



Conference Paper

Research of Geopolymer Foam Concrete on the Base of the Wastes Produced By Kemerovo Heat and Power Enterprises

A A Kargin^{1,2}, V S Baev², and N A Mashkin²¹T.F. Gorbachev Kuzbass State Technical University, 28, Vesennyya St., Kemerovo, Russia²Novosibirsk State University of Architecture and Civil Engineering, 113, Leningradskaya St., Novosibirsk, Russia

Abstract

The article shows the results of the research on geopolymer foam concrete production on the base of the wastes of Kemerovo heat and power enterprises. Relationships between the compression strength and average density of geopolymer foam concrete and the alkaline activator amount, alkaline concentration, foaming agent amount and duration of the blend mechanical activation were determined. It was found out that being in its optimal composition the material obtained has strength 2.0-3.5 MPa under density from 350 up to 500 kg/m³. Infusion of the developed construction material on the basis of the industrial wastes will allow to change more expensive construction materials on the cement base and provide the utilization of the industrial wastes.

Corresponding Author:

A A Kargin

say-bay@mail.ru

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1. Introduction

The main construction material is concrete, and the volume of its production increases year by year. The concrete is mainly produced on the basis of Portland cement which demands a large volume of power and mineral resources for its production. Additionally it is known that approximately 1 tonne of carbon dioxide evolves when producing 1 tonne of Portland cement [1].

One of the problem solutions is engineering and developing different technologies of clinkerless binders. Over recent years a large number of researchers are engaged in studying geopolymer materials technology [2-5]. They are produced during alkaline activation of natural or industrial aluminosilicate raw materials with formation of law-basic hydrated calcium silicates, silicic acid, alkali hydroalumosilicates and alkali and alkali-earth hydroalumosilicates, hydroaluminates, hydroferrites.

The theoretical foundations of alkaline binder hydration and solidification are formed by Glukhovskiy V.D. According to the theory and understanding physical-and-chemical



mechanics of dispersion structures, the alkaline binder structure formation is seen as a combination of successive and competing physical-chemical transformations. The main transformations are disruption of initial disperse phase up to the value of special units of unstable structure; their contact interaction with formation of disperse-coagulative thixotropic units; their development on the basis of condensation-crystallization structure of hydrated newgrowths. In general the composition of the formed stone of slag-alkaline substance is determined by chemical and mineral composition of the slag and the nature of the alkaline activator. It is represented by tobermorite-like low-basic hydrated calcium aluminosilicates, hydrogarnets with alternative composition, alkaline hydroaluminosilicates like zeolites and mica, as well as alkali and alkali-earth hydroaluminosilicates and aluminosilicate compounds [38].

In the strength synthesis the crucial role belongs to low-basic hydrosilicates modified by alkaline hydroaluminosilicates and ferrisilicates which are represented by gelly-like phase (70... 85%) and crystalline formations (15...30 %). Strength and lifetime of geopolymer stone is also provided by low basic capacity and solubility of newgrowths. Binding capacity (compression strength) of highly basic hydrated phases is 2.5-3.0 times less than of low-basic tobermorite phases. As for the first phases the reason is the quantity decrease of stronger covalent links like Si-O-Si and the quantity increase of weaker ionic links like Ca-O-Si.

The crystalline grid energy of minerals in geopolymer materials is higher than the crystalline grid energy of minerals in clinker binders. And the minerals formed at binders on the main slags, has lower energy of crystalline grid than the minerals formed when using neutral and acid slags [42]. In addition the connection is between the energy of crystalline grid and solubility of the minerals: the higher the energy of crystalline grid is, the lower the solubility is.

The high density of domination of closed porosity is typical for geopolymer stone pore structure.

This technology allows to get construction materials with low energy costs (during production the specific fuel consumption is 3-5 times less in comparison with Portland cement) because in the manufacturing process there is no burning operation. Moreover fly ash application as a main element of geopolymer materials allows practically not to spend additional energy on pulverization.

2. Materials and methods

In the research the fly ash of Kemerovo SDPP was used as the main component of the initial blend because in near future it is planned to turn completely to the pneumatic ash handling system at this station. The fly ash chemical composition was preliminarily identified with atomic emission spectrometer iCAP 6500 Duo LA. The results are included in Table 1.

TABLE 1: Chemical composition of Kemerovo SDPP fly ash.

Component	SiO ₂	Al ₂ O ₃	CaO	Fe ₂ O ₃	Na ₂ O	K ₂ O	MgO	TiO ₂	P ₂ O ₅	Ba	S	MnO
Mass content, %	60.9 ± 0.2	21 ± 1	5.6 ± 0.6	3.64 ± 0.01	2.8 ± 0.3	2.2 ± 0.2	1.6 ± 0.3	0.72 ± 0.03	0.41 ± 0.07	0.21 ± 0.01	0.11 ± 0.03	0.05 ± 0.01

The specific surface area value and porous structure characteristics (total pore volume V_{Σ} (cm³/g), volume of macro-, meso - and micropores – V_{ma} , V_{me} и V_{mi} (cm³/g) of Kemerovo SDPP fly ash sample were calculated from the analyses of N₂ adsorption-desorption isotherm under -195.808°C (77 K) measured with the volume vacuum static system ASAP-2020. Before adsorption measurement the test sample was vacuumized directly in a special port of the device under 200°C for 6 hours up to residual pressure min 0.510-3 mmHg. The nitrogen adsorption-desorption isotherms were measured within the equilibrium relative pressures from 10⁻³ to 0.995 P/Po.

The specific surface area value was determined by BET method. The total pore volume was determined under P/Po 0.995. The micropore volume was determined by the comparative t-method. The mesopore volume was determined by BJH method. The average pore diameter was calculated as follows: $D_{avg} = 4V_{ads}/S$ by BET method, and the average pore diameter was calculated by BJH method.

The results are included in Table 2.

TABLE 2: Specific surface area value and porous structure characteristics of Kemerovo SDPP fly ash.

Specific surface area, m ² /g	Total pore volume, cm ³ /g	Micropore volume, cm ³ /g	Mesopore volume, cm ³ /g	Macropore volume, cm ³ /g	D _{avg} , nm	
					BET	BJH
0.84	0.0013	0.0004	0.0006	0.0003	6.2	26

The caustic liquor (NaOH) of different concentration was used for activation. The initial chemical composition of the liquor is shown in Table 3.

Commercial hydrogen peroxide solution 40% (H₂O₂) was used as a porogen.

TABLE 3: Caustic liquor chemical composition.

Component	NaOH	Na ₂ CO ₃	NaCl	Fe ₂ O ₃	NaClO ₃	H ₂ O
Mass content, %	44.0	0.8	3.8	0.02	0.3	48.92

Relationships between the samples density and compression strength and the change of different blend characteristics and its preparation technology were evaluated on the initial composition samples with one parameter change.

The initial composition parameters were conditionally taken as the following: the mass ratio of alkali to the ash – 0.5, the mass ratio of peroxide to the ash – 0.05, alkali concentration – 5 moles, activation time – 30 s, holding temperature – 90°C, high-temperature holding time – 24 h, hardening time – 7 days.

The blend was activated in a laboratory pulverizer. The components were put in the pulverizer in the following sequence: fly-ash, alkali, hydrogen peroxide.

3. Results

3.1. Measurement of geopolymer foam concrete properties depending on the initial blend composition parameters

Influence of the mass ratio of the alkali to the ash in the initial blend on the density and strength of the material produced was primarily studied. Heterogeneity of the chemical composition at different power stations demands the necessity of separate adjustment of alkaline activator amount. Relying on the researches performed before [3-6] the sodium hydroxide was added at the rate from 0.2 to 0.7 of the ash mass content with the period of 0.1. The results are depicted in Fig. 1.

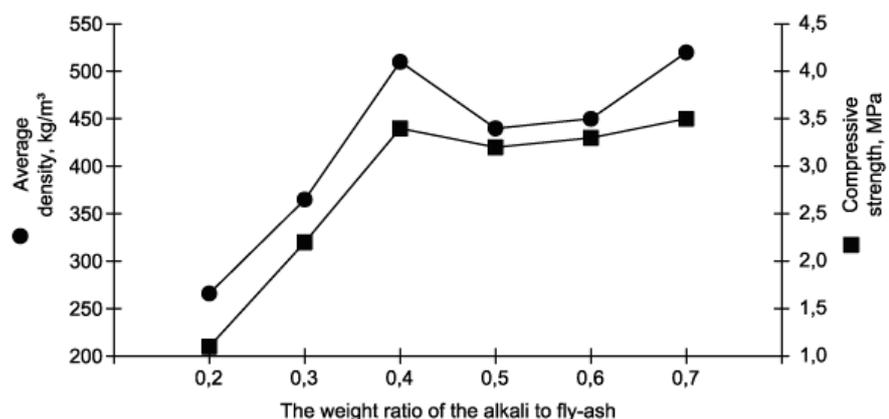


Figure 1: Relationship between the geopolymer foam concrete density and strength and the mass ratio of the alkali to the fly ash in the blend composition.

It is evaluated that the production of hardening material is possible as a result of alkaline activation of the fly-ash with sodium hydroxide. The quantity increase of NaOH from 0.2 up to 0.4 of the fly content allows increasing the strength of the samples from 1.2 up to 3.4 MPa.

Disproportionateness of the changing strength and density curves after increasing NaOH content from 0.4 up to 0.7 is explained by non-optimum water-binder ratio of the blend. It was evaluated before that when increasing the holding temperature the alkaline concentration in the hardening blend increases because of dehydration [3].

Therefore to produce the geopolymer foam concrete with increased strength it is necessary to increase the alkali amount and simultaneously increase the holding temperature or apply the liquor with higher NaOH concentration. Then the influence of alkaline concentration in the initial blend on the density and strength of the material produced was studied. The relation received is depicted in Fig. 2.

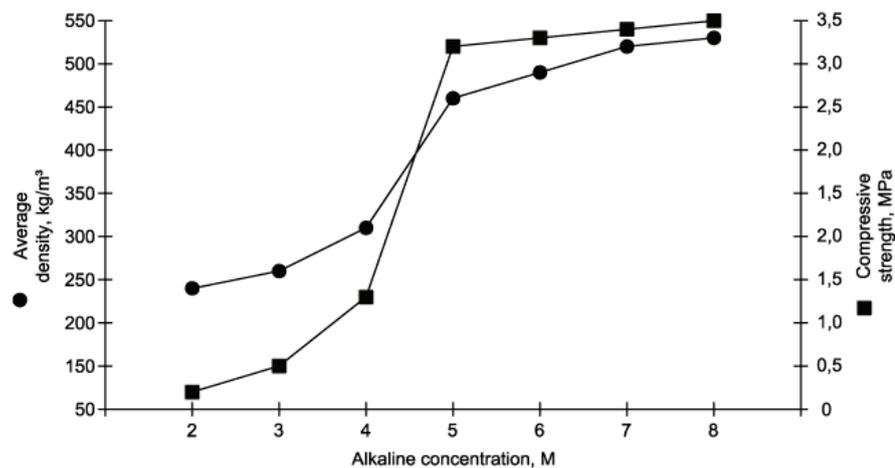


Figure 2: Relationship between geopolymer foam concrete density and strength and alkaline concentration in blend composition.

The influence of the porogen value on the density and strength of the material produced was also studied. The results received are depicted in Fig. 3.

The data of Fig. 1 shows that after increasing alkali solution concentration from 4 to 5 moles the density and strength of the samples increase sharply. However the strength of the samples changes insignificantly when increasing the concentration over 5 moles. It is explained by the fact that in the concrete the alkali amount which was not in the reaction increased.

It is known that in the geopolymers a substantial proportion of free alkali from the liquor undergoes a hydration reaction [7]. Consequently, geopolymer foam concrete hardening will continue when increasing the holding temperature or its duration, but the alkali amount which was not in the reaction – will reduce.

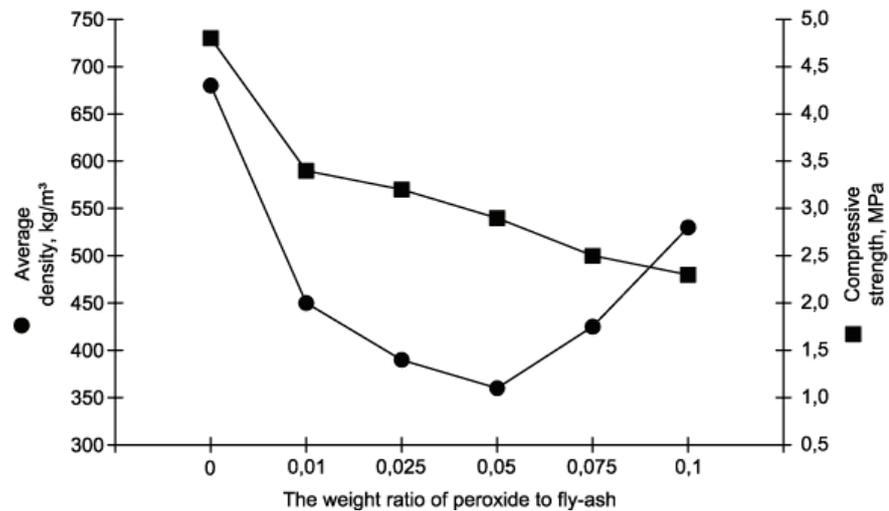


Figure 3: Relationship between geopolymer foam concrete density and strength and the mass ratio of the peroxide to the ash in the blend composition.

The porogen amount which is hydrogen peroxide primarily influences the material density.

According to Fig. 3 it is possible to estimate that the strength value in relation to the density within the range from 0.025 to 0.05 is maximum. The increase of peroxide content in the composition over this range results in decreasing the density with simultaneous decreasing strength that is inadmissible for the class of the construction-heat-insulating materials.

Consequently the efficient amount of hydrogen peroxide in relation to the fly ash mass amounts to 0.025-0.05.

3.2. Measurement of geopolymer foam concrete properties depending on manufacturing parameters

This research studied how the term of the mechanical activation of the blend influences the ultimate material properties. The blend of the same composition was activated in the laboratory mill within different periods of time and poured in the laboratory moulds. Then the blend was hold during 7 days as follows: high-temperature processing – 24 h, then it was hold at room temperature. The results received are depicted in Fig. 4.

Although the blend activation duration influences insignificantly the strength of the ultimate material, but it is necessary to take it into account. Thus Fig. 4 shows that the strength value in relation to the density is maximum when activating within 30 s, and it is optimal.

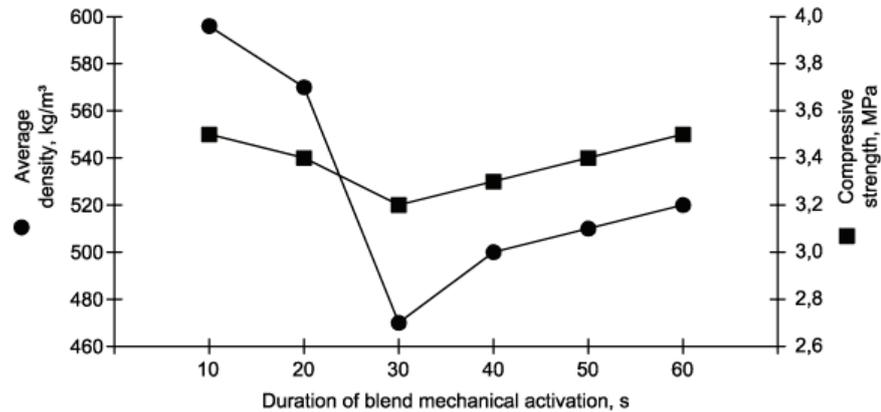


Figure 4: Relationship between geopolymer foam concrete strength and density and duration of blend mechanical activation.

4. Conclusion

Summing it up, one can conclude, that:

- the optimum value of the mass ratio of the alkali to the ash amounts to 0.5;
- the optimum caustic liquor concentration is 5 moles;
- the optimum mass ratio of the hydrogen peroxide to the ash is 0.05;
- the activation time for preparation of the optimum blend amounts to 30 s;
- the collected characteristics of the geopolymer foam concrete are comparable to the characteristics of the "classic" heat-insulation-construction materials such as foam- and gas-concrete on a clinker binder when fulfilling the conditions of optimal composition and preparation technology, and the main component of the geopolymer foam concrete is the industrial waste.

Therefore the geopolymer materials technology infusion in the production process will allow to decrease the Portland concrete consumption and, consequently, the amount of carbon dioxide emissions in the atmosphere, and thus to improve ecological situation in the region.

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