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To cite this article: D S Dusebinov *et al* 2021 *J. Phys.: Conf. Ser.* **1926** 012041

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Complex application of ash of hydraulic removal and modified additives such as CMA, CM-2 in the production of non-autoclaved foam concrete

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Abstract. The paper presents studies on the use of ash of hydraulic removal in combination with modifier additives in the production of non-autoclaved foam concrete. The research is aimed at obtaining high-quality non-autoclaved foam concrete based on industrial waste with high construction and technical properties. The main objective of the paper is to determine the quality indicators of non-autoclaved foam concrete, according to standard methods, corresponding to the normative and technical documentation. The studies were carried out under laboratory conditions on certified and calibrated test equipment. The industrial waste considered in the paper, the ash of hydraulic removal and food industry waste, are common waste in all countries of the world, which gives high relevance to the research topic within the framework of waste disposal. The conducted studies confirmed the effectiveness of the integrated use of waste, to obtain the best result. As it is known, ash reduces the thermal conductivity, which is a positive effect, but at the same time reduces the strength of the material and frost resistance. In the paper it was proved that with the use of oil processing waste, it is possible to obtain an increase in frost resistance due to volumetric hydrophobization, as well as with the use of alcohol production waste, a significant increase in strength is achieved, due to the plasticizing effect of the casein contained (polymer components) in the composition of alcohol production waste. The obtained results of the study on thermal conductivity, strength and frost resistance confirm the effectiveness of the use of ash in combination with modified additives based on food industry waste CM-2 and CMA-P. In conclusion, a comparative analysis of the effectiveness of the use of industry waste the ash of hydraulic removal in combination with modified CM-2 and CMA-P additives is carried out.

1. Introduction

Light and heavy concrete remain mass construction materials, largely determining the level of development of civilization [1]. Statistics of cases of extreme impact on reinforced concrete structures make it possible to verify visually the high construction and technical properties of light and heavy concrete [2].

At the present stage of development of construction technology, the problem of improving the quality and durability of light and heavy concrete in many practically important cases can be successfully solved by using new chemical additives [3].

Heavy concrete directly depends on the quality of the binder and aggregates, and if the technological processes are followed, it is possible to obtain concrete with high-quality design parameters. Unlike heavy concrete, cellular concrete requires a more professional approach, as its



quality is affected by many parameters, from the preparation of the solution to the insertion of gas-forming agents or foaming agents into its composition [5].

Cellular concretes are lightweight concretes with evenly distributed air pores [6]. Due to this, they have a low density and low thermal conductivity, which make it possible to make high-performance wall structures for civil and industrial buildings [7].

For the production of cellular concrete, a binder, a fine-ground silica component, a pore-forming agent, special additives and water are used [8]. The binders are usually cement, lime, ground blast furnace slag with hardening activators (lime and gypsum), and nepheline cement. As a silica component, ground quartz sand, fly ash from thermal power plants, and ground blast furnace slag are used [9].

The insertion of a silica component reduces the consumption of the binder and improves the quality of foam concrete. Ordinary quartz sand should contain (by weight) not less than 80% SiO₂, not more than 0.5% mica and 0.3% silty and clay particles. To increase the reactivity, the sand is ground in mills to a specific surface area of 2000-3000 cm²/g. Grinding is usually carried out in a wet way. Industrial waste, such as ground granulated blast furnace slag and fly ash from thermal power plants, is also widely used. The ash of hydraulic removal must contain (in % by weight): SiO₂-not less than 40, Al₂O₃-not more than 30, Fe₂O₃-not more than 15, MgO-not more than 3, sulfur and sulfuric acid compounds (in terms of SO₃) - not more than 2-3. In the ash, the presence of up to 5% of unburned coal particles is allowed. The specific ash surface according to the PSKH-2 device should be at least 2500 cm²/g [10].

According to leading scientists, it is effective to use fly ash for foam concrete materials, as ash from dumps is heterogeneous in composition and size [11].

Cellular concrete is divided into foam concrete and aerated concrete, the difference of which is in the process of forming a pore structure, aerated concrete forms pores during the chemical reaction of the gas-forming agent and the binder, as a result of which the formed pores are connected. The process of obtaining the pore structure of foam concrete consists in inserting the finished foam into the solution, as the solution envelops the foam bubbles forming cells and as a result, the resulting cells have a closed structure [12-18].

The aim of the paper is to study the effect of fly ash in combination with additives modifiers CM-2 and CMA-P on the quality characteristics of foam concrete.

2. Methods

Cement CEM I 42.5 B was used for the research. Sand was taken according to its characteristics of density, modulus of size of contamination the results of the sand study are presented in Table 1. For the study, the ash of hydraulic removal was used. The chemical composition of ash is presented in Table 2. The composition of additives CM-2 and CMA-P are presented in Table 3,4. To determine the quality of foam concrete based on ash with additives CM-2 and CMA-P, the compositions presented in Table 5 were adopted.

Table 1. Sand test results.

Sand characteristics				
Size modulus	Bulk density, kg/m ³	Density, g/cm ³	Void ratio, %	Pollution level, %
1.2	1500	2.59	42.8	0.9

Table 2. Chemical composition of ash of hydraulic removal.

Mineral content in %							
SiO ₂	Al ₂ O ₃	CaO	MgO	Fe ₂ O ₃	SO ₃	Alkali metals	Ash residue
51.5	17.4	12.4	1.9	6.2	3	1.3	6.3

Table 3. Composition of the additive CM-2.

Alkaline NaOH ₂	Post-alcohol bard (PSB)	Cubic residues of synthetic fatty acids (CRSFA)
0.5%	66 %	33.5%

Table 4. Composition of the additive CMA-P.

Ash of hydraulic removal	Ground diorite crushed stone	Post-alcohol bard (PSB)	Cubic residues of synthetic fatty acids (CRSFA)
40%	20%	20%	20%

Table 5. Composition of ash-based foam concrete with and without additives.

Composition	Cement, kg	Ash, kg	Sand, kg	Additive CM-2, l	Additive CMA-P, kg	Total amount of water, l	Foam concentrate, l
D 600	340	260	-	-	-	180	1.2
D 600	340	260	-	6	-	153	1.2
D 600	340	260	-	-	14	160	1.2
D 700	350	260	85	-	-	186	1.1
D 700	350	260	85	6	-	158	1.1
D 700	350	260	85	-	14	165	1.1
D 800	370	260	165	-	-	195	1
D 800	370	260	165	6	-	168	1
D 800	370	260	165	-	14	175	1
D 900	390	260	245	-	-	207	0.9
D 900	390	260	245	6	-	176	0.9
D 900	390	260	245	-	14	183	0.9

Evaluation of the thermal conductivity and thermal resistance of the materials of the compared methods samples of standard sizes in the form of a rectangular parallelepiped were used. The measurements were carried out on the ITP MG-4 device according to the principle of generating a stationary thermal flow passing through a flat sample and directed perpendicular to the front faces of the sample. The calculation of the thermal conductivity λ (effective thermal conductivity) is performed by Eq. 1, and the thermal resistance R_n (in stationary thermal mode) according to Eq. 2:

$$\lambda = \frac{H \cdot q}{T_h - T_c}, \quad (1)$$

$$R_H = \frac{T_h - T_c}{q} - 2R_k, \quad (2)$$

Where, λ – effective thermal conductivity, W/m · °C; R_H – thermal resistance of the measured sample, m²·°C/W; R_k – thermal resistance between the front face of the sample and the working surface of the instrument plate, m²·°C/W; H – thickness of the measured sample, mm; q – the density of the stationary heat flow passing through the measured sample, W/m²; T_h – temperature of the hot face of the measured sample, °C; T_c – temperature of the cold face of the measured sample, °C.

Frost resistance was determined on samples-cubes of 100x100x100 that reached 28 days. 18 samples: 6 samples each, placed in a container with water and gradually every 8 hours in two stages increased the depth of immersion, and after 16 hours, the samples were completely submerged and the load was set so that the samples did not float up and in this state survived for another 24 hours.

Relative strength reduction R_{rel} in % was determined by the formula (3):

$$R_{rel} = \left(1 - \frac{\bar{R}_{mtn}}{\bar{R}_{mtk}}\right) * 100 \tag{3}$$

Where R_{mtn} – the average strength value of the main samples after the specified test cycles in MPa, R_{mtk} – the average value of the strength of the control samples in MPa.

The mass loss Δ_{mb} % was calculated using the formula (4):

$$\Delta_m = \frac{m_n (1-w_n) - \bar{m}_n (1-\bar{w}_n)}{m_n (1-w_n)} 100 \tag{4}$$

Where m_n – average mass of the main samples after water saturation in grams

w_n – the average value of the humidity of the control samples in parts of one after water saturation;

\bar{m}_n – the average value of the mass of the main samples after passing the intermediate number of cycles in grams; \bar{w}_n – the average humidity value of the main samples in parts from one after passing the intermediate number of cycles.

3. Results and discussion

Studies showed that ash reduces the thermal conductivity of foam concrete. The results of the studies are presented in Table 6.

Table 6. Thermal conductivity of foam concrete based on fly ash with additives CM-2 and CMA-P.

Type of foam concrete	Grade of concrete by average density	Coefficient of thermal conductivity W/m ·°C		
		Ash	Ash with additive CM-2	Ash with additive CMA-P
Structural and thermal insulation	D 600	0.12	0.11	0.11
	700	0.15	0.14	0.14
	800	0.18	0.16	0.16
	900	0.21	0.20	0.195

Table 6 shows that the thermal conductivity of foam concrete without additives is 9% higher at a density of D 600. However, in the process of increasing the density, the thermal conductivity in the difference between samples without additives and with additives decreases to 5% with the addition of CM-2 and CMA-P to 7.5% at a density of D 900. This result is justified by the fact that with an increase in the density of foam concrete, the ash content in the material also increases, which provides low thermal conductivity, and additives having a polymer component in their composition enhance this effect. The difference between the compositions with the addition of CM-2 and CMA-P is explained by the fact that the composition of the additive CMA-P contains salt as a filler, giving the additive a dry state, thus the total sol content in the material increases.

The insertion of ash into foam concrete leads to a decrease in its strength, which affects negatively the quality of structural and thermal insulation and structural foam concrete products. Studies were conducted on the effect of additives CM-2, CMA, on the construction and technical properties of foam concrete. Complex hydrophilic-hydrophobizing additives of the CMA type increase the mobility of closed cement systems. Dispersed fillers, which are part of the CMA, increase the uniformity of the contact zones, providing a strong fusion of cementing new formations and the adhesion of the cement stone to the aggregates. The deformation and strength properties of the modified concrete are improved: strength indicators are increased, shrinkage is reduced, and crack resistance increases. Hydrophysical properties – reduced water absorption and increased water resistance, due to the favorable pore structure and hydrophobic effect, as well as the modification of ice and corrosion products under the influence of additives, the high frost resistance and corrosion resistance of modified concrete is determined.

It is noteworthy that when converting a liquid emulsified modifier to a solid state, its properties are not lost, the degree of influence on the liquefaction (rheology) of cement systems, their physical and mechanical properties after solidification are preserved.

The results of the compression test are shown in Figure 3A. Tests on the frost resistance of similar samples were also carried out. The results of the studies are shown in Figure 3B.

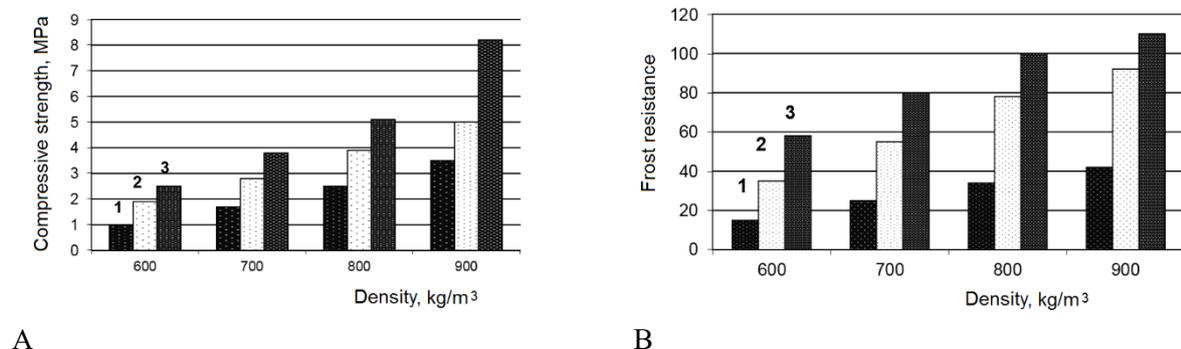


Figure 1. Impact of additives on the strength of foam concrete based on the ash of hydraulic removal as a filler: 1 – without additive; 2 – CMA additive; 3 – CM-2 additive.

From the results obtained, we can see that the strength and frost resistance of foam concrete with additives is significantly increased. The best results were obtained for foam concrete with the addition of CM-2. Studies showed that samples of foam concrete with the addition of CM-2, even with low strength, do not break down when interacting with water, which indicates the effectiveness of the use of this additive. Post-alcohol bard, which is part of the CM-2 additive, contains gluten, which, when interacting with the filler and fine filler of foam concrete, polymerizes, forming contact films that increase the resistance of the material to water. Also the composition of the additive CMA-P, which contains ash as filler, is not important.

The sample was examined on a scanning microscope with a magnification of 1000 (Figure 5).

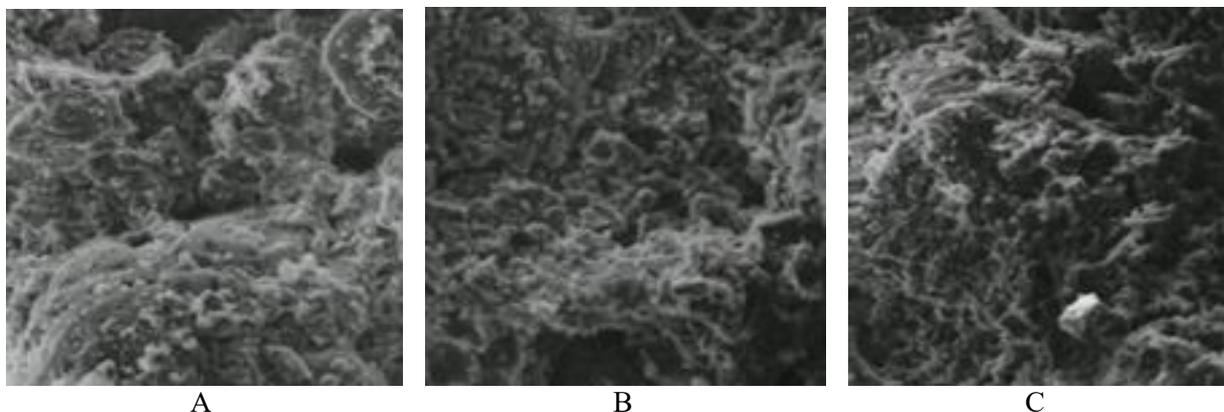


Figure 5. Microstructure of foam concrete. Magnification x 1000: A - without the additive, B - with the addition of CM-2, C - with the addition of CMA-P.

The conducted research suggests that the hydrophilic-hydrophobic additives CMA-P and CM-2 improve the construction and technical properties of the cement binder, give a closed pore structure, thereby increasing the strength and frost resistance of the foam concrete material.

4. Summary

Thus, it can be seen from the conducted studies that when using fly ash, the use of complex additives of the hydrophilic-hydrophobic type is effective to obtain a strong and effective material. Additives CMA and CM-2 plasticize and reduce the water-cement ratio and thereby increase the strength of the product, create a high-quality pore structure, which allows saving cement binder and solving the problem of waste disposal of ash of hydraulic removal.

The paper presents an increase in the strength of samples with the addition of CM-2 in relation to CMA samples by 32% while without additives more than twice, the frost resistance also with the addition of CM-2 increases from 11% to 55% depending on the density of the material in relation to the addition of CMA and more than twice in contrast to samples without additives.

Studies showed that the use of all elements and new developments in the production of foam concrete in the selection of the optimal number and modes will allow getting high-quality materials.

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