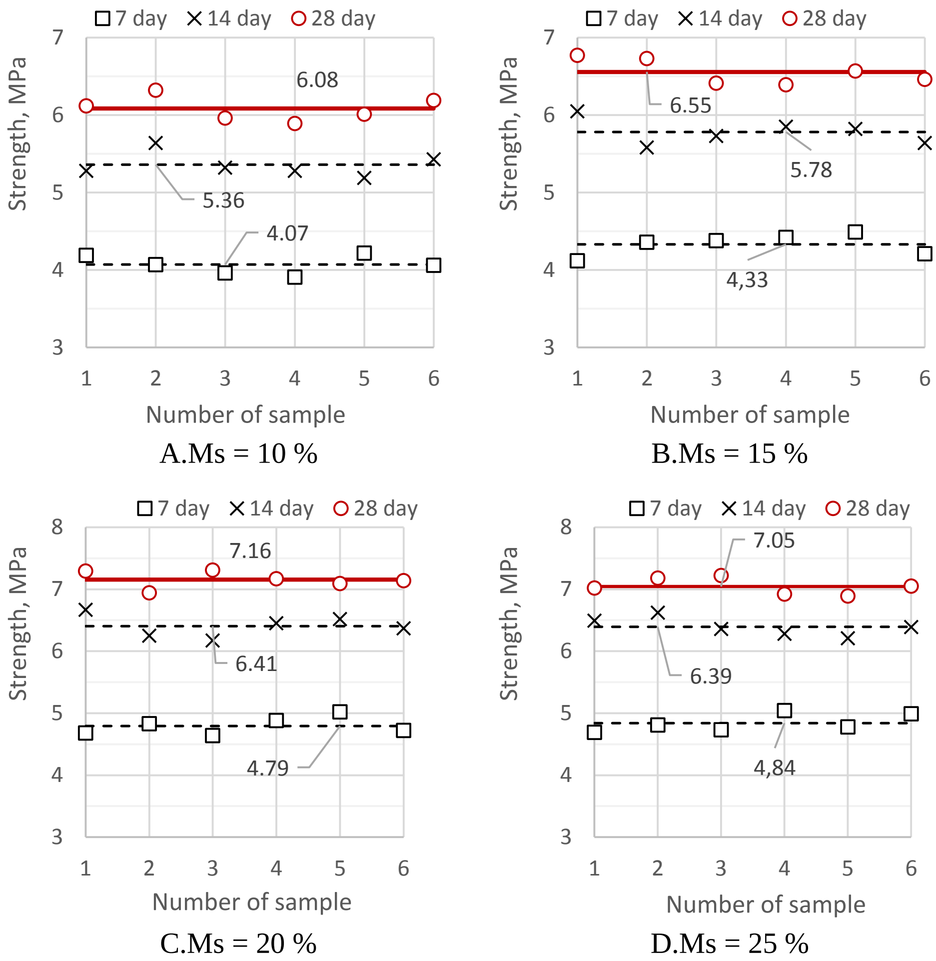
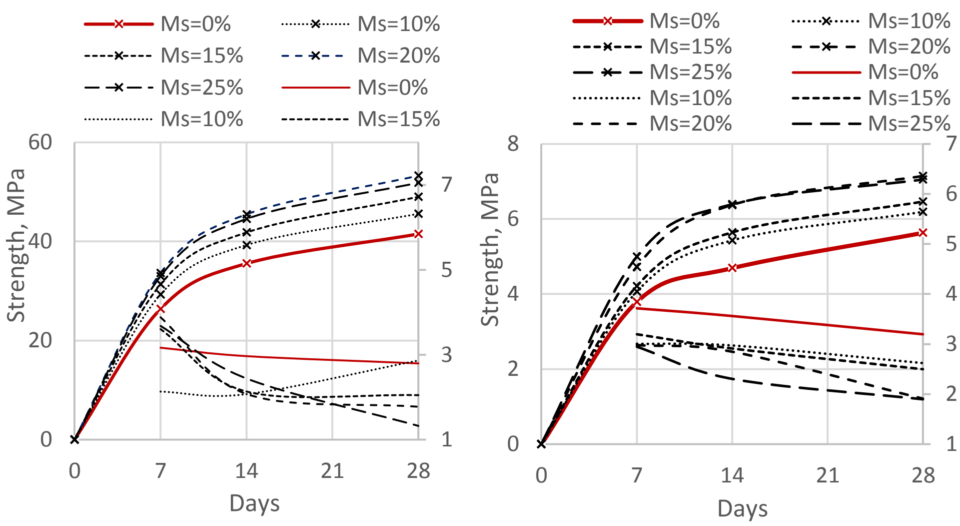


Fig. 5. Test results of beam specimens under bending

The flexural strength of specimens with 10% microsilica (Ms) content was: at 7 days old, 4.07 MPa, exceeding the reference sample strength by 7.1 %; at 14 days old, the strength was 5.43 MPa, surpassing the reference sample by 15.8 %; at 28 days old, 6.19 MPa, exceeding the reference sample by 9.9 %. Samples with 15 % Ms content showed the following strength characteristics: at 7 days old, 4.21 MPa, exceeding the reference sample strength by 11.1 %; at 14 days old, the strength surpassed the reference sample by 20.3%, reaching 5.64 MPa; at 28 days old, 6.46 MPa, surpassing the reference sample by 14.7 %. For specimens with 20 % Ms content, the strength was: at 7 days old, 4.72 MPa, exceeding the reference sample strength by 24.6 %; at 14 days old, the strength was 6.37 MPa, surpassing the reference sample by 35.8 %; at 28 days old, 7.14 MPa, exceeding the reference sample by 26.8 %. For specimens with 25 % Ms content: at 7 days old, 4.99 MPa, exceeding the reference sample strength by 31.6 %; at 14 days old, the strength was 6.37 MPa, surpassing the reference sample by 36.2 %; at 28 days old, 7.05 MPa, exceeding the reference sample by 25.2 %.

Figure 6. shows the comparison diagrams of the obtained strength characteristics, along with their corresponding coefficients of variation: A – compressive strength, B – flexural strength.



A.Compression B.Bending

Fig. 6. Comparative diagrams of strength characteristics

The comparative diagram reveals a noticeable influence of microsilica on the strength properties of concrete: all curves of specimens with the additive lie above the curve of the reference sample. The coefficients of variation, overall characterizing the close relationship between individual strength values, tend to stabilize the results as the strength of specimens accumulates. The coefficients of variation of compressive strengths range from 1.32% to 3.88%, while those of flexural strengths range from 1.89% to 3.71%.

Figure 7 depicts the changes in strength characteristics with varying microsilica content in the specimens: A – compressive strength, B – flexural strength.

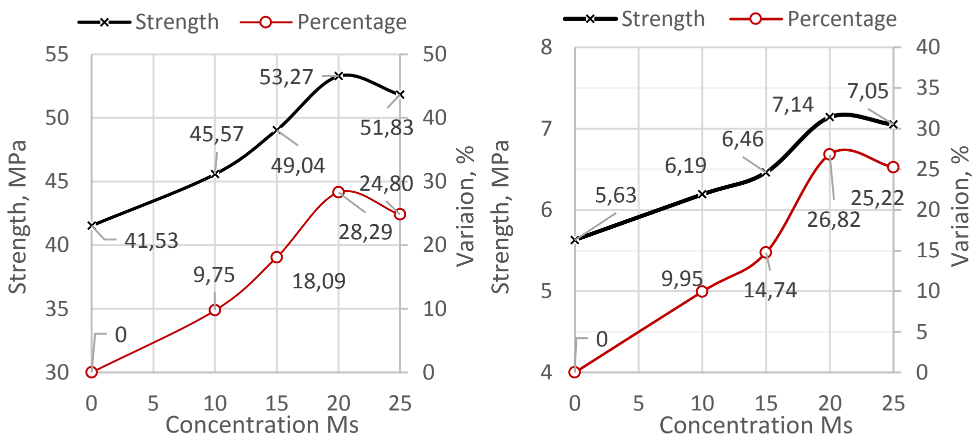


Fig. 7. Strength variation with microsilica content

According to the obtained diagrams, the maximum increase in strength, both in compression and in bending of the specimens, corresponds to a microsilica content of 20 % relative to cement. The peak compressive strength values reach 53.27 MPa, exceeding the reference sample strength by 28.29 %. The peak flexural strength values reach 7.14 MPa, surpassing the reference sample by 26.82 %. With a microsilica content exceeding 20 %, there is a decrease in strength, both in compression and in bending.

Discussion of scientific results. The observed increase in compressive and flexural strength with the addition of up to 20 % of microsilica can be attributed to pozzolanic reactions favoured by the high silica content of microsilica. Microsilica, consisting mainly of amorphous silica (SiO_2), reacts with calcium hydroxide ($Ca(OH)_2$), a by-product of cement hydration, to form additional calcium silicate hydrates (C-S-H).

It is worth noting that the effects of microsilica on concrete properties can also depend on other factors, such as the water-to-binder ratio, curing conditions, and the presence of other supplementary cementitious materials or chemical admixtures. Careful optimization of the concrete mix design, taking into account the interactions between various components, is crucial to achieving the desired strength and durability characteristics.

In summary, the study's main result is that the maximum increase in both compressive and flexural strength of concrete was achieved with a 20 % microsilica content relative to the mass of cement. Further increases in microsilica content above 20 % resulted in a decrease in strength characteristics, suggesting an optimal range for the additive's composition.

Conclusion. Standard tests were conducted on beam specimens for both flexural and compressive strength. The tests were carried out on specimens with varying microsilica (Ms) content: 10 %, 15 %, 20 %, and 25 % by mass of cement.

According to the compressive strength test results, the maximum strength increase was observed in specimens with 20 % Ms content, while the reference sample exhibited the lowest strength. On average, the increase in strength relative to the reference sample, based on Ms content, was: 9.7 % for 10 % Ms content; 18.1 % for 15 % Ms content; 28.3 % for 20 % Ms content; and 24.8 % for 25 % Ms content.

However, when the Ms content exceeds 20%, there is a decrease in strength by 2.3% compared to the maximum average strength obtained with 20% Ms content.

The flexural strength test results showed a similar trend of strength increase. The maximum strength was also observed in specimens with 20% Ms content. On average, the increase in strength relative to the reference sample, based on Ms content, was: 9.9% for 10% Ms content; 14.7% for 15 % Ms content; 26.8% for 20% Ms content; and 25.2% for 25 % Ms content. A decrease in strength of specimens is also observed at high Ms concentrations (above 20 %): the strength values of specimens with 25% Ms content are 1.3% lower than those of specimens with 20% Ms content.

The coefficients of variation, overall characterizing the close relationship between individual strength values, tend to stabilize the results as the strength of specimens accumulates. The coefficients of variation for compressive strengths range from 1.32% to 3.88%, while those for flexural strengths range from 1.89% to 3.71%.

The decrease in strength may be attributed to the increase in silicon content in the cement composition, as the microsilica content consists of approximately 90% silicon and above. The application of up to 20% microsilica increases the silicon content in the percentage composition of alite and belite, improving the quality of the cement's mineralogical composition. However, an excess of silicon constituents leads to a decrease in the quality parameters of the binder.

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МИКРОСИЛИКАНЫҢ ЕКІ КОМПОНЕНТТІ МОДИФИКАЦИЯЛАНҒАН ҚОСПАНЫҢ ҚҰРАМЫНДА ҚОЛДАНЫЛАТЫН БЕТОННЫҢ БЕРІКТІГІНЕ ӘСЕРІН ЗЕРТТЕУ

Аңдатпа. Қазіргі заманғы құрылыста бетонның өнімділігін арттырудың экологиялық қауіпсіз және үнемді әдістерін іздеуге көп көңіл бөлінеді. Бұл жұмыста өнеркәсіптік қалдықтар, атап айтқанда микросилика, фосфогипсум, сабын және алкогольден кейінгі бард негізінде бетонды модификациялау үшін жасалған күрделі қоспаның әлеуеті зерттелген. Зерттеудің мақсаты қоспаның әрбір құрамдас бөлігінің бетонның түрлену процестеріне, әсіресе оның беріктік сипаттамаларына әсерін бағалау болып табылады. Зертханалық зерттеулер микросиликаның құрамы әртүрлі үлгілерде жүргізілді және нәтижелер цемент массасына қатысты микросиликаның 20% мөлшерінде беріктіктің максималды жоғарылауына қол жеткізілгенін көрсетті. Әрі қарай жүргізілген талдау микросиликаның мөлшері 20 % - дан жоғары болған кезде беріктік көрсеткіштерінің төмендегенін көрсетті, бұл байланыстырғыш құрамындағы кремнеземнің артық болуына байланысты болуы мүмкін.

Тірек сөздер: микросилика, фосфогипс, сабын, алкогольден кейінгі бард, бетон модификациясы, екі компонентті модификацияланған қоспа.

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ИССЛЕДОВАНИЕ ВЛИЯНИЯ МИКРОКРЕМНЕЗЕМА НА ПРОЧНОСТЬ БЕТОНА, ИСПОЛЬЗУЕМОГО В СОСТАВЕ ДВУХКОМПОНЕНТНОЙ МОДИФИЦИРОВАННОЙ ДОБАВКИ

Аннотация. В современном строительстве значительное внимание уделяется поиску экологически безопасных и экономически эффективных методов улучшения эксплуатационных характеристик бетона. В данной статье исследуется потенциал комплексной добавки, разработанной на основе промышленных отходов, в частности микрокремнезема, фосфогипса, соапстока и послеспиртовой барды, для модификации бетона. Целью исследования является оценка влияния каждого компонента добавки на процессы трансформации бетона, особенно на его прочностные характеристики. Лабораторные испытания были проведены на образцах с различным содержанием микрокремнезема, и результаты показали, что максимальное повышение прочности было достигнуто при содержании микрокремнезема 20 % по отношению к массе цемента. Дальнейший анализ выявил снижение прочностных показателей при увеличении содержания микрокремнезема более чем на 20 %, что может быть связано с переизбытком кремнезема в составе связующего.

Ключевые слова: микрокремнезем, фосфогипс, соапсток, послеспиртовая барда, модификация бетона, двухкомпонентная модифицированная добавка.