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Industrial Waste and Burning Temperature Effect to Building Ceramics' Properties

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This work contains results of building ceramics properties research. The samples were made using clay, sand and an additive, made during the making of granulated foam glass. Moulding compound's compositions were discovered using triangular diagram according the experiment planning method. Samples, produced from planned forming masses, were burned in three burning temperatures: 1000, 1030 and 1050 °C using different exposure duration in higher temperatures. Upon receiving the samples their physical, mechanical and structural properties were determined, as well with calculation of the prognosis of operational resistance to frost.

KEYWORDS: burning temperature, ceramic, composition, experiments planning, waste.

Introduction

At this moment in the world there are countless researches which in one way or another recommend to utilize waste in building ceramics. The waste put into ceramic forming masses aren't only those that in high temperature sinter with building ceramics but that also burn during the burning process and removes itself from building ceramics, additionally other wastes are used that disintegrate during the burning process and the disintegration products evaporate from building ceramics (Kizinievič *et al.* 2014). In ceramics not only can the technogenic waste be utilized but also waste from leftover energetics industry (Binhussaina *et al.* 2014) or water treatment industry (Kizinievič *et al.* 2013).

Waste formed in granulated foam glass industry still hadn't been used in building ceramics production. With this waste there still hadn't been any research works. This material is obtained during the production, when the cullet glass moistened with binder is not suitable for further production due to unfit size. This material is sift before reaching the furnace and is unfit for secondary use making

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glass pellets, so it is utilized. The matrixes are materials providing grinded glass mixture binding properties, needed to form pellets and to keep their plastic strength. In this case, the used matrix is liquid glass. This waste should be attributed to microdispersion fusible additive group.

With this observational work we sought to determine if it is possible to use a waste formed during the making of foam glass to make ceramic products as well as determine what composition is most appropriate for small porous building ceramics production. Performed experiments determined which burning temperature is most appropriate to make building ceramic and how burning temperature influences building ceramics properties.

Methods and materials

Materials

Materials used in the work are clay, sand and an additive – a waste formed during the making of granulated foam glass (later PGGW). The chemical composition of clay is shown in the first table. Loss of clay during burning is 12 %.The used clay is attributed to light melting hydromicous clay group. It is half acidic and calcareous, since it's contaminated with carbonated insertions, which are ≥ 3,0 %. This clay is attributed to a clay group with big amount of colouring oxygen, since it has 5,29 % iron oxide Fe_2O_3. Clay's plasticity number is 10, while linear drying shrinkage 4.9 %. According to granuliometric composition clay is the type, in which the smallest pieces' mass, whom size is smaller than 0.001 mm, is even 51.7%.

Used quartz sand had 0/1 fraction, in which SiO_2 takes up no less than 95%. The waste formed during granulated foam glass production is an unfit for further technological cycle granulate, its chemical composition is given in the Table 2.

This material is attributed to nonflammable materials, since its resistance to heat reaches 750 °C temperature. Specific surface 2000-15 000 cm^2/g (according to Blain method). The material is light grey color powder.

SiO_2	$Al_2O_3+TiO_2$	Fe_2O_3	CaO+MgO	K_2O	Na_2O	SO_3
47.1	16.5	5.3	14.1	3.6	1.2	0.2

Table 1

Chemical composition of clay, %

SiO_2	Al_2O_3	K_2O+Na_2O	CaO+MgO	Fe_2O_3	Other
71–73	1.5–2	13–14	8–10.5	≤0.3	≤0.5

Table 2

Chemical composition of PGGW, %

The needed amounts of materials to make the mixture are determined by experiment planning method written by researchers (Žurauskienė *et al.* 2009). This planning method was selected to lower the number of experiments, when during the duration of experiment three composite materials' amounts are changed. The mixture formation compositions' are formed using the triangular diagram. The triangular diagram shows in what materials amount zone the executed experiments were chosen (Fig. 1), that area is marked red.

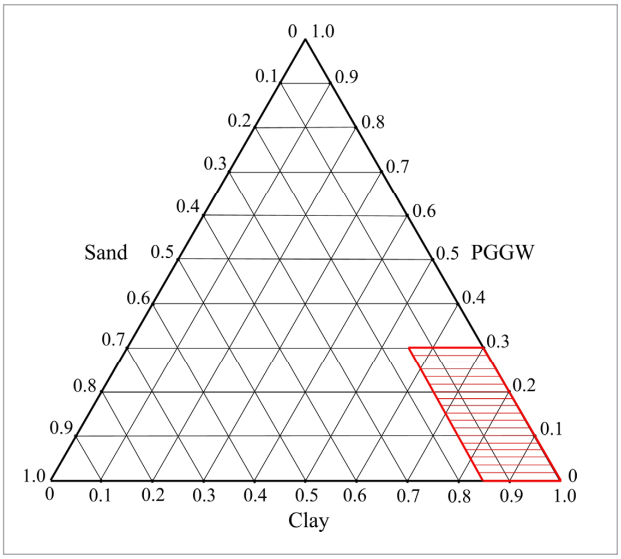
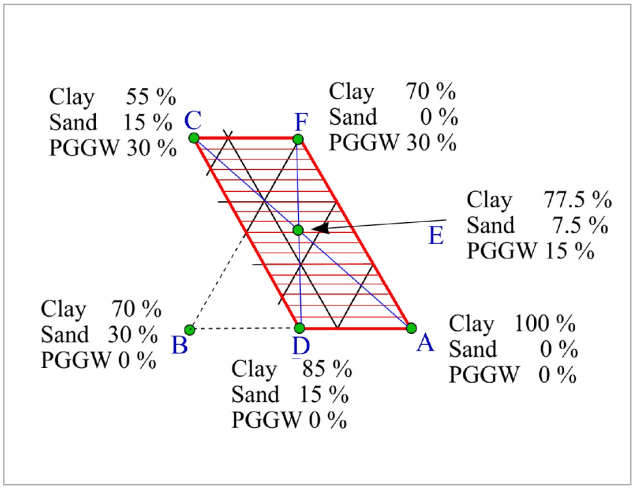


Fig. 1

Triangular compositions selection diagram

Fig. 2
Formation masses composition



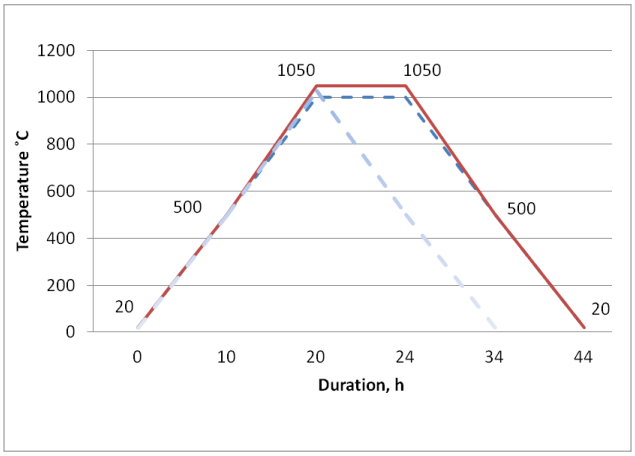
The lowest and highest material levels were selected: clay part in mixture 0.55-1.0, sand part in mixture 0-0.15, PGGW part in mixture 0-0.3.

In the experimented area five points were distinguished according to which formation mixture compositions were determined. Formation mixture compositions are shown in Fig. 2. Sixth formation mixture composition (B) is chosen so experimentally compare properties, when the mixture has maximal amount reducing additive.

Samples' production technology

Raw materials were dried in 100-105 °C temperature. Distributed component mixture at first was mixed dryly, later moistened to right dampness for forming. The moist mass is left for three day in (95±5) % dampness environment, to allow the moister to spread equally. After three days of storage the formed masses were formed into 70×70×70 mm samples.

Fig. 3
Samples' burning parameters



Formed semi-finished products at first were dried in natural conditions for 5 days in a laboratory, afterwards 2 more days dried in an electronic dryer. In it samples were dried in 60±5 °C temperature the first day and 105±5 °C temperature the second day. Samples were burned in 1000 °C, 1030 °C and 1050 °C temperatures, total longest burning duration 44 h, keeping in the highest burning temperature for 4 hours. Each sample's batch's samples were burned changing highest burning temperature and the duration in it. Samples' burning parameters are shown in Fig. 3.

Samples' burning temperatures were selected according to earlier research results. With these researches the limit usable clays' burning temperature was determined. The samples formed only of analysed clay without fractions only hold 1000 °C temperature. This temperature can be held for a longer duration, for example 4 h. With this research it was aimed to determine, what burning temperature would be appropriate to produce high density, small impregnation building ceramics. After the sample burning samples' physical and mechanical properties were determined.

Research methodology

Building ceramics compressive strength determined according to LST EN 772-1:2003, netto dry density determined according to LST EN 772-13:2003, water impregnation according to LST EN 771-1:2011 however samples were soaked not for 24, but 72 hours.

Shrinkage was calculated by this formula:

$$L = \frac{L_0 - L_1}{L_0} \cdot 100, \% \quad (1)$$

where:
L_0 – distance between indentations in formed sample, mm;
L_1 – distance between indentations in burned sample, mm.

Building ceramics effective and total open porous, as well exploited prognosis of resistance to frost determined according to (Mačiulaitis and Malaiškienė, 2009) method.

Burned in 1000 °C, 1030 °C ir 1050° C temperatures forming masses with sand and PGGW additive physical and mechanical properties shown in examples Fig. 4–9.

Results

Linear shrinkage

Samples' linear shrinkage depends on forming masses composition. Putting 30 % PGGW additive into the forming mass achieves the biggest linear shrinkage, which in 1050 °C temperature can reach even 19.3 % (F in Fig. 4.).

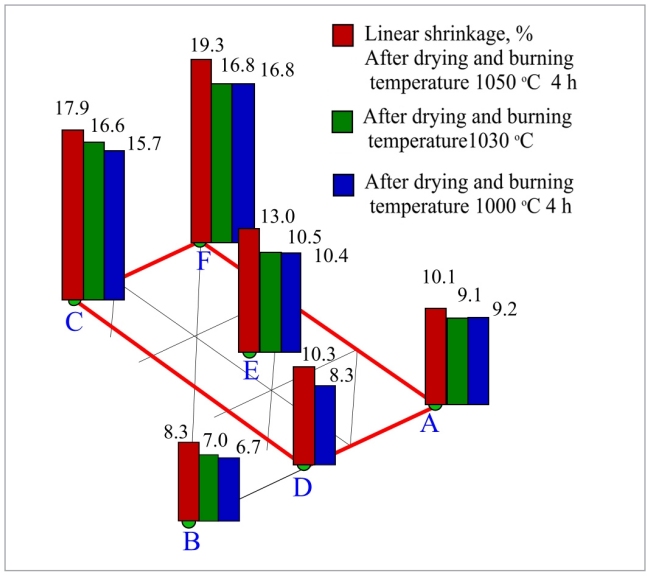


Fig. 4
Linear shrinkage of samples

Samples image after burning in 1050 °C temperature are shown in Fig. 5. From the image, we see, that this temperature is too high for burning samples formed only from clay mixture (samples fracture burning in such temperature).

Samples which forming masses composition has big amount of PGGW evidently shrank but also changed its own colour. Mass marked with the letter C after burning became yellow, marked F – dark brown.

Fig. 5
Samples image after burning in 1050 °C temperature

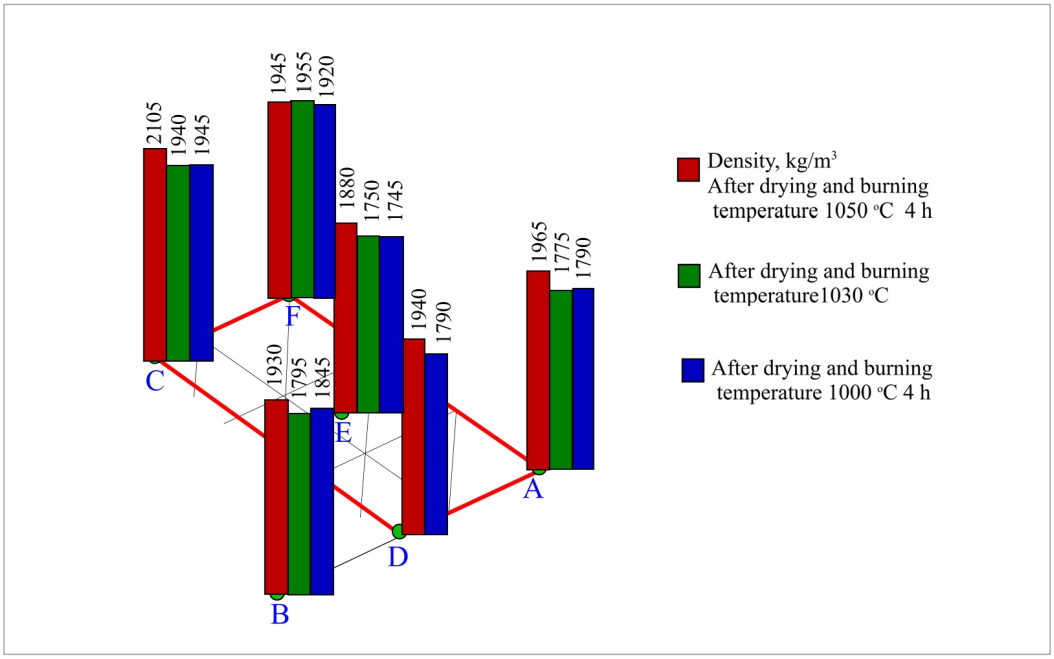
Density

Dry sample density was determined. It's shown in Fig. 6.

Entering into forming mass 30 % waste additive and burning in 1000 °C burning temperature building ceramics density reaches 1920 kg/m^3 (Fig. 6), and controlled (only clay was used for forming mass) building ceramics density – 1790 kg/m^3. 30 % waste additive building ceramics density near 1000 °C burning temperature rises 7 %. By rising the burning temperature to 1030 °C building ceramics (F) density comparing with controlled building ceramics (A) rises 10 % and in 1050 °C lowers 1 %. Highest density results were reached burning samples in 1050 °C temperature, and highest density value was achieved when in the forming mass were added 30 % waste and 15 % sand.

Obtained all group density results showed that microdispercion waste additive can significantly rise building ceramics density. Products made from analyzed ceramics forming masses can be attributed to HD product group according to dry density (LST EN 771–1:2011).

Fig. 6
Density of samples



Water impregnation

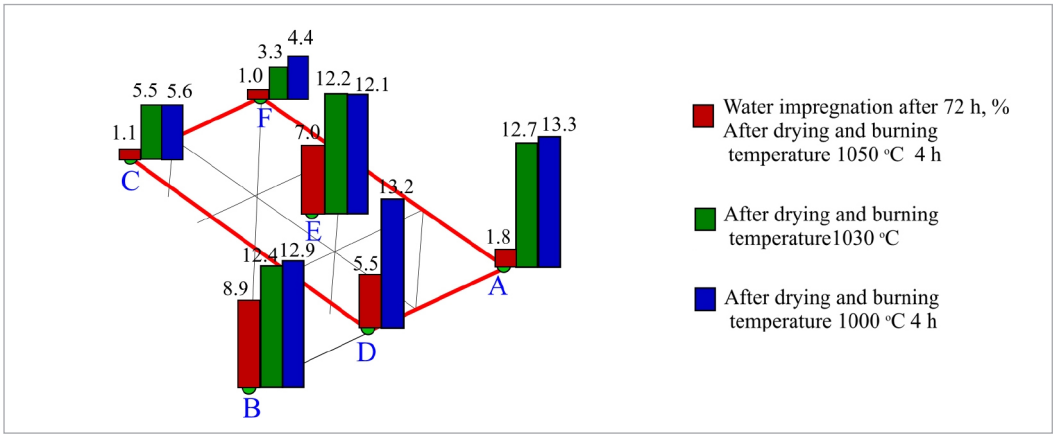
Fig. 7 shows A, B, C, D, E, F group sample impregnation value after 72 h soaking, %. Lowest average water impregnation after 72 h determined for F group samples – 1.0-4.4. %, formed from 70 % clay and 30 % additive. Building ceramics, which had 30 % additive after burning in 1050 °C temperature maintaining in this temperature for 4 h, had the lowest impregnation, which reached only about 1 %. In this temperature building ceramics with maximal additive amount rapidly shrinks, lowering the volume of pores, and fills this volume with emerged liquid phase.

Highest average water impregnation after 72 h determined for A group samples - 13.3 %, burned in 1000 °C temperature with maintaining it in it for 4 h.

Impregnation determined after 72 h of soaking are needed to calculate effective and general samples' porous, as well as exploited prognosis of resistance to frost.

Analysing determined lowest impregnated sample results after 24 h soaking, it is visible that their impregnation during the remaining two days changed only 0.1 % (after 24 h these samples' impregnation reached 0.9 %). Producing small porous construction building ceramics it is important, that these ceramics impregnation would be <6 %.

Fig. 7
Water impregnation of samples



Compressive strength

Ceramics samples' compressive strength averages are shown in Fig. 8.

According to determined compressive strength results we can see that the additive PGGW positively affects building ceramics' strength. Even 15 % of additives amount quite significantly influences compressive strength results. When temperature and maintenance are higher compressive strength may lower due to micro-cracks that formed during 1050 °C temperature with 30 % additive (F). Sand on the other hand reduces compressive strength. Such sands influence can be explained by the fact that its particles with building ceramics don't sinter together. Sand only works as a reduced additive and at the same time reduces building ceramics shrinkage and waters need for mixing plastic ceramic mass.

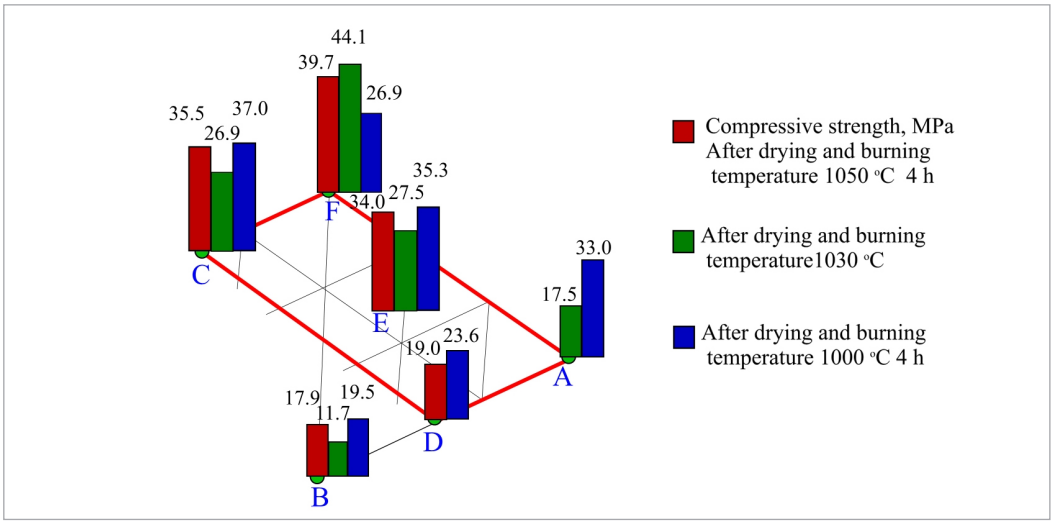


Fig. 8
Compressive strength of samples

Frost resistant

According to determined samples' structural indicators exploited prognosis of resistance to frost was calculated. General tendencies - exploited prognosis of resistance to frost rises significantly

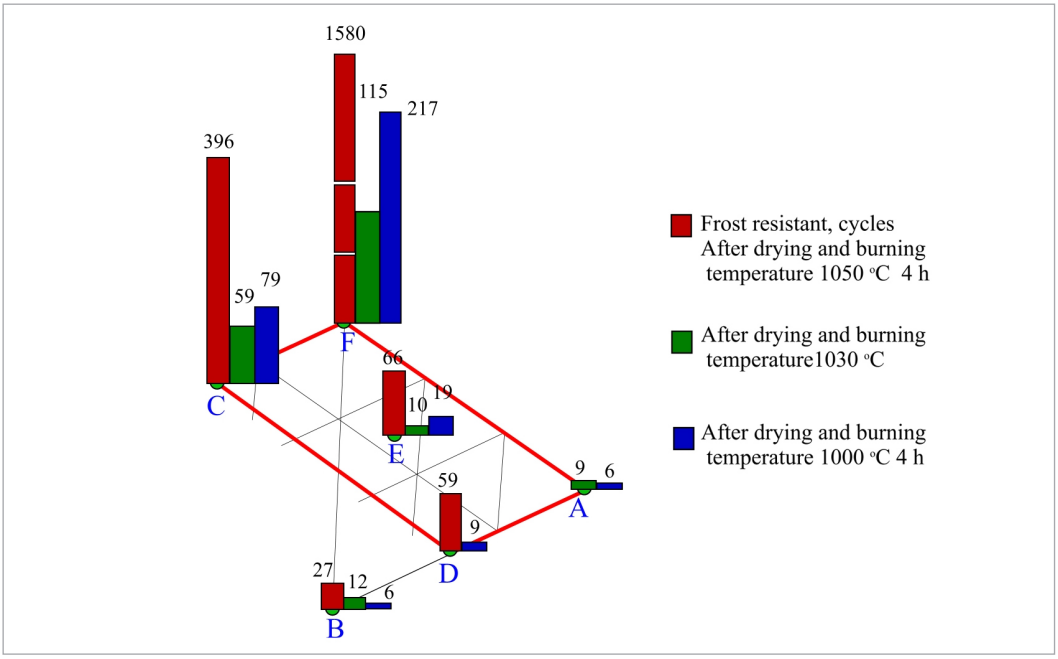


Fig. 9
Frost resistant of samples

after rising the burning temperature to 1050 °C and maintaining the samples in it for 4 h. However not all samples handle such burning temperature, for example, samples produced only from clay disintegrated from such burning temperature.

Samples' exploited prognosis of resistance to frost is shown in Fig. 9.

The start of samples' disintegration goes from 6 to 1580 cycles. Taking into account obtained structural indicators and calculated resistance to frost prognosis values, other technological factors should be noted (forming masses composition, structures inhomogeneity), duration of burning and similar) since they also have influence on products durability prognosis. C and F samples burned in 1050 °C temperature structural purposefulness unevenness indicator is equal 1.

The higher same compositions forming masses burning temperature and the more fusible additive, the lower effective and general open porous values, that's why exploited prognosis of resistance to frost rises. As you can see, exploited prognosis of resistance to frost for group's F samples are significantly better than other group samples'.

Building ceramics exploited resistance to frost really depends on pore and capillary space filling with water degree or left reserve space. All samples produced from mass F have a very big reserve of pore volume (above 50 %) as well as mass C burned in 1050 °C temperature.

Discussion

Wanting to get predetermined property ceramic products it is important to choose not only the forming mass composition, but also technological burning parameters. Changing the burning temperature and the duration in highest temperature it is possible get different property products from the same forming mass. In the examined case it was predetermined to make samples with as high as possible exploited resistance to frost, which would sufficiently mechanically strong and would absorb water as less as possible. Such products can be made from light melting hydromicous clay with waste additive. Burning such forming masses important factors are not only the burning temperature but also the duration in it, since during the making of building ceramics in the highest temperature happens the forming of new materials, forming of structure, and closing of pores. All these procedures determine that after the burning dense sinter building ceramics are obtained. However the structures rising density is related to such phenomenon as significant ceramics shrinkage and because of these reasons precise measurement ceramic products production becomes problematic.

Conclusions

This works results showed that the higher (from 1000 °C to 1050 °C) sample burning temperature, the higher building ceramics with granulated foam glass waste additive density. Highest density value was reached in those samples that were made from 55 % clay, 15 % sand and 30 % waste additive and were burned in 1050 °C temperature with the duration of keeping it at the highest burning temperature for 4 h in the highest temperature – 2105 kg/m^3.

Analysing research data it was determined that in the highest sample burning temperature average water impregnation and open sample porous are the lowest. The highest sample absorption was determined in that sample group in which samples were produced from 100 % clay and burned in 1000 ° C temperature with the duration of keeping it at the highest burning temperature for 4 hours, while smallest average water impregnation is in those samples' groups in which the samples are made from 70 % clay and 30 % waste additive and burned in 1050 °C temperature with maintaining it for 4 hours.

It was determined that samples with 30 % additive amount burned in 1050 °C temperature with maintaining it in the highest temperature for 4 hours, average general porous is 72 % smaller than samples, burned in 1030 °C temperature without maintenance and 76 % than samples burned near 1000 °C temperature with the duration of keeping it at the highest burning temperature for 4 hours. Similar tendencies are typical for sample groups with 55 % clay, 15 % sand and 30 % waste additive amount.

Analysing obtained data it was determined that the higher samples' burning temperature and the longer duration of keeping it at the highest burning temperature, the bigger compressive strength

and density values. Also the samples with biggest waste additive, comparing with controlled samples, have higher compressive strength. It can be said, that the samples strength properties depend on burning temperature and waste additive amount.

The highest prognosis for resistance to frost were determined to be samples with 30 % waste additive amount, which were burned in 1050 °C temperature with the duration of keeping it at the highest burning temperature for 4 hours. It was observed that the samples with 30 % waste additive amount prognosis for resistance to frost raised with raising burning temperature. Other samples' resistance to frost values are very different and depend on technological factors – forming mass's composition, structures inhomogeneity, duration of burning and similar.

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