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INVESTIGATION OF THE INFLUENCE OF POST-ALCOHOL DISTILLERS' GRAINS ON THE STRENGTH OF CONCRETE USED IN A TWO-COMPONENT MODIFIED ADDITIVE

Abstract. This article investigates the influence of industrial waste on the properties of concrete. The components used include microsilica (Ms), phosphogypsum (PhG), soapstock (Sp), post-alcohol distillers' grains (PaB), and caustic soda (NaOH). The research aims to assess the impact of each of these components on the properties of concrete. Special attention is given to the influence of post-alcohol distillers' grains on the transformative processes of concrete, specifically its strength indicators, water absorption, and frost resistance. A reference sample is presented as a cement-sand mixture with a 20% inclusion of microsilica, 15% phosphogypsum content, and 10% soapstock content by the weight of cement, microsilica, and phosphogypsum. As a result, hydrophobic concrete with increased strength is obtained. This research represents a significant step towards sustainable construction practices, utilizing industrial waste to enhance the properties of concrete.

Keywords: phosphogypsu, soapstock, concrete, additive, two-component modified additive, concrete strength.

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Introduction. In the modern world, the issue of industrial waste disposal is becoming increasingly relevant. However, these wastes can be used as secondary raw materials in various industries, including construction. In this article, we investigate the possibility of using industrial waste to improve the properties of concrete.

Concrete is one of the most common building materials, but its production requires a large amount of energy and natural resources. Therefore, finding alternative components for concrete that can improve its properties and reduce its environmental impact is an important task [1].

In this article, we present the results of a study on the influence of various industrial wastes on the properties of concrete. Specifically, we consider the use of microsilica (Ms), phosphogypsum (PhG), soapstock (Sp), post-alcohol distillers' grains (PaB), and caustic soda (NaOH) as additives to concrete. Our goal is to assess the influence of each of these components on the properties of concrete, including its strength, water absorption, and frost resistance.

The composition of the additive is assumed to use industrial waste, specifically the following components: microsilica (a by-product of metallurgical production, henceforth Ms), phosphogypsum (a by-product formed during the production of phosphoric acid, henceforth PhG), soapstock (a by-product of refined oil production, henceforth Sp), post-alcohol distillers' grains (a by-product of alcohol production, henceforth PaB), and caustic soda (NaOH) as a stabilizer [2].

To increase the strength indicators of concrete, microsilica is introduced into its composition, which is a finely dispersed medium of active minerals. For its better sealing and plasticizing, post-alcohol distillers' grains are introduced into the composition, which is essentially a surfactant additive [3]. For mineralogical balance as a result of the addition of microsilica, which contains up to 95% silicon dioxide, phosphogypsum is introduced into the concrete mixture. The use of soapstock in the composition of concrete contributes to its volumetric hydrophobization due to its fatty acid composition. A small amount of caustic soda is also introduced into the additive composition, necessary for the leaching of soapstock and slowing down the process of its oxidation [4]. Ultimately, we get hydrophobic concrete with increased strength.

The aim of the research is to assess the influence of each of the above-mentioned additive components. However, this article will present the results of the final stage of the research, namely the influence of post-alcohol distillers' grains on the transformative processes of concrete, specifically on its strength indicators, water absorption, and frost resistance. As a reference sample, a cement-sand mixture is presented with a 20% inclusion of microsilica by the weight of cement, 15% phosphogypsum content by the weight of cement and microsilica, 10% soapstock content by the weight of cement, microsilica, and phosphogypsum. The technological composition of the reference sample was obtained based on the results of previously conducted research on the influence of microsilica, phosphogypsum, and soapstock on the quality of the concrete mixture city, and country (if the authors work in different companies, the last name of the author and the relevant company should be numbered) [5].

Materials and methods. The proposed additive is a composite mixture of industrial waste, consisting of a liquid and a solid phase. 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) is post-alcohol distillers' grains [6].

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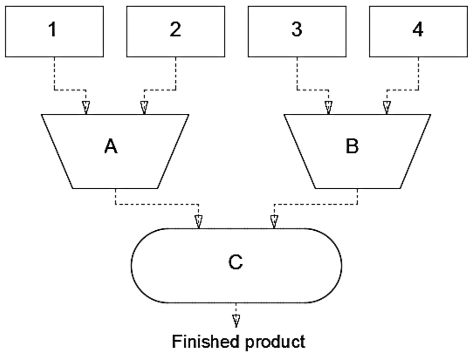
Figure 1 presents the technological scheme of the production of the modified additive. The technological process of production includes two subsequent stages of production. At the first stage, the preparation of the dry component of the additive is carried out, during which the grinding, drying, and mixing of microsilica and phosphogypsum are carried out. The grinding of components is necessary to obtain a homogeneous finely dispersed medium, to achieve their maximum activity in the process of concrete hydration. Drying is necessary for the quality selection of components by mass and the exclusion of unaccounted water in the composition of the additive. At the second stage, the preparation of the liquid component of the additive is carried out, specifically the mixing of soapstock with post-alcohol distillers' grains and their subsequent neutralization by acidity [10-12].



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

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.

Fig. 1. Technological stage of additive production

The post-alcohol distillers' grains were variably replaced from 5.0 to 12.5% (multiplicity 2.5%) by the mass of water.

The strength indicators of the samples were evaluated during compression and bending of the beam samples according to the standard method GOST 310.4 (Fig. 1). The comparison of the strength of the samples of variable composition was carried out to assess the optimal composition of the modified additive and evaluate its performance. Comparing the strength indicators of samples with and without the additive will allow assessing the influence of the additive components on the modification of concrete and its transformation in terms of improving strength. The evaluation of the samples for water absorption capacity of the compared concrete samples was carried out according to GOST 12730.3 (Fig. 1).

Table 1 illustrates the variant compositions of mixtures in the first stage of the research, specifically compositions with varying contents of microsilica (hereafter referred to as Ms).

Table 1

Variant compositions of the investigated mixtures

Type	Component content by weight, g							
	Sand	Cement	Water	Ms	PhG	Sp	NaOH	PaB
Reference	1500	306	200	77	68	50	0.5	-
PaB=2.5%	1500	306	195	77	68	50	0.5	5
PaB=5%	1500	306	190	77	68	50	0.5	10
PaB=7.5%	1500	306	185	77	68	50	0.5	15
PaB=10%	1500	306	180	77	68	50	0.5	20

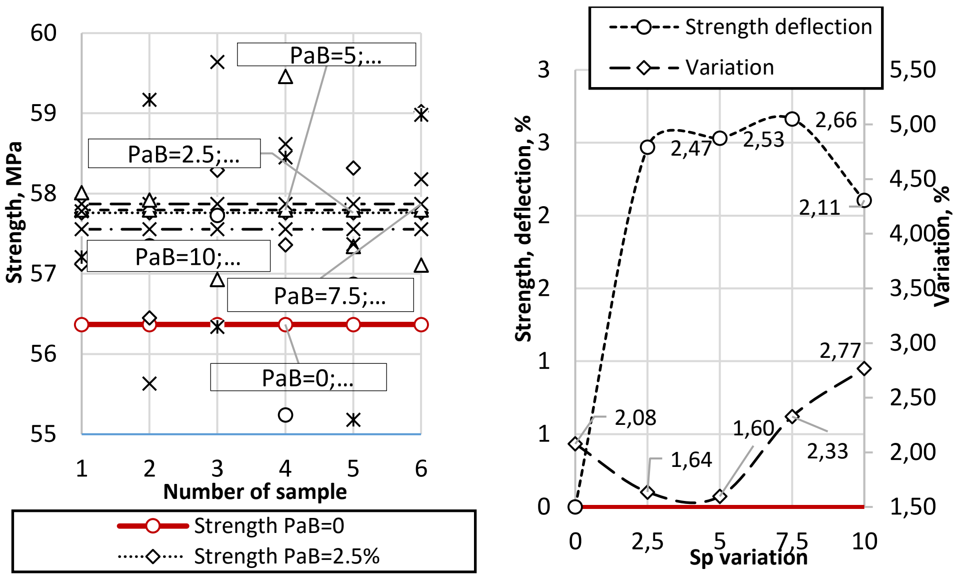
Comparing the water absorption of concrete will allow assessing the operational suitability of concrete using the modified additive, primarily related to the service life of the material. The hydrophobicity of the material will characterize resistance to the destructive effect of water during operation, as well as increasing its frost resistance (taking into account the mechanics of frost resistance tests). The evaluation of the samples for frost resistance of concrete samples was carried out according to GOST 10060 (Fig. 1). Comparing the frost resistance indicators of variable types of concrete is also related to the assessment of the operational suitability of the material, assessing its durability. The sequence of cyclic freezing and thawing of samples was carried out from the condition of reducing the number of cycles, that is, as the cycles increased, the terms of control measurements were reduced (from 50 to 25 cycles). Control measurements of strength and mass were carried out: at 50, 100, 150, 175, 200, 225, and 250 cycles

Table 2

Conducting Laboratory Tests

Durability	Water absorption	Frost resistance
		

Research results. Figure 2 shows the results of strength measurements of beam samples, carried out within the framework of linear comparisons of sequential (alternating) additions of components: Ms, PhG, Sp, and PaB. Figure 2A presents the results of partial and average strength values at different concentrations of distillers' grains, and Figure 2B – statistical indicators of variation coefficients and comparison in percentage terms from the optimal Ms=20%, PhG=15%, and Sp=10%.



A B

Fig. 2. Strength Measurement of Beam Samples

According to previously conducted tests, an optimal concentration of Sp=10% corresponded to an average strength increase up to 56.37 MPa. When PaB=2.5% was included in the composition, the average strength was 57.76 MPa, with individual values ranging from 55.45 to 59.02 MPa. For samples with a PaB content of 5%, the strength ranged from 56.93 to 59.46 MPa, with an average of 57.79 MPa. The same values for samples with a PaB content of 7.5% ranged from 55.63 to 59.64 MPa, with an average of 57.87 MPa. For samples with a PaB content of 10%, the strength ranged from 55.18 to 59.17 MPa, with an average of 57.55 MPa. According to the comparative diagram of Figure 2B, there are no significant changes in strength with each subsequent addition of distillers grains. A noticeable change occurs with the first inclusion of distillers grains, at a low concentration, equal to 2.5% of water. The evaluation of variation coefficients did not reveal the influence of distillers grains on the stability of results. The variation coefficients range from 1.60 to 2.77%, indicating a high degree of convergence of individual values. The absence of the influence of distillers grains at concentrations above 2.5% on strength is evidenced by the variation coefficient of average strength values of variable PaB concentrations. This coefficient is only 0.23%, therefore, comparing it with the variation of individual values within a certain concentration (1.60-2.77%), changes in strength (with a change in the concentration of distillers grains) can be attributed to statistical error. Thus, the optimal concentration of PaB is 2.5%, its high concentration does not affect the strength of concrete.

Figures 3-6 show graphs of strength loss and mass loss as a result of cyclic freezing and thawing of cubic samples with variable inclusion of post-alcohol distillers grains (PaB). Figure 3A shows absolute individual values of strength losses, Figure 3B shows mass losses, as well as their corresponding variation coefficients. The scales on all figures have a fixed range, for visualizing differences in dependency curves (strength from .64 to 79 MPa, variation from 0 to 24%). Figure 3A presents two relative indicators: the first is the average strength of the reference sample without the inclusion of additives (Figure 3-6 – solid red line), the second is the average strength of samples with an optimal concentration of Sp=10%, at which the best frost resistance of concrete is manifested (Figure 3-6 – dashed red line).

The change in strength from freezing cycles from 50 to 200 in samples with a PaB content of 2.5% varies from 69.12 to 65.19 MPa. The maximum decrease in strength, obviously, corresponds to the maximum number of cycles, and a noticeable decrease in strength occurs with 150-175 cycles. At the same time, variation coefficients increase with an increase in the number of cycles, varying within 1.93-4.85%. The change in strength indicators of samples with a percentage content of PaB=5.0% varies from 68.88 to 67.35 MPa, a decrease in strength is also observed with 175-200 cycles. Variation coefficients are relatively stable, varying from 1.77 to 3.32%. The change in strength indicators of samples with a percentage content of PaB=7.5% varies from 69.17 to 67.03 MPa, a decrease in strength occurs, also starting from 175 cycles, variation coefficients range from 3.41 to 5.69%. For samples with the maximum percentage content of PaB=10.0%, a decrease in strength indicators occurs similarly, from 175 cycles, with a variation in strength values from 69.15 to 66.77%, and a variation coefficient from 2.31 to 7.83%.

The reduction curves of the samples by mass are similar to the strength curves, exhibiting a similar dependence. The reduction of samples with the smallest content of post-alcohol distillers grains PaB=2.5% varies within the range of 2386 to 2310 grams, the initial mass reduction is observed at 100 cycles, and variation coefficients change from 1.36 to 7.12%. As with strength, an increase in variation coefficients is observed with an increase in the number of cycles for all variations of PaB. For samples with PaB=5.0%, the variability of losses ranges from 2392 to 2344 grams, the initial reduction also occurs at 150 cycles, and variation coefficients increase from 1.36 to 2.98%. Samples with PaB=7.5% showed a mass loss from 2395 to 2318 grams, losses were also observed at 150 cycles, and variation coefficients increase from 1.36 to 4.54%. For samples with the maximum content of PaB=10.0%, mass losses start from 150 cycles, vary from 2391 to 2321 grams, and variation coefficients change from 1.36 to 4.39%.

It should be noted that the initial strength indicators for all variations of distillers grains are comparable, within the statistical error. That is, all samples with different concentrations of PaB observed a similar increase in strength relative to the reference sample. The quantitative increase in strength does not depend on the concentration of PaB: for samples with a content of PaB = 2.5%, the increase in strength on average was 4.12%, for samples with PaB = 5.0% – 3.77%, for samples with PaB = 7.5% – 4.20%, for samples with PaB = 10.0% – 4.17%. Similar indicators of strength increase relative to samples with an optimal content of Sp=10%, numerically range from 4.17 to 4.61%. Minor deviations can be attributed to statistical error, as deviations do not exceed the previously defined variation of the reference sample = 1.45%. However, the decrease in strength of all (except 2.5%) variations of distillers grains begins from 175 cycles, but subsequent reduction is different: with an increase in the concentration of distillers grains, there is a sharp decrease in strength after exceeding 175 cycles. At the same time, the higher the concentration of distillers grains, the more rapid the decrease in strength.

The analysis of variation coefficients in both cases indicates a decrease in the stability of strength (and mass) results with an increase in freezing cycles, however, their quantitative indicator depends on the quantitative change in strength (and mass) relative to the original (corresponding to 0 cycles). The latter is confirmed by the smallest values of variation coefficients in samples with a content of PaB=5.0%, which show the smallest loss of strength at 200 cycles. Quantitatively, the variation coefficient of strength in samples with a content of PaB=5.0% is 3.09 times less than in the reference sample, and relative to other variations of PaB, it is 1.29-2.03 times less. The variation coefficient of mass in samples with a content of Sp=5.0% is 3.85 times less than in the reference sample, and relative to other variations of PaB, it is 1.63-2.64 times less. Overall, the analysis of variations showed that samples with a content of post-alcohol distillers grains in a percentage ratio of 5.0% have the most stable results (at 200 cycles) both in terms of strength and mass.

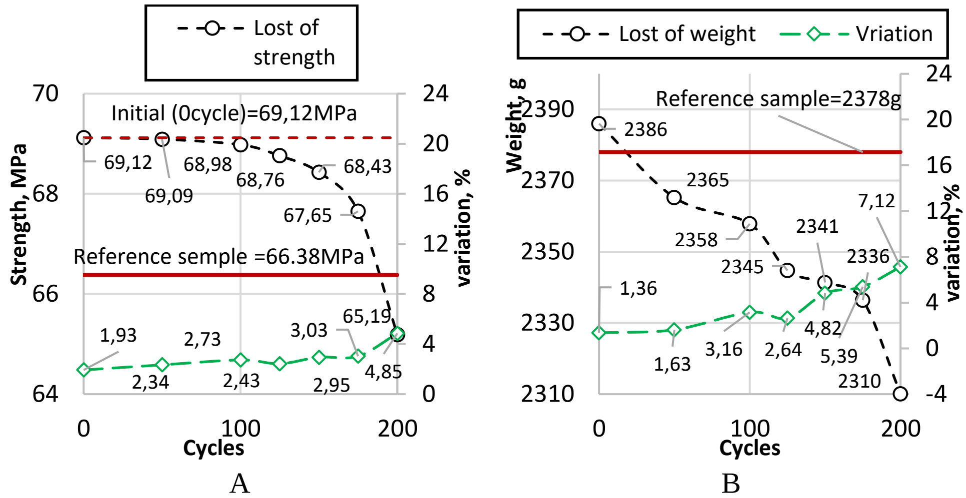


Fig. 3. Strength and mass losses at PaB=2.5%

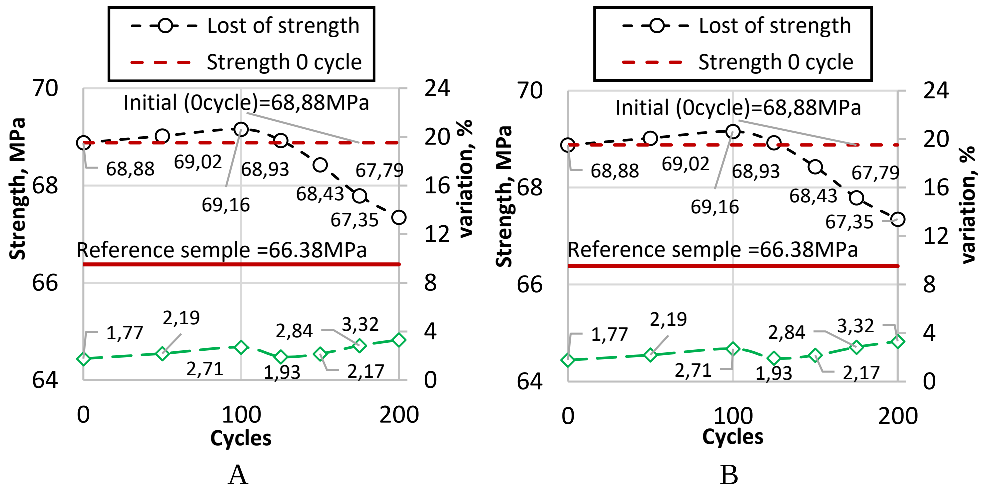


Fig. 4. Strength and mass losses at PaB=5.0%

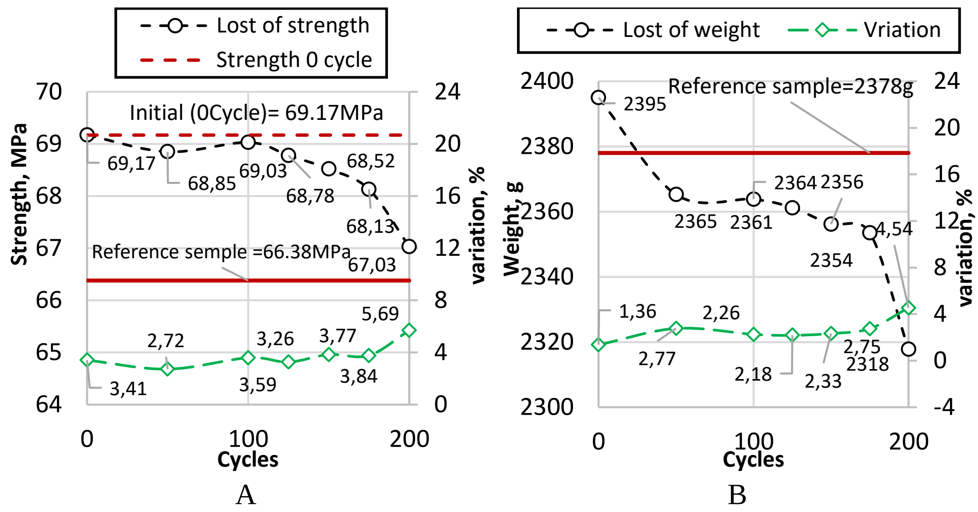


Fig. 5. Strength and mass losses at PaB=7.5%

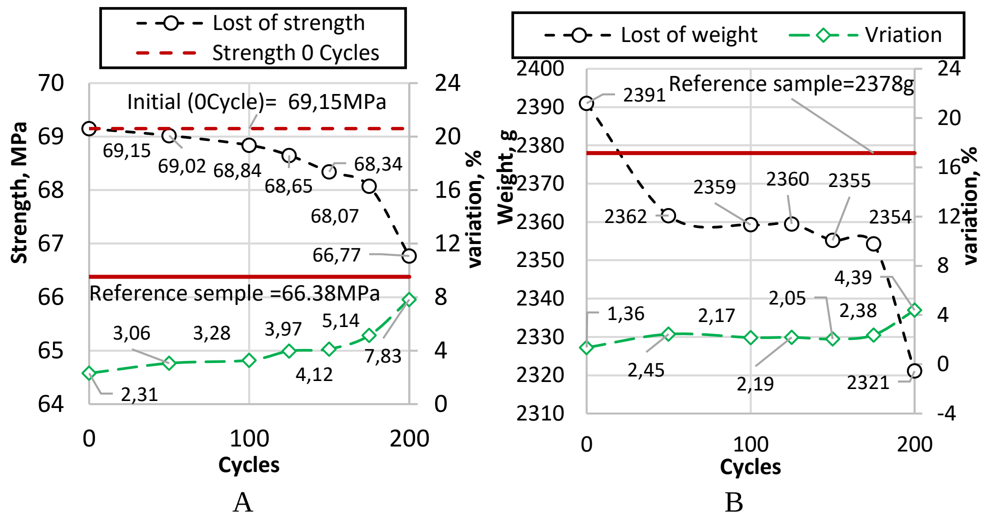


Fig. 6. Strength and mass losses at PaB=10.0%

Figure 7 presents comparisons of strength and mass losses in percentage terms depending on the content of post-alcohol distillers grains in the sample. (Figure 7A shows a comparison of strength losses, Figure 7B shows mass losses). Comparative diagrams are made relative to the reference sample (solid red curve) and relative to the optimal content of soapstock Sp=10%. The curves show both qualitative and quantitative changes in samples by mass and strength. The diagrams also provide numerical values of maximum losses, corresponding to maximum cycles (200 cycles).

The curves in Figure 7 vividly demonstrate the impact of post-alcohol distillers grains on the durability of concrete, relative to its resistance to cyclic freezing. For samples with a PaB content of 2.5%, the maximum strength losses are 5.69%, and the maximum mass losses are 3.18%, which is 2.9 and 1.9 times less than the same values of the reference sample, respectively.

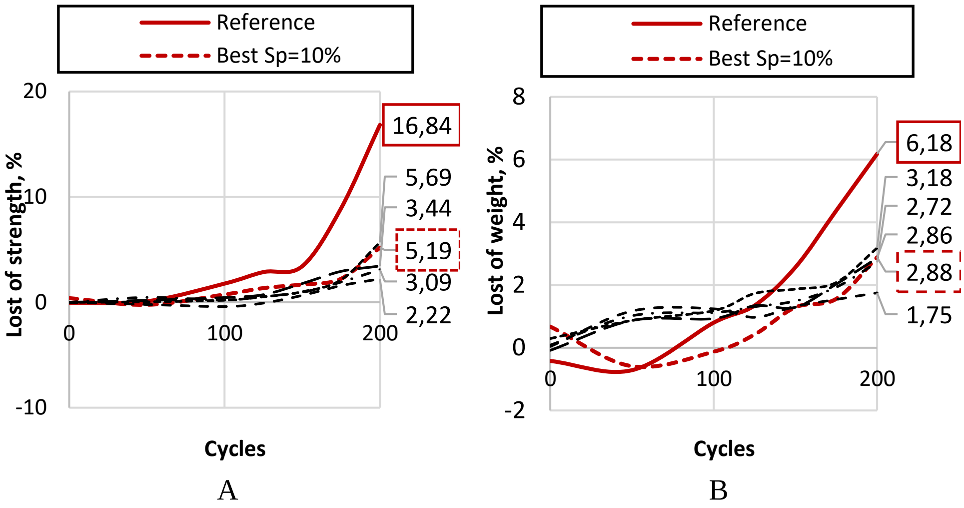


Fig. 7. Comparison of maximum strength and mass losses

For samples with a PaB content of 5%, the same indicators are significantly less, amounting to 2.22% for strength and 1.75% for mass, which is already 7.6 and 3.5 times less than the same values of the reference sample, and 2.3 and 1.6 times less than the same values of samples with an optimal Sp=10%. For samples with a PaB content of 7.5%, the indicators are 3.09% for strength and 2.86% for mass, which is 5.4 and 2.2 times less than the same values of the reference sample, respectively. For samples with the maximum PaB content of 10%, the strength indicators are 3.44%, and the mass indicators are 2.72%, which in turn is 4.9 and 2.3 times less than the same values of the reference sample, respectively. Thus, the maximum resistance to cyclic freezing was found in samples with a PaB content of 5%. At this concentration of PaB, frost resistance in terms of strength, relative to the reference sample, increases by 100% (200/100), and relative to the optimal Sp=10%, it increases by 33% (200/150). For other variations of PaB, frost resistance in terms of strength, relative to the reference sample, increases by 75% (175/100). In terms of mass loss, the frost resistance of the optimal concentration of PaB=5%, relative to the reference sample, increases by 33% (200/150), and relative to the optimal Sp=10%, it increases by 14% (200/175). For other variations of PaB, frost resistance in terms of mass, relative to the reference sample, increases by 17% (175/200).

Figure 8 shows the results of permeability measurements of samples with different PaB contents, but with the addition of a previously determined optimal concentration of Sp=10%. Figure 8A shows individual water absorption values and their corresponding average indicators. The straight lines on the diagram correspond to the average water absorption value of each type, with the aim of visualizing deviations of individual values from the average indicator. Figure 8B shows comparisons of average water absorption indicators of samples with different PaB contents, as well as their corresponding variation coefficients.

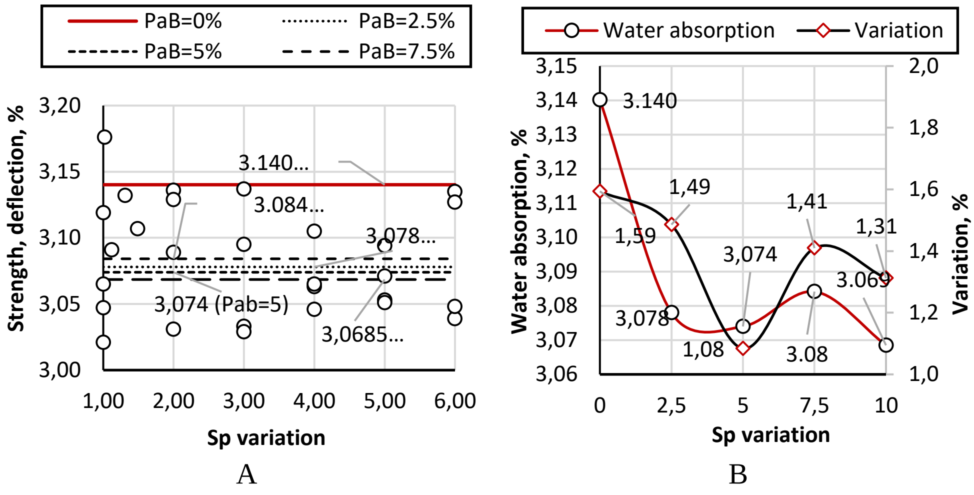


Fig. 8. Water absorption results

Discussion of scientific results. According to previously conducted tests, the average water absorption indicator for samples with a Sp=10% content was 3.150%. Relative to this indicator, the effectiveness of post-alcohol distillers grains will be evaluated and the optimal concentrate will be determined. For samples with PaB=2.5%, water absorption varies from 3.033 to 3.136%, with an average of 3.078%. For samples with PaB=5%, water absorption ranges from 3.039 to 3.129%, with an average of 3.074%. For a PaB content of 7.5%, it ranges from 3.031 to 3.127%, with an average of 3.084%. For PaB=10%, it ranges from 3.021 to 3.137%, with an average of 3.069%. When a minimal amount of distillers grains is added, a decrease in water absorption is observed, but with its subsequent increase, there are no significant changes in the water absorption indicator. Relative to Sp=10% and PaB=0%, the decrease is: for samples with PaB=2.5%, the decrease is 2.29%; for PaB=5% – 2.47%; for PaB=7.5% – 2.18%; for PaB=10% – 2.66%. Numerically, the increment is: 0.13, -0.29, 0.49% from each subsequent addition of distillers grains (2.5%). A sharp drop in water absorption with the minimal addition of distillers grains followed by its stabilization (with its subsequent addition) indicates the achievement of maximum effectiveness relative to the hydrophobizing effect on the material. The analysis of variation coefficients showed a high degree of convergence of individual values of all PaB concentrations: variation coefficients range from 1.31 to 1.59%. The statistical evaluation of average water absorption values at different concentrations of distillers grains confirmed the absence of the influence of increasing distillers grains on water absorption. The variation coefficient in terms of average water absorptions of different concentrations is only 0.99%. Considering the previously given variations within each type of sample (from 1.31 to 1.59%), the variation coefficient of 0.99% attributes the scatter of water absorption values at different PaB contents to statistical error.

Conclusion. Standard tests were conducted on beam samples for strength under bending and compression, standard cubic samples for water absorption and frost resistance. The tests were carried out for samples with different contents of post-alcohol stillage (Sp): 2.5, 5, 7.5, and 10% by mass of water.

The strength measurement of the beam samples showed that the optimal effect regarding the increase in material strength is achieved at a 2.5% content of post-alcohol stillage. Subsequent addition of stillage does not bring significant transformations to the strength indicators of the material. On average, the increase in strength at PaB=2.5% is 2.5%. The obtained curve of the dependence of water absorption change on the concentration of stillage showed an optimal gradient of water absorption, which corresponds to PaB=2.5%. With the subsequent increase in stillage, the reduction in the water absorption indicator does not occur. The average indicator of reducing water absorption is 2.3%.

Frost resistance tests showed that the maximum resistance to cyclic freezing is observed in samples with PaB=5%, subsequent increase in the content of stillage reduces frost resistance. It should be noted that the beginning of the loss of strength (as well as mass) for all variations of PaB is observed at the same cycles (175 for strength and 150 for mass). However, in subsequent cycles, the greater the decrease in strength mass, the higher the concentration of stillage. If the assessment of brand strength and water absorption showed that the concentration of PaB, at which the optimal effect of the transformation process is achieved, is 2.5%, then in the case of frost resistance, such a concentration corresponds to PaB=5%. The latter can be explained by the change in concrete tension, which is a key indicator, under conditions of cyclic water saturation, freezing, and thawing. The overall decrease in frost resistance at an increased concentration of PaB may be associated with a decrease in the number of micropores in the structure of the binder (at a high concentration of PaB). As a result of reducing the area of the walls connecting with inert fillers, the contact zone is reduced with the formation of a brittle structure. However, until the moment of partial destruction, resistance to cyclic freezing is maintained due to the dense structure of the material, including due to the plasticizing effect of PaB.

The obtained curve of the dependence of water absorption change on the concentration of stillage showed an optimal gradient of water absorption, which corresponds to PaB=2.5%. With the subsequent increase in stillage, the reduction in the water absorption indicator does not occur. The average indicator of reducing water absorption is 2.3%.

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ДИСТИЛЛЯТОРЛАРДЫҢ СПИРТТІК ДӘНДЕРІНЕН КЕЙІНГІ ЕКІ КОМПОНЕНТТІ МОДИФИКАЦИЯЛАНҒАН ҚОСПАНЫҢ ҚҰРАМЫНДА ҚОЛДАНЫЛАТЫН БЕТОННЫҢ БЕРІКТІГІНЕ ӘСЕРІН ЗЕРТТЕУ

Аңдатпа. Бұл мақалада өнеркәсіптік қалдықтардың бетон қасиеттеріне әсері зерттеледі. Компоненттер ретінде микро кремний диоксиді (Ms), фосфогипс (PhG), сабын ерітіндісі (Sp), алкогольден кейінгі астық (PaB) және каустикалық сода (NaOH) қолданылады. Зерттеудің мақсаты – осы компоненттердің әрқайсысының бетон қасиеттеріне әсерін бағалау. Алкогольден кейінгі Дистилляция дәндерінің бетонның трансформациялық процестеріне, атап айтқанда беріктік, суды сіңіру және аязға төзімділік көрсеткіштеріне әсеріне ерекше назар аударылады. Бақылау үлгісі ретінде 20% микрокремнеземді, 15% фосфогипсті және цемент, микрокремнезем және фосфогипс массасы бойынша 10% сабын ерітіндісін қосатын цемент-құм қоспасы ұсынылған. Нәтижесінде жоғары беріктігі бар гидрофобты бетон пайда болады. Бұл зерттеу бетонның қасиеттерін жақсарту үшін өнеркәсіптік қалдықтарды пайдалана отырып, тұрақты құрылыс жолындағы маңызды қадам болып табылады.

Тірек сөздер: фосфогипс, сабын ерітіндісі, бетон, қоспа, екі компонентті модификацияланған қоспа, бетонның беріктігі.

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ИССЛЕДОВАНИЕ ВЛИЯНИЯ ПОСЛЕСПИРТОВЫХ ЗЕРЕН ДИСТИЛЛЯТОРОВ НА ПРОЧНОСТЬ БЕТОНА, ИСПОЛЬЗУЕМОГО В СОСТАВЕ ДВУХКОМПОНЕНТНОЙ МОДИФИЦИРОВАННОЙ ДОБАВКИ

Аннотация. В данной статье исследуется влияние промышленных отходов на свойства бетона. В качестве компонентов используются микрокремнезем (Ms), фосфогипс (PhG), мыльный раствор (Sp), послеспиртовое зерно (PaB) и каустическая сода (NaOH). Цель исследования – оценить влияние каждого из этих компонентов на свойства бетона. Особое внимание уделено влиянию зерен послеспиртовой перегонки на трансформационные процессы бетона, в частности, на показатели прочности, водопоглощения и морозостойкости. В качестве контрольного образца представлена цементно-песчаная смесь с 20% включением микрокремнезема, 15% содержанием фосфогипса и 10% содержанием мыльного раствора по массе цемента, микрокремнезема и фосфогипса. В результате получен гидрофобный бетон с повышенной прочностью. Данное исследование представляет собой значительный шаг на пути к устойчивому строительству, используя промышленные отходы для улучшения свойств бетона.

Ключевые слова: фосфогипс, мыльный раствор, бетон, добавка, двухкомпонентная модифицированная добавка, прочность бетона.