Geopolymer foam based on coal fly ash and metakaolin as an economic and environment friendly porous construction material

Spumă de geopolimer pe bază de cenușă zburătoare de cărbune și metacaolin ca un material de construcție poros, economic și ecologic

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Abstract. *Geopolymer foam based on fly ash and metakaolin was designed and tested. The usual technique of activating alumino-silicate materials in a highly alkaline medium was applied, the generation of the geopolymer being favoured by developing the geopolymerization reaction. The traditional foaming agent (hydrogen peroxide) has been replaced by sodium perborate, which is more stable and easier to handle. The work originality was the use of a nanomaterial (bentonite clay), having the ability to increase the mechanical strength. Density and thermal conductivity of the new product had low values (470 kg·m^{-3} and 0.104 W·m^{-1}·K^{-1}) and compressive strength reached 7.5 MPa.*

Key words: geopolymer foam, geopolymerization, sodium perborate, nanomaterial, thermal insulating properties.

Rezumat. *O spumă de geopolimer pe bază de cenușă zburătoare și metacaolin a fost proiectată și testată. A fost aplicată tehnica uzuală de activare a materialelor aluminosilicatice în mediu înalt alcalin, generarea geopolimerului fiind favorizată prin desfășurarea reacției de geopolimerizare. Agentul tradițional de spumare (peroxid de hidrogen) a fost înlocuit cu perborat de sodiu, mai stabil și mai ușor de manipulat. Originalitatea lucrării a fost utilizarea unui nanomaterial (argilă de bentonită), având*

capacitatea creșterii rezistenței mecanice. Densitatea și conductivitatea termică ale noului produs au avut valori reduse (470 kg·m^{-3} și 0,104 W·m^{-1}·K^{-1}), iar rezistența la compresiune a atins 7,5 MPa.

Cuvinte cheie: spumă de geopolimer, geopolimerizare, perborat de sodiu, nanomaterial, proprietăți termoizolante.

1. Introduction

Under the current global conditions, in which the construction materials industry (especially cement) is strongly affected by the excessively high emissions of greenhouse gases responsible for the partial destruction of the planet's ozone layer as well as by the excessive consumption of fossil fuels [1], the use of silico-aluminous materials (natural or resulting as industrial by-products) has become a necessity. The remarkable invention of the French scientist Davidovits from the last decade of the last century created the possibility of turning this type of materials into geopolymers following the geopolymerization reaction favoured by a highly alkaline aqueous medium. Having excellent pozzolanic properties, geopolymers are suitable as construction materials with outstanding physical, thermal, mechanical, and structural characteristics [2]. According to their inventor, geopolymers are inorganic, ceramic materials based on aluminum and silicon covalently bonded, forming a three-dimensional polymer chain that includes Si-O-Al-O bonds [3]. In addition, their manufacture requires only a very low energy consumption and carbon dioxide emissions in the atmosphere are almost negligible.

Using different techniques and materials, a varied range of geopolymers was experimentally made, between very dense products with very high mechanical properties and porous products made by foaming the mixture with excellent thermal insulating properties and much lower strength. All of these are suitable for using in construction, their manufacture being economic and environmental friendly. In the current study, only the porous geopolymers forming the category of geopolymer foams were analyzed.

According to the literature [4], hydrogen peroxide (H_2O_2) is widely used in industry, having the tendency to decompose due to the instability of the hydrogen-oxygen bond. It is the most used expanding agent in the manufacturing process of fly ash-geopolymer foam, favourably influencing the thermal insulation properties (density, thermal conductivity, and porosity) of geopolymer [5]. The experiment presented in this paper included metakaolin (as a natural alumino-silicate material) and fly ash (as an industrial by-product) in a 2:1 weight ratio. The raw materials were activated with hydrated sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) in the form of pellets dissolved in deionized water as alkaline activators [6]. Low values of thermal conductivity (below 0.107 W·m^{-1}·K^{-1}) were experimentally obtained. Also, the density of geopolymer foam had relatively low values below 560 kg·m^{-3}.

Parameters of making process of geopolymer foam based on metakaolin were experimentally optimized by Jaya et al. [7]. Thus, the optimal NaOH concentration

was established at 10M, the weight ratio of alkaline activator was limited at 1 %, and the metakaolin/alkaline activator ratio was determined at 0.8. The indicated foaming agent was H_2O_2, which together with the Tween 80 surfactant (polyethylene glycosorbitan monooleate) led to obtaining the following performances of the geopolymer foam characteristics: density within the limits of 471-1212 $kg \cdot m^{-3}$, porosity between 36-80 %, thermal conductivity in the range of 0.11-0.30 $W \cdot m^{-1} \cdot K^{-1}$, and compressive strength within the acceptable limits of 0.4-6 MPa.

Metakaolin and calcium phosphate $Ca_3(PO_4)_2$ biomass ash mixture in 1:1 weight ratio was activated with NaOH and Na_2SiO_3 solution and subjected to foaming with H_2O_2 (5 wt. %) for experimental manufacturing geopolymer foam [8]. Low values of density (310 $kg \cdot m^{-3}$) and thermal conductivity (0.073 $W \cdot m^{-1} \cdot K^{-1}$), but also a low level of compressive strength (0.6 MPa) characterized the optimal sample of geopolymer foam. Thermal-structural sandwich panel is the recommended application domain for this geopolymer.

The use of H_2O_2 as an expanding agent can create some difficulties related to the inhomogeneity of pores, which negatively influence the physical, thermal, and mechanical characteristics of geopolymer foam, according to [9]. It was found that the higher ratio of Na_2SiO_3 in the alkaline activator mixture can influence the stability of the H_2O_2 decomposition process. The open porosity observed in the geopolymer foam microstructure could be decreased from 58 to 22 vol. % by increasing the stability of the foaming process with H_2O_2. Also, the uniformity of the pore distribution is favoured, increasing from 82 to 98 % by stabilizing the same foaming process. The thermal insulation properties of metakaolin-based geopolymer foam can be improved by 16 % due to the foam homogenization. The compressive strength can be favourably influenced in the case of a more homogeneous microstructure.

According to Bai et al. [10], vegetable oil (sunflower oil, canola oil, olive oil). can successfully play the role of foam stabilizing agent. Its introduction in very low proportions (0.1-0.5 wt. %) in the manufacturing mixture of geopolymer foam together with H_2O_2 as an expanding agent allowed to obtain excellent features: density within the limits of 370-740 $kg \cdot m^{-3}$, porosity between 66-83 %, thermal conductivity in the range of 0.11-0.17 $W \cdot m^{-1} \cdot K^{-1}$, and compressive strength between 0.3-11.6 MPa. The work conclusion was that the highest ratio of vegetable oil as a stabilizer agent contributed to improving the thermal insulating properties (density, thermal conductivity, and porosity), even if the compressive strength was reduced within acceptable limits.

In the paper [11], lightweight geopolymer concrete based on class C-fly ash (with over 20 % CaO) was produced by activation of the alumina-silicate material in 12M NaOH solution by adding NaOH pellets to distilled water and Na_2SiO_3 solution (30.1 % SiO_2, 9.4 % Na_2O and 60.5 % water) with SiO_2/Na_2O molar ratio of 3.2. Polycarboxylate-based superplasticizer used as a foaming agent was added into the material mixture. Geopolymer paste obtained by mixing solid and liquid components was poured into molds and subjected to curing process in two variants: at 60 ºC and at room temperature. The measurement of the geopolymer characteristics after 1, 7, and

28 days led to the conclusion that the hot curing favoured the highest compressive strength values of a maximum of 18.2 MPa. Water absorption (1.22 vol. %) and porosity (6.78 %) were significantly decreased. Instead, the geopolymer density reached 1667 $kg \cdot m^{-3}$.

Authors of current paper previously tested the manufacture of geopolymer foam based on residual alumino-silicate materials (fly ash and old clay brick recovery from building demolition). The raw material activation was done in the highly alkaline aqueous environment consisting of NaOH and Na_2SiO_3. The foaming agent used in this experiment was H_2O_2 (1.99-3.32 wt. %). The experiment peculiarity was the addition of olive oil (0.06-0.19 wt. %) as a surfactant into the geopolymer paste. Other components of the starting mixture were expanded perlite (about 10.3 wt. %) as a siliceous additive, and fine sand (0.06-0.19 wt. %). The main geopolymer foam characteristics were: density between 420-560 $kg \cdot m^{-3}$, thermal conductivity within the limits of 0.08-0.122 $W \cdot m^{-1} \cdot K^{-1}$, porosity between 71.5-76.9 %, compressive strength in the range of 4.1-5.6 MPa, and water absorption between 3.1-3.8 vol. % [12].

Perlite, an amorphous alumino-silicate volcanic glass, is valorized as a by-product resulting from the industrial exploitation of the volcanic rock. The material containing over 70 % SiO_2 and over 13 % Al_2O_3 is in dusty state with extremely low mean particle size (below 7 μm). According to Vaou and Panias [13], perlite is suitable for its use as an alumino-silicate raw material in the manufacturing process of geopolymer. The geopolymer foam prepared from non-expanded perlite had the thermal conductivity of 0.03 $W \cdot m^{-1} \cdot K^{-1}$, compressive strength of 0.78 MPa, and maximum application temperature of 700 ºC.

Other expanding agent type used in manufacturing process of geopolymer foam based on metakaolin, according to Wattanarach et al. [14], was sodium perborate (NaH_2BO_4) between 0.5-2 wt. %. This was mixed with metakaolin and then with already known alkaline activator solution (NaOH and Na_2SiO_3) for forming a paste. The paste was poured into silicon mold for performing the curing process at 60 ºC for 24 hours, followed by keeping at room temperature for 28 days. The use of increasing weight proportion of NaH_2BO_4 had the effect of increasing the porosity from 54.7 to 67.6 % as well as decreasing the density from 1077 to 750 $kg \cdot m^{-3}$, the thermal conductivity from 0.325 to 0.218 $W \cdot m^{-1} \cdot K^{-1}$, and the compressive strength from 6.7 to 5.2 MPa. Decreasing the compressive strength is not disturbing due to the relatively high level of the strength.

Korat and Ducman [15] carried out studies on the manufacture of fly ash-based geopolymer foam by the already known method of alkaline activation using sodium perborate monohydrate (NaH_2BO_4) as a foaming agent and sodium dodecyl sulfate ($NaC_{12}H_{25}SO_4$) as a stabilizing agent, both in weight proportions between 0.9-2.8 %. The curing process was carried out at 70 ºC for 24 hours, continued with keeping the sample removed from the mold for 3 days. The results showed values of density within the limits of 330-670 $kg \cdot m^{-3}$, thermal conductivity between 0.143-0.205 $W \cdot m^{1} \cdot K^{-1}$, and compressive strength in the range of 1.02-6.33 MPa, corresponding to a fly ash with relatively low CaO content of 6.1 %.

Various types of additive ((polypropylene fiber, nano-silica, carbon nano-tubes, sodium dodecyl sulfate, rosin, sodium lauryl ether sulfate, proteins, etc.) and expanding agent (H_2O_2, NaH_2BO_4, sodium hypochlorite, etc.) can be used in manufacturing process of geopolymer foam. Organic materials (cellulose fiber, expanded perlite, etc.) are also adequate for manufacturing new environment friendly products [16, 17]. A 90/10 mixture of metakaolin and sand as alumina-silicate binder activated with aqueous solution of 8M NaOH and Na_2SiO_3 (1:2.5 weight ratio), H_2O_2 (3 wt. %) and aluminium powder (very low proportion) as foaming agents were used by Kurek et al. [16]. Expanded perlite as an additive contributed to decrease the thermal conductivity and density of the geopolymer foam. The compressive strength did not been significantly affected.

Other manufacturing technique of fly ash-geopolymer foam was tested by Phavongkham et al. [18], using Na_2SiO_3 as a foaming agent and detergent (0.1-0.5 wt. %) as a surfactant helping to increase the fineness of the geopolymer macrostructure. Thermal conductivity decreased from 0.32 to 0.27 $W \cdot m^{-1} \cdot K^{-1}$ and compressive strength reached 4.82 MPa starting from 4.21 MPa. The increase in mechanical strength is due to the 28 day-curing process. Also, the fire resistance increased due to the surfactant proportion increasing.

The paper [19] studied the effect of polypropylene fibers on thermal conductivity and mechanical properties of fly ash-geopolymer foam. Class C fly ash (with high CaO content of 14.6 %) was used as alumino-silicate raw material and NaOH and Na_2 SiO_3 solution mixture was used as an alkaline activator. The foam was prepared by mechanically mixing the surfactant Sika Poro 40 ID (produced in Indonesia) and distilled water into the foam generator. The homogenized foam was added in weight proportions of 40 and 60 % to the mixture of fly ash, fibers, and alkaline activator and mixed further for 5 min aiming at the formation of slurry. This was poured into a mold and the curing process of the fresh material was carried out at ambient temperature. The geopolymer characteristics determining was performed after 7 and 28 days. The polypropylene fibers had the effect of increasing the tensile strength (up to 1.35 MPa). Also, fibers led to increasing the thermal conductivity (0.6-0.8 $W \cdot m^{-1} \cdot K^{-1}$).

The objective of the current work is the manufacture of high-performance geopolymer foam based on a rich SiO_2 and Al_2O_3-industrial by-product of the energy industry (coal fly ash) and a widely available natural alumino-silicate material (metakaolin). The already well-known system invented by Davidovits of the activation of alumino-silicate materials in a highly alkaline liquid environment created by the combination of NaOH and Na_2SiO_3 solutions favourable for developing the geopolymerization reaction was generally kept. The technical solution originality is the addition of sunflower oil as a stabilizing agent for homogenizing the pore structure, the use of bentonite clay, a nanomaterial that has the ability to increase the mechanical strength of geopolymer as well as the replacement of the commonly used foaming agent (H_2O_2) with a more stable agent (NaH_2BO_4).

2. Methods and materials

As mentioned above, the foaming agent chosen for this experiment is sodium perborate. Through the hydrolysis of sodium perborate in contact with water, hydrogen peroxide (H_2O_2) and the tetrahydroxyborate anion $[B(OH)_4]^-$ are released [20]. More explicitly, in aqueous solution, the cyclic anion $\{[B(OH)_2OO]^2\}^{2-}$ hydrolyzes into two anions $[B(OH)_3(OOH)]^-$, which further enter into equilibrium with boric acid $B(OH)_3$, hydrogen peroxide H_2O_2, the hydroperoxyl anion OOH^-, and the tetrahydroxyborate anion $[B(OH)_4]^-$. Through the decomposition process, H_2O_2 releases molecular hydrogen and molecular oxygen in form of bubbles that contribute to expanding the mixture.

On the other hand, the conversion of alumino-silicate materials into geopolymer takes place by activating these materials in an aqueous high alkaline environment containing NaOH and Na_2SiO_3 solutions, which create appropriate conditions for the initiation and development of the geopolymerization reaction. The reaction leads to the formation of a „three-dimensional polymer chain and ring structure" including Si-O-Al-O bonds [21]. According to Provis and Rees [22], the geopolymerization is a particularly complex process, which develop in three stages, that can intersect and influence each other. Deep knowledge of the process mechanism is still difficult and its understanding requires additional research.

As in most manufacturing techniques involving solid and liquid materials, the preparation of each group of components was separately carried out in different containers. In the case of geopolymers making, it is known the recommendation on preparing the liquid mixture of the alkaline activator about 24 hours before mixing it with the solid components represented by the alumino-silicate materials (with the role of binder) and the foaming agent. The alkaline activator adopted for this experiment was composed of NaOH in the form of pellets dissolved in distilled water at a concentration of 10M and the 38 % Na_2SiO_3 aqueous solution commercially available in this state. The preparation of the alkaline activator involved the combination of the two solutions and their mechanical stirring at a rate of 1000 rpm for at least 3 min. Pouring the alkaline activator over the solid mixture and mixing them together with the supplementary addition of stabilizing agent (sunflower oil) and nanomaterial (bentonite clay) led to the formation of the geopolymer paste. The curing process of the geopolymer paste poured into metal molds of different forms and dimensions (depending on the conditions required by the device for determining the characteristics of geopolymer) took place at 80 ºC for 24 hours, followed by keeping the material removed from the molds at room temperature in a dry medium for 3 days. The testing of the geopolymer characteristics was carried out after a storage time at room temperature of 28 days.

Alumino-silicate materials adopted for experimental manufacturing process of the geopolymer foam were fly ash and metakaolin [23]. Given the considerations of the French researcher Davidovits regarding the adequate fly ash type for the geopolymerization process [3], class F fly ash (according to the ASTM C 618-12 standard), characterized by low CaO content (below 5 %) was chosen. 6-7 years ago,

Paroseni-thermal power station (Romania) supplied the companies Cosfel Actual SRL and Daily Sourcing & Research SRL with a batch of class F fly ash that was stored for future research works. The batch of fly ash came from the period of the station operation with anthracite. The chemical composition of the two mentioned alumino-silicate materials as well as of the bentonite clay nanomaterial is shown in Table 1.

Table 1

Chemical composition of alumino-silicate materials

Material	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3
Metakaolin	53.0	43.0	0.8	1.2	0.5	0.4	0.4	-	-
Fly ash	54.4	26.5	1.5	4.8	3.5	2.5	0.4	0.6	1.7
Bentonite clay	66.5	16.8	0.1	3.3	1.4	3.1	1.2	0.5	-

Fly ash available at a grain size below 200 μm required additional processing in a ball mill to reduce the maximum grain size limit below 40 μm. Metakaolin is commercially available as a very fine powder with a particle size of 1-2 μm. The dosing of fly ash and metakaolin was done in a 70/30 weight ratio. The foaming agent (NaH_2BO_4) as a crystalline material (more stable and easier to handle than H_2O_2) [14] was added together with the two mentioned materials in variable proportions between 0.5-2 wt. %. The mixing was done by stirring with an electric stirrer at a rate of 750 rpm for 2 min. After pouring the previously prepared alkaline activator over the solid mixture, stirring continued for 5 min, during which sunflower oil as a stabilizing agent and bentonite clay as a nanomaterial additive to increase mechanical strength were added, until the formation of the geopolymer paste.

Investigation methods for determining geopolymer foam characteristics were those presented below. The density was measured by weighing the mass with an electronic balance relating this value to that of the specimen volume [24]. The apparent porosity was determined using a vacuum saturation method [25]. Compressive strength was tested with TA.XTplus Texture Analyzer and the flexural strength was determined according to SR EN ISO 1412:2000 [26]. Immersing method under water of specimen for 24 hours (ASTM D570) was adopted to determine the water volume absorbed into the geopolymer mass. The thermal conductivity was investigated by the guarded-comparative-longitudinal heat flow method (ASTM E1225-04) and the microstructural appearance of geopolymer foam specimens was examined with ASONA 100X Zoom Smartphone Digital Microscope.

3. Results and discussion

Four experimental variants were adopted for manufacturing the geopolymer foam based on fly ash and metakaolin. The weight ratio of the two types of alumino-silicate material varied between 70.7/29.3-72.9/27.1. The alkaline activator composed of Na_2SiO_3 and NaOH solutions was designed under the conditions of 2.48 weight ratio, kept constant. The weight ratio between the total amount of alumino-silicate materials (fly ash and metakaolin) and the alkaline activator was 2.80, constant for all

variants. The additive in the form of nanomaterial (bentonite clay) had increasing values between 0.85-1.35 wt. % and the stabilizing agent (sunflower oil) had also increasing values between 0.36-1.43 wt. % (from variant 1 to variant 4). The composition of the experimental variants is shown in Table 2.

Table 2

Composition of experimental variants

Material ($kg \cdot m^{-3}$)	Variant 1	Variant 2	Variant 3	Variant 4
Fly ash	297	300	303	306
Metakaolin	123	120	117	114
Bentonite clay	5	6	7	8
10M NaOH solution	46	46	46	46
Na_2SiO_3 solution	114	114	114	114
Sodium perborate	5	7	9	11
Sunflower oil	2	4	6	8
Water addition	10	10	10	10

Determining the physical, thermal, mechanical, and morphological characteristics of geopolymer foam specimens was performed after 28 days, while the mechanical characteristics (compressive strength and flexural strength) were also measured after 7 days. The results of the measurements are presented in Table 3.

Table 3

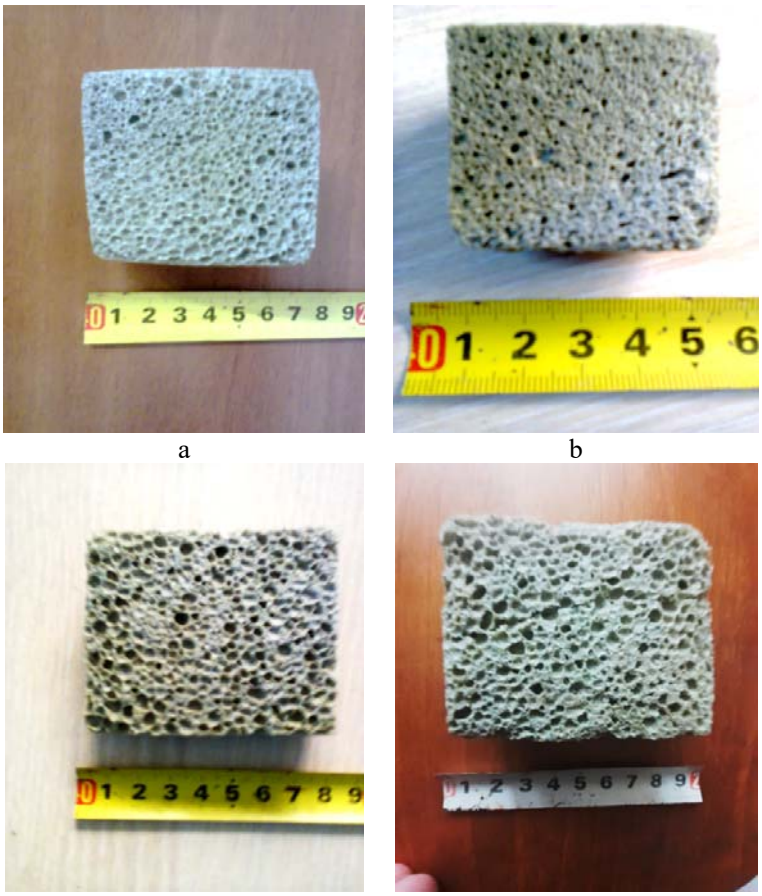
Characteristics of geopolymer foam specimens

Characteristic	Variant 1	Variant 2	Variant 3	Variant 4
Density ($kg \cdot m^{-3}$)	516	502	487	470
Apparent porosity (%)	70.8	73.9	75.2	76.4
Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)	0.122	0.119	0.111	0.104
Compressive strength (MPa)				
- after 7 days	3.9	4.4	5.0	5.2
- after 28 days	6.8	7.2	7.5	7.5
Flexural strength (MPa)				
- after 7 days	2.9	2.9	3.0	3.3
- after 28 days	3.1	3.3	3.5	3.4
Water absorption (vol. %)	3.7	3.0	2.4	1.8
Pore size (mm)	0.2-0.5	0.4-0.7	0.6-0.9	0.7-1.0

According to the data in Table 3, the thermal insulating properties of geopolymer foam samples (density, thermal conductivity, and porosity) exhibit qualities suitable for this role as construction materials. Thus, the density of the porous material had values in the range of 470-516 $kg \cdot m^{-3}$, the thermal conductivity fell within excellent limits (0.104-0.122 $W \cdot m^{-1} \cdot K^{-1}$), and apparent porosity had relatively high values between 70.8-76.4 %. The density and thermal conductivity had decreasing values with the increase of the foaming agent (NaH_2BO_4) ratio from 5 to 11 $kg \cdot m^{-3}$ as well as the increase of the proportion of sunflower oil from 2 to 8 $kg \cdot m^{-3}$, although in percentage terms these values are very low (below 2 wt. %). According to the literature [10], the use of vegetable oil as a stabilizing agent contributes to

improving the thermal insulation properties and the foaming agent obviously favoured the increase of the material porosity as well as the reduction of density and thermal conductivity. Usually, having a porous structure, the geopolymer foam has quite low mechanical strength. To compensate for this disadvantage, the manufacturing recipe included a nanomaterial that contributes to increasing the concrete strength. Bentonite clay in very small amounts (5-8 $kg.m^{-3}$) was chosen in this experiment. Thus, the compressive strength had increasing values reaching 7.5 MPa after 28 days of curing and 5.2 MPa after 7 days. The flexural strength, which usually has much lower values compared to compressive strength, increased to 3.5 MPa after 28 days (3.3 MPa after 7 days), but the role of the nanomaterial was not very conclusive in this case.

Appearance images of geopolymer foam specimens are presented in Fig. 1 and microstructural pictures of these specimens are shown in Fig. 2.



a b c d

Fig. 1. Appearance images of geopolymer foam specimens
a – variant 1; b – variant 2; c – variant 3; d – variant 4.

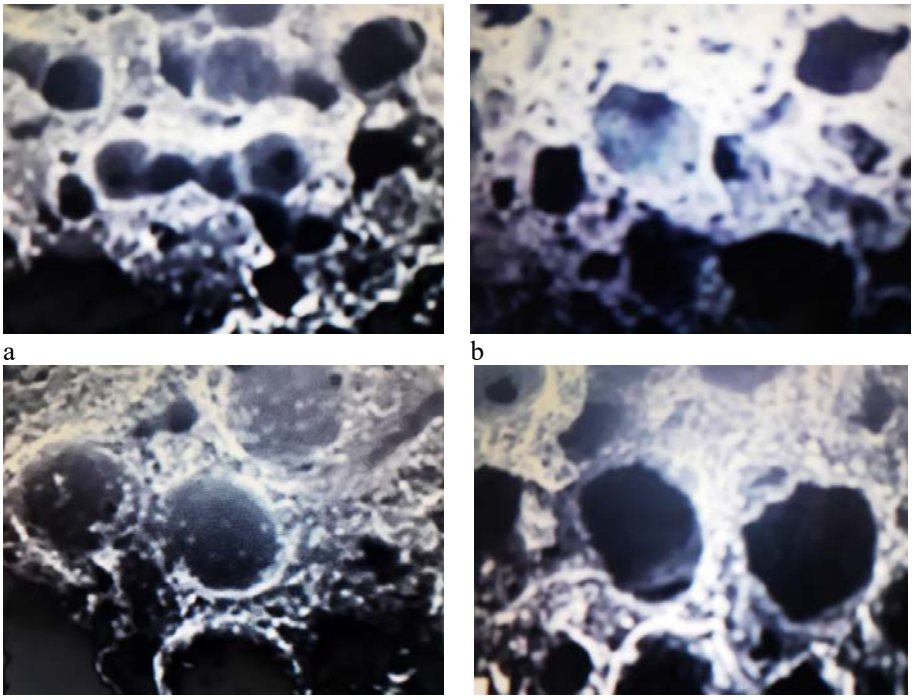


Fig. 2. Microstructural pictures of geopolymer foam specimens
a – variant 1; b – variant 2; c – variant 3; d – variant 4.

From a macro- and microstructural point of view, the porous aspect of specimens is accentuated from variant 1 to variant 4. In this experiment, a higher Na_2SiO_3/NaOH weight ratio of the alkaline activator (2.48) was adopted, which has the ability to homogenize the material pores according to the literature [9]. Fig. 2 is eloquent in terms of obtaining a microstructure with uniformly distributed pores, significantly improved compared to microstructures obtained in the case of using H_2O_2 as a foaming agent. On the other hand, according to the images in Fig. 2, the open porosity was greatly diminished. Microstructural homogenization plays an important role in improving all types of geopolymer characteristics (physical, thermal, and mechanical). The pore size had low values (below 1mm) according to the data indicated in Table 3.

4. Conclusions

Producing an economic and environment friendly geopolymer foam based on fly ash and metakaolin in 2.3-2.5 weight ratio was the research objective in this work. The basic principle of the alkaline activation of the two alumino-silicate materials in a highly alkaline aqueous medium containing NaOH and Na_2SiO_3, which created the conditions for the initiation and developing the geopolymerization reaction as well as the basic technique of the curing process of the geopolymer paste before the investigation of physical, thermal and mechanical properties of the final product were the relatively constant elements of manufacturing the foamed material. In the last two

decades, numerous methods have been tested in the world regarding the nature and amount of the used materials (additives and foaming agents) aiming to improve the properties of the geopolymer. The current work used an unusual type of foaming agent (NaH_2BO_4) as a substitute for H_2O_2, a nanomaterial (bentonite clay) not used in the manufacture of geopolymer foam, but applied in the case of concrete manufacture to increase mechanical strength, and a vegetable oil (sunflower oil) for the stabilization and homogenization of the foam. Optimum results were obtained in the case of variant 4, characterized by the highest proportions of the foaming agent and the additives mentioned above. The density of geopolymer foam had the value of 470 $kg \cdot m^{-3}$, apparent density reached 76.4 %, thermal conductivity was 0.104 $W \cdot m^{-1} \cdot K^{-1}$, compressive strength reached the maximum value after 28 days of 7.5 MPa and after 7 days of 5.2 MPa. Flexural strength had much lower values of 3.4 MPa after 28 days and 3.3 MPa after 7 days. The water absorption recorded the minimum value of 1.8 vol. % and the pore size was the highest (between 0.7-1.0 mm) compared to the other variants, but at a satisfactory level. Comparing the obtained results with those reported in the literature, the values of physical, mechanical, thermal, and microstructural characteristics are approximately at the level of those obtained in the world. The work originality is the use of nanomaterial in this process as well as replacing the usual H_2O_2 with NaH_2BO_4.

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