

Use of industrial waste in the production of non-autoclaved foam concrete

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Abstract. The paper presents the relevance of the use of industrial waste, in particular, fuel ash generated by thermal power plants. The application of fly ash in the production of non-autoclaved cellular concrete, namely foam concrete is substantiated. The mechanism of structural formation of foamed concrete with the use of silica component is given. The dependence of the strength of foam concrete with density D600 on the ratio of silicious component to binder by mass is determined, and the macrostructure of the developed compositions is shown. It is concluded that it is reasonable to use TPP fly ash as a silica component for foamed concrete mixtures.

1 Introduction

During new construction, repair and reconstruction, first of all, important attention is paid to the resource and energy efficiency of construction processes, and first of all building materials and products [1, 2]. At the same time, there are also problems of energy costs for the operation of existing buildings. Especially nowadays there is a growing interest in the use of efficient heat-insulating products and materials in urban construction, namely non-autoclaved cellular concrete based on industrial wastes, in particular fuel ashes and slags from TPPs [3, 4].

Ash and ash and slag wastes, which are constantly accumulated in ash and slag storages, are a valuable raw material resource for the production of building mixtures, concrete and reinforced concrete products [5, 6]. Their use under certain conditions can significantly improve the quality of multicomponent material and increase the technical and operational characteristics of finished products. However, the variability of TPP ash properties, including dispersibility, chemical mineral composition, content of alkali metal oxides and unburned coal residue, limits its use in concrete production. Lack of specific recommendations regarding the optimum content of TPP ash in concrete and mortars, especially high class, also does not favor its use.

Fly ash constitutes about 90 % of coal ash. Not more than 40 % of the fly ash generated is utilized in various industries, out of which up to 20 % is used in the production of concrete and only a small part is used in the production of binders. Fly ash is produced in

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thermal power plants by burning coal fuel and consists of solid spherical particles and a small number of hollow elements. The main substance of fly ash is silicate glass containing oxides of silicon, aluminum, iron and calcium. The dosage of fly ash and its effect on the properties of blended cement depends largely on its chemical and mineralogical composition [7].

For most foams, it is preferable to obtain a closed cell structure because such materials have better thermal insulation properties. When considering the strength indicators of highly porous cement stone, it is necessary to distinguish the strength of the cement dough itself in the interstitial space and the strength of the porous composite material. In view of the above, it is necessary to maximize the strength while reducing the density of the product as much as possible. This can be achieved by optimizing cement materials and selecting high quality blowing agents and silica components.

When designing the compositions of non-autoclaved foamed concrete, there is a need to obtain foam concrete with the lowest possible values of average density and thermal conductivity coefficient, low sorption moisture, sufficient frost resistance, as well as the required strength [8]. It is with the involvement of fuel ashes in the production process of non-autoclaved foamed concrete that the necessary performance characteristics are achieved [9].

Replacement of sand in the production process of aerated concrete with ash from TPPs will significantly improve the environment, since the use of sand in this type of concrete has a negative impact on the environment - ash occupies large areas for ash dumps (hundreds and tens of thousands of hectares), and the removal of sand disturbs the natural land cover.

2 Results

For the use of fly ash as a silica component for non-autoclaved foam concrete must meet the requirements of GOST 25818-2017 "Fly ash from thermal power plants for concrete. Technical conditions" and not to exceed the standardized indicators:

- on the content of calcium oxide (not more than 10 %);
- Magnesium oxide content (not more than 5 %);
- on the content of sulfur compounds in terms of SO₃ (not more than 3%);
- on the content of alkaline oxides in recalculation to Na₂O (not more than 3%);
- on losses at calcination (not more than 5%).

At observance of these requirements, ashes are suitable for manufacture of all kinds of concrete. Data of chemical composition of ash samples are presented in Table 1.

Table 1. Chemical composition of fly ash from Zuevskaya TPP.

Sample	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	CaO _{ew}	K ₂ O	Na ₂ O	SO ₃	S	P ₂ O ₅	lg.l.
1	56.64	1.03	19.61	7.75	2.76	0.004	1.77	7.05	0.88	1.64	0.01	0.74	0.02	0.04	0,80
2	56.07	1.03	19.07	7.62	2.77	0.005	1.80	6.52	0.90	2.40	0.66	0.89	0.06	0.06	0,64
3	57.32	1.01	19.86	7.40	2.77	0.005	1.58	6.90	1.24	1.82	0.02	0.67	0.02	0.14	0,40
Av.	56.31	1.02	19.42	7.53	2.77	0.009	1.96	6.84	0.88	1.64	0.01	0.74	0.02	0.04	0,80

Cement of CEM-I 42.5 N type of Amvrosievsky cement plant was used for the preparation of foam concrete mixture, fly ash from Zuevskaya TPP was used as a silica component. Surfactants are represented by protein blowing agent "Etalon" and water-

reducing chemical additive Chemix "Art-2". Additionally, sodium sulfate (Na_2SO_4) was used as a setting and hardening gas pedal. Preparation of the foam concrete mixture was made in one stage, which includes the introduction of the foam concentrate into the previously prepared mortar mixture. The compositions of non-autoclaved foam concrete are given in Table 2.

Table 2. Compositions of non-autoclaved foam concrete with density D600.

no.	Silicious component to binder ratio by weight	W/T	Cement, kg	Chemix "Agt-2", kg	Sodium sulphate, kg	Compressive strength at 28 days, MPa
1	1:3	0.35	391	3.32	3.91	1.8
2	1:2	0.35	348	2.95	2.48	1.9
3	1:1	0.35	261	2.21	2.61	1.7
4	2:1	0.35	174	1.47	1.74	1.3
5	3:1	0.35	131	1.11	1.11	1.1
K	-	0.42	522	-	-	2.5

Using fly ash from Zuevskaya TPP as a silica component in combination with a chemical additive of polycarboxylate type "Chemix Art-2", as well as gas pedal of setting and hardening of concrete, it is possible to achieve optimum indicators "density - strength" for non-autoclaved foam concrete, and most importantly allows to save the most resource-intensive component - cement. When using fly ash, the compressive strength is slightly lower relative to the control composition, but is within the limits allowed by the current normative document for non-autoclaved cellular concrete.

Dependence of foam concrete strength on the ratio of silica component to binder by weight is presented in Fig. 1.

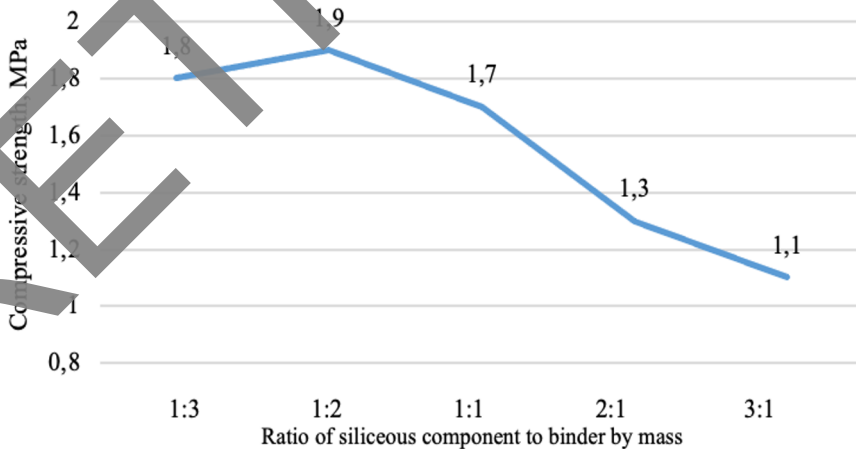


Fig. 1. Dependence of foam concrete strength on silicious component ratio (fly ash from thermal power plants) to binder by weight

The macrostructure of composition No. 3 in comparison with the control composition determined using a Technival 2 stereomicroscope is shown in Fig. 2.

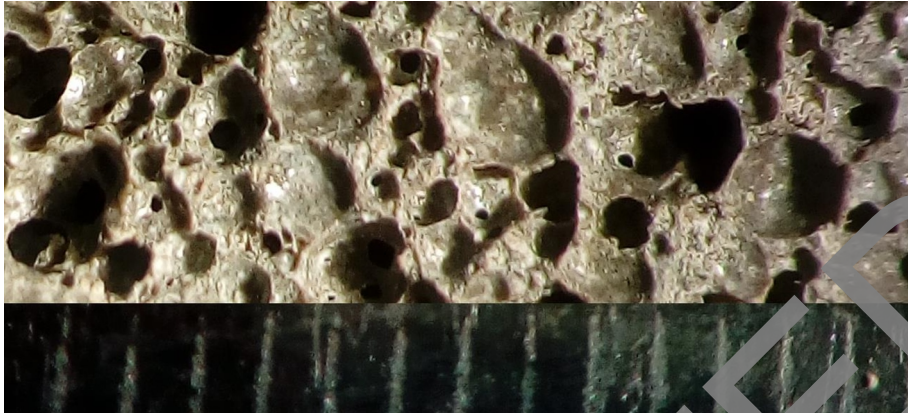


Fig. 2. Macrostructure of composition No. 3

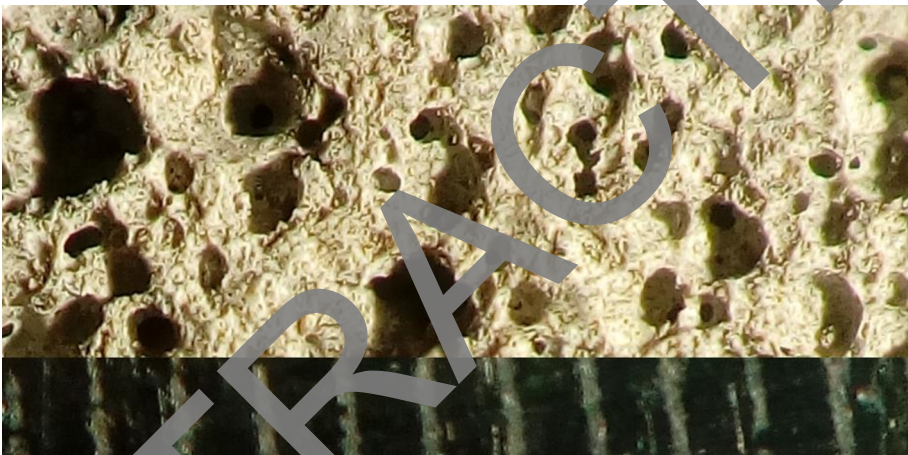


Fig. 3. Macrostructure of the control composition

The interstitial partitions in the material must be uniform in thickness, otherwise their different thicknesses negatively affect the strength of the material. During loading, the thinnest partitions collapse faster, increasing the load on the others according to the hyperbolic law. The uniformity of the thickness of interstitial partitions in the material mainly depends on the uniformity of the distribution of the pore formers in the initial mixture, the homogeneity of the temperature field and the rheological properties of the material.

The higher the macroporosity of the material at the same average density value, the thicker the interstitial partitions should be. Macroporosity also affects the thermal conductivity: the higher the macroporosity, the lower the thermal conductivity of the material. Microporosity, in turn, affects the thickness of the baffles. The baffle thickness consists of three parameters: minimum cross-sectional area, uniformity of cross-sectional area around the perimeter of the pore (uniformity of cross-sectional area within a single pore), and uniformity of baffle thickness in the material. The minimum achievable partition thickness depends on the size of mineral phase particles and their packing density.

The most important characteristic of the cells is their degree of confinement. For most foams, a closed cell structure is sought because such materials have better thermal

insulation properties. At the same time, open cell foam has a higher sound absorption coefficient.

3 Conclusions

Analyzing the data of Table 2 and Figures 2 and 3 it follows that the addition of dispersed mineral additives in the form of TPP fly ash to the foam concrete mixture, firstly, contributes to the creation of dense uniform structures, and secondly, actively interacting with charged radicals of surfactant molecules, create a kind of protective layer around the foam film. This layer prevents the adhesion of active radicals of surfactants on the surface of cement particles, which in turn promotes active hydration of clinker minerals. In addition, fly ash promotes the formation of a better porous structure of foam concrete, which is characterized by a uniform distribution of small pores in the cement matrix (Fig. 2). The pores in such a material are close to a spherical shape with a dense even surface. Thus, the optimal structures should include material structures with the highest value of strength at a given density with the shape of pores approaching the honeycomb.

The proposed resource-saving technologies on the example of the use of fly ash from thermal power plants as a silica component for foam concrete mixtures, will reduce the amount of ash and slag waste in the ash disposal area of the plant, as well as reduce the need for targeted production of traditional building raw materials.

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