PORE-FORMING ADDITIVES IN GLASS-CLAY COMPOSITION

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Abstract. The aim of the present research was to evaluate the influence of pore-forming additives on the composition of glass ceramics from glass waste with a gasifier, which allows production of lightweight materials with minimum weight. Gasifiers used in the research were charcoal, anthracite and soot. All samples were made from a composition consisting of glass, clay and a gasifier. Compression, water absorption tests, volume expansion measurements and SEM for the best test sample have been performed for the specimen with different compositions. Overall glass waste was used in an amount from 83.00% to 90.32%, clay from 9.158% to 12.00% and the gasifier from 0.179% to 5.00% of the total amount of the composition with 10.00% of water amount of total composition weight. The range of the temperature used to perform the evaluation was from 800 ºC to 900 ºC. The time span for heating in an oven was in the range of 60 to 120 minutes. The best results received from all samples were with the glass-clay composition with soot as a gasifier. The range of results received for volume weight was from 232.13 $kg \cdot m^{-3}$ to 472.48 $kg \cdot m^{-3}$, compression strength from 0.45 MPa to 0.77 MPa, and volume expansion from 3.04 to 4.18 times. The water absorption results have been received with a high percentage and a conclusion about that amount. A conclusion about the factors influencing the pore-forming using different gasifiers has been made. A conclusion about the crystallisation phase in the production of samples has been made by evaluating SEM results.

Keywords: porous ceramics, glass-clay compositions, pore-forming additive, glass, clay.

Introduction

Waste usage, energy economy during production and low-cost production are very important issues in the nowadays world. Therefore, it was taken into account to use as less cycles of raw material reproduction as possible. The lightweight materials in the construction industry are used widely. The components used in the research can be used to produce a lightweight material for partition walls or as an insulation material for inner applications. Four criteria are used in the research to produce material for one of these applications taking into account the usage of waste glass and energy economy. Overall glass waste compositions can be used in different applications, but in this research only glass-clay compositions are used. There are several pore-forming additives, which can be used in glass-clay compositions, and charcoal, anthracite and soot are among the mineral components meeting the criteria of low-cost products and waste materials (for soot). Organic additives are also being used as additives apart from mineral additives in glass-glay compositions, for example, sawdust. Some researchers added sawdust as a medium to diminish pore sizes [1-4]. Some additives such as boric acid allow to increase the viscosity of the composition and lower the size of the pores when adding an amount to 5% of a benchmark composition (the results of this research are in process of publication in another author's article). In the framework of the research the specimens were fired in oven in the range of temperatures from 800 ºC to 900 ºC at the range of time from 60 to 120 minutes and the results are analysed. There were made compression tests, water absorption tests, expansion measurements and thermal conductivity definition for the best samples.

There are several types of glass-ceramics, which can be produced from waste glass from metallurgical processes- slagceram (glass-ceramics with slag applying the conventional two stage production method and the petrurgic method), silceram (glass-ceramics with slag applying the one stage production method), glass-ceramics using coal fly ash, other slag-type wastes [5].

The aim of the research is to evaluate the influence of pore-forming additives on the composition of glass ceramics from glass waste with a gasifier.

Materials and methods

The compositions of this research have been made according to the previous research [6; 7] and technologies elaborated by other researchers [2; 3; 8-11].

Raw materials used are glass, clay, soot and sawdust. The clay is used from a quarry "Lielauce". In another author's research [7] a comparison was given of two used clays- from the quarry "Lielauce" and "Samiņi". The glass used in this research was window waste glass.

The chemical composition of the clay from the quarry "Lielauce" is SiO_2- 45.67%, Al_2O_3- 12.27%, Fe_2O_3- 5.34%, TiO_2- 0.67%, CaO- 11.60%, CO_2- 11.22%, K_2O + Na_2O- 4.56%, other parts- 8.67%. The chemical composition of window glass is SiO_2- 71.75%, Na_2O- 13.55%, CaO- 9.07%, MgO-4.24%, Al_2O_3- 0.77%, K_2O- 0.29%, SO_3-0.20%, Fe_2O_3- 0.08%, other parts- 0.05%. The chemical composition of the used soot is C (94.84%), H (0.88%), S (0.01%), O (4.25%), and other parts (0.02%). Possible maximums and minimums of the chemical components are discussed in another author's publication [6]. The compositions used in this research are shown in Table 1.

Table 1

Compositions of the research

Composition No	Grounded glass, %	Charcoal, %	Anthracite, %	Soot, %	Sawdust, %	Clay, %
1.1.	83.00	5.00	0.00	0.00	3.00	9.00
1.2.	72.00	5.00	0.00	0.00	3.00	20.00
1.4.	20.00	5.00	0.00	0.00	3.00	72.00
1.5.	15.00	5.00	0.00	0.00	3.00	77.00
1.6.	70.00	15.00	0.00	0.00	6.00	9.00
1.7.	78.00	5.00	0.00	0.00	3.00	14.00
1.8.	87.00	5.00	0.00	0.00	3.00	5.00
2.1.	89.50	0.00	1.34	0.00	0.00	9.16
2.2.	83.00	5.00	0.00	0.00	0.00	12.00
2.3.	89.50	0.00	0.00	0.18	0.00	10.32

The compositions from 1.2. to 1.8. allowed us to understand the possible range of end lightweight products, which can be received using the components.

In the experiment two types of metal forms were used: one fully metal initial form to fill the raw materials (dimensions 50×50×50 mm), a second with holes folded in a foil (to avoid adhesion to metal during the firing process)**.** The raw materials were ground in a planetary ball mill and sieved through a 500 mkm sieve. After sieving the materials were dried in an oven at a temperature 60 ºC for 24 hours. Mixed components were mixed with water component added to the composition. Afterwards, the composition was mixed for two minutes and placed in a form for 24 hours at room temperature, unmoulded, placed in an oven at a temperature 60 ºC for 24 hours and placed in an oven in a form to fire according to one of the schemes mentioned below (see Fig. 1).

Weight and density of the fired samples were measured and evaluated by considering the mass-to-volume ratio. Compression strength and thermal conductivity of the specimens were tested.

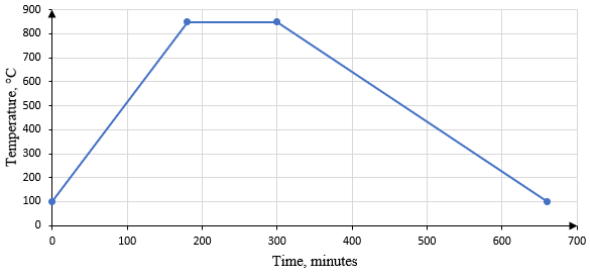

Fig. 1. **Firing scheme with maximum 850 ºC for 120 minutes**

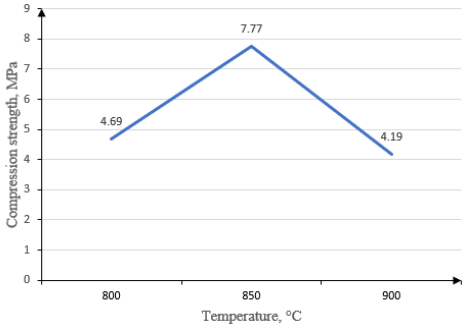

Fig. 2. **Maximum temperature and compression strength for 1.1. composition**

The firing schemes used were with a maximum temperature of 1200 ºC at a maximum duration of 120 minutes by a total maximal duration of 260 minutes in the temperatures from 800 ºC to 1200 ºC.

Analysis of results

Dependence of the compression strength of pores for composition 1.1. on the firing temperature in the range from 800 to 900 ºC can be seen in Fig. 2. The maximum value for compression strength for this composition is reached at the temperature of 850 ºC. Dependence on the density of ceramic from

the amount of clay in the composition is seen in Fig. 3. The lowest density is obtained in the range content of clay from 5% to 20% in the composition. More clay amount makes the end product dense with a range from 624 to 1699 kg·m^{-3}. Fig. 3. and Fig. 4. show the results of the testing for the compositions starting from 1.1. to 1.8. with each composition below the x axis.

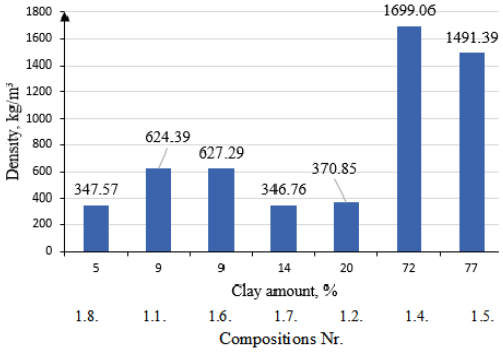

Fig. 3. **Density of composition versus the content of clay**

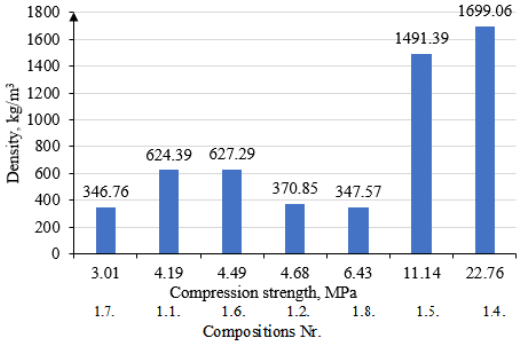

Fig. 4. **Compression strength and density**

The results shown in Fig. 3 and Fig. 4 are obtained for the samples fired for 120 minutes with a maximum temperature of 900 ºC. By analysing the results presented in Fig. 3 and Fig. 4, it may be concluded, the higher the amount of clay in the composition, the higher its density and compression strength. In the series of tests mentioned above the best results from the lightweight construction received were with soot as a pore-additive gasifier. The received samples with sawdust have smaller open pore sizes than those without sawdust and the density of samples is higher: 1.1. composition density is 624 kg·m^{-3} (with sawdust) and 2.2. composition density is 329 kg·m^{-3} (see Fig. 4 and Fig. 5 for reference). In the compositions from 2.1. to 2.3. different pore-forming additives were used - anthracite (for 2.1.), charcoal (for 2.2.), and soot (for 2.3.). The results presented in Fig. 5 were received by firing samples for 120 minutes at a maximum firing temperature of 850 ºC. Although the compression strength received for samples with anthracite is slightly higher, density is much higher than for samples with charcoal and soot (see Fig. 4 and Fig. 5). Dark blue colour in Fig. 5 represents the compression strength results versus density and light blue colour represents water absorption. The smallest increase of the composition volume by sintering is 3.04 times for the sample of composition 2.2. with charcoal as a pore-forming additive, 3.16 times with anthracite, 3.36 times with soot and the best result was 4.18 times for a composition with soot as a pore-forming additive with a density of 232 kg·m^{-3} [6], so the range of results for soot as pore-forming media was from 3.36 to 4.18 times.

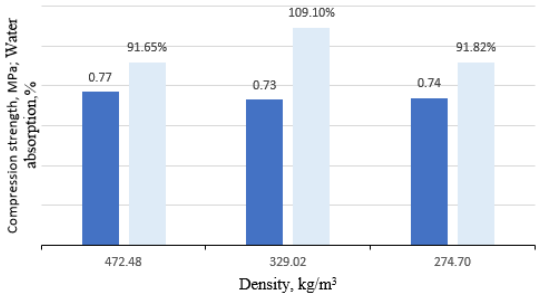

Fig. 5. **Density, water absorption and compression strength of compositions 2.1. 2.2. and 2.3.**

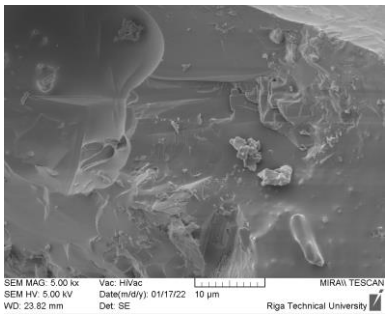

Fig. 6. **SEM image of composition with soot**

Visually it is possible to see that the pore sizes for the composition 2.3. with lowest volume weight are bigger (see for reference Fig. 7 and Fig. 8).

All samples for compositions 2.1., 2.2. and 2.3. show high water absorption values because of the high amount of open and connected pores (see Fig. 8). The SEM image shows the structure of composition with soot without essential aggregation of crystals (Fig. 6). The thermal conductivity for a sample with soot is 0.088 W·(m·K)$^{-1}$.

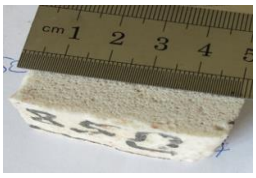

Fig. 7. **Sample for 1.1. composition**

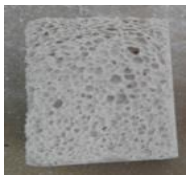

Fig. 8. **Sample for 2.3. composition**

Conclusions

1. The crystallisation phase makes the values of the volume weight higher, water absorption higher and the compression strength lower, because of the essential increase in local viscosity during the pore-forming period the best-estimated gasifier is soot, which makes it the most appropriate substance making less crystallisation effect in the material with best overall results of the volume weight, compression, volume measurement.
2. By comparing pore-forming additives, such as anthracite, charcoal and soot, the best results from the point of view of minimum volume weight are obtained for soot with the ceramic specimen density 274.70 $kg \cdot m^{-3}$ and the compression strength of 0.74 MPa and expansion by firing in 3.36 times vs 472.48 $kg \cdot m^{-3}$ and the compression strength of 0.77 MPa and expansion by firing in 3.16 times with anthracite, 329.02 $kg \cdot m^{-3}$ and the compression strength of 0.73 MPa and expansion by firing in 3.04 times with charcoal.

Author contributions

Previous research analysis, P.T.; Compositions' creation, P.T. and A.K.; data analysis, P.T.; writing – original draft preparation, P.T.; writing – review and editing, P.T. and A.K. All authors have read and agreed to the published version of the manuscript.

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