Porous Ceramics Produced From Glass and Clay

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Abstract

Porous ceramics as sustainable material can become and, in some industries, already are used to achieve environmental applications considering their properties. Research on important composition properties helps to identify the best product to be used in construction industry with a priority of a minimum number of raw materials and simplest and energy-efficient technology during production process. The elaborated research identifies compositions with glass waste, clay, and soot with minimum volume density within the range of chosen product line. Water absorption, thermal conductivity, and compressive strength were researched to identify possible applications of elaborated material in construction industry.

Keywords: porous ceramics, glass, clay, waste materials.

Introduction

Today, improving energy and environmental performance is a key goal, of the construction industry and it is strategically important for achieving sustainability of construction materials. The development of new ecological insulation materials produced from municipal waste, ground glass waste, combustion waste, and raw materials is a topical problem in Latvia.

The effective properties of porous ceramics are depending on the microstructure as the result of fabrication technology. Exploration of the relation between properties of material and microstructure can be used to quantify the influence of microstructure on properties of porous ceramic. One of the basic and important microstructural information is the pore volume fraction (porosity).

A very important property of porous materials is their mechanical strength, which is mainly due to their composition and structure, preparation and treatment of raw materials as well as the technology of production. The second important property of porous materials is thermal conductivity. These two important properties are being evaluated in the research about porous ceramics.

The utilization of waste glass in a porous material for construction industry is an important issue to be researched.

"The versatility of the glass-ceramic production process is manifested by the many wastes that have been used as raw materials for glass-ceramics, which include coal fly ash..., mud from zinc hydrometallurgy ..., slag from steel production ..., ash and slag from waste incinerators ..., red mud from alumina production ..., waste glass from lamp and other glass products ... as well as electric-arc furnace dust and foundry sands .... ". (Rawlings, 2006).

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Following raw materials glass waste, clay and a gasifier have been applied for obtaining porous ceramic, and sintering technology was the subject of this research.

Virtually all ceramic materials are constructed systems consisting of crystalline, glass, and gas phases (Дятлова, 2012) In general, the temperature of the ceramic sintering process is between 800°C and 1200°C.

Fabrication temperature, which is used in the production of foam glass is in the range 790°C and 860°C (Можегов, 2000), and in the range 700°C and 920°C (Rautanen, 2020). The temperature of sintering depends on the gasifier used (Dorokhova, 2017), (Yakub, 2012).

According to previously made researches the basic principle of porous material manufacture on a basis of glass waste using sintering methods of powder is to generate a gas in glass at the temperature between 700°C and 900°C (Дятлова, 2012), (Можегов, 2000), (Rautanen, 2020), (Dorokhova, 2017). The gas expands thus forming a structure of cells and producing a porous body. During the process of fabrication from green body to end product the material expands.

The aim of the research is to elaborate the optimal composition of porous ceramics based on waste glass as raw materials with minimum number kind of raw materials with additives and low sintering temperature.

Materials

Compositions has been made according to previous researches and technologies elaborated by other researchers (Dorokhova, 2017), (Chen, 2021),. (Капустинский, 2010), (Погребенский, 2001), (Апкарьян, 2009), (Дамдинова, 2014), (Rincon, 2018).

Following raw materials have been taken for preparing mixes for manufacturing porous ceramics: waste glass, clay, charcoal, sawdust, soot, and anthracite.

Table 1
Clay chemical composition

Part	Ingredient volume from the total raw material volume, %
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

Table 2
Glass chemical composition

Part	Ingredient volume from the total raw material volume, %
SiO_2	from 69 till 74%
Na_2O	from 10 till 16%
CaO	from 5 till 14%
MgO	from 0 till 6%
Al_2O_3	from 0 till 3%
Other parts	from 0 till 5%

The ability of the clay to expand is very important in the porosity process. Clays with good superficial properties contain illite, montmorillonite, iron oxide, aluminum oxide and calcium compounds, feldspar, dolomite, and quartz. Clays are aluminosilicate materials with high SiO_2 (in our case 45.67%) and low Al_2O_3 (12.27%) content, which participate in the formation of the ceramic partition. The low Al_2O_3 content helps to reduce the softening temperature to 380°C and the resulting inflation temperature to 530°C. The high content of Fe_2O_3 (5.34%) and CaO - 11.6% reduces the crystallization rate and temperature of SiO_2. SiO_2 and Fe_2O_3 affect the viscosity, melt surface tension. The clays from the production plant of Ltd. "Ceplis" have been used as raw material in the mixes.. Chemical composition of the clay is shown in **Table 1**. Chemical composition of used soot is C (94.84%), H (0.88%), S (0.01%), O (4.25%, other parts (0.02%).

Glass waste has been obtained from window glass. The chemical content of this one is shown in **Table 2**.

Methods

Sawdust obtained from the mixed hardwood and conifers was dried in an oven at 60° C for 48 hours before applying. Glass waste was ground to a powder substance to a powder substance in planetary ball mill Retsch PM400. Glass was sieved through a 500 mkm sieve.

Based on the former researches three mixtures have been designed for investigation of the influence of different kinds of raw materials on the properties of porous ceramic. Mixtures content by weight is shown in Table 3.

Table 3
Research compositions

Experiment Nr.	Molten glass, %	Burning temperature, °C	Time of burning, minutes	Soot, %	Clay, %	Water, %
	X1	X2	X3			
	1	2	3	4	5	6
2.3.1. experiment	89.500	850	60	0.179	10.321	10.000
2.3.2. experiment	89.500	850	120	0.179	10.321	10.000
2.3.3. experiment	89.500	850	180	0.179	10.321	10.000
2.3.4. experiment	89.500	800	60	0.179	10.321	10.000
2.3.5. experiment	90.320	800	120	0.200	9.480	10.000
2.3.6. experiment	90.320	800	180	0.200	9.480	10.000
2.3.7. experiment	89.500	900	60	0.179	10.321	10.000
2.3.8. experiment	90.320	900	120	0.200	9.480	10.000
2.3.9. experiment	89.500	900	180	0.179	10.321	10.000
2.3.10. experiment	90.000	800	180	0.179	9.821	10.000
2.3.11. experiment	90.000	800	60	0.179	9.821	10.000
2.3.12. experiment	90.000	800	120	0.179	9.821	10.000
2.3.13. experiment	90.000	850	180	0.179	9.821	10.000
2.3.14. experiment	90.000	850	60	0.179	9.821	10.000
2.3.15. experiment	90.000	850	120	0.179	9.821	10.000
2.3.16. experiment	90.000	900	180	0.179	9.821	10.000
2.3.17. experiment	90.000	900	60	0.179	9.821	10.000
2.3.18. experiment	90.000	900	120	0.179	9.821	10.000
2.3.19. experiment	89.000	800	180	0.179	10.821	10.000
2.3.20. experiment	89.000	800	60	0.179	10.821	10.000
2.3.21. experiment	89.000	800	120	0.179	10.821	10.000
2.3.22. experiment	89.000	850	180	0.179	10.821	10.000
2.3.23. experiment	89.000	850	60	0.179	10.821	10.000
2.3.24. experiment	89.000	850	120	0.179	10.821	10.000
2.3.25. experiment	89.000	900	180	0.179	10.821	10.000
2.3.26. experiment	89.000	900	60	0.179	10.821	10.000
2.3.27. experiment	89.000	900	120	0.179	10.821	10.000

Three factor experiment was performed taking into estimation three parameters: X1- ground glass % in the whole composition, X2- burning temperature °C; X3 – time of burning in minutes.

After weighing the raw materials were mixed by Food mixer 1340 in dry conditions for 10 minutes. Water was added continuously mixing during additional 10 minutes. The mix was molded in cube forms 50 * 50 * 50 mm and plate forms 300 * 300 * 30 mm , preparing samples for conductivity tests.

Molded compositions were left curing for 24 hours at room temperature. Dried samples were fired in an oven for sintering. The operating temperature of each gasifier must be 50-70°C higher than the initial temperature of the melting glass powder. The softening temperature and the rate of increase of the partial pressure must be low. There were elaborated nine burning schemes (see Fig. 1...Fig. 9)

Fig. 1

Burning scheme with maximum temperature 800°C during 60 minutes

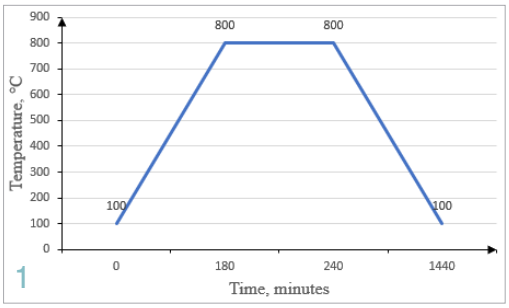


Fig. 2

Burning scheme with maximum temperature 800°C during 120 minutes

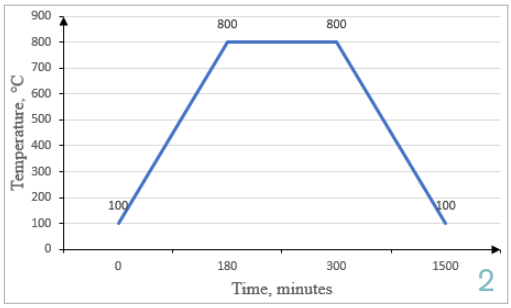


Fig. 3

Burning scheme with maximum temperature 800°C during 180 minutes

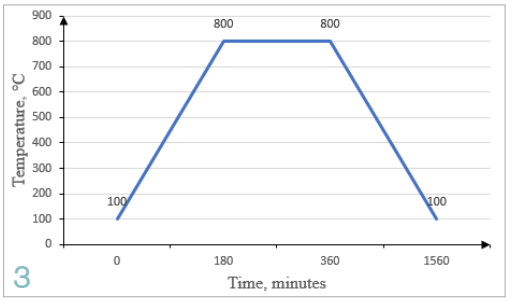


Fig. 4

Burning scheme with maximum temperature 850°C during 60 minutes

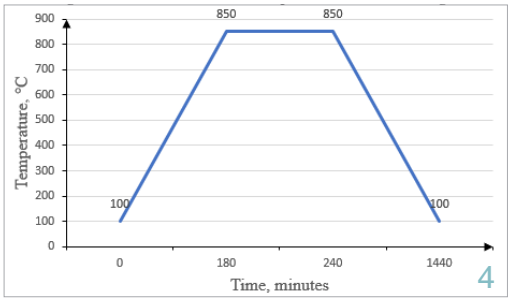


Fig. 5

Burning scheme with maximum temperature 800°C during 120 minutes

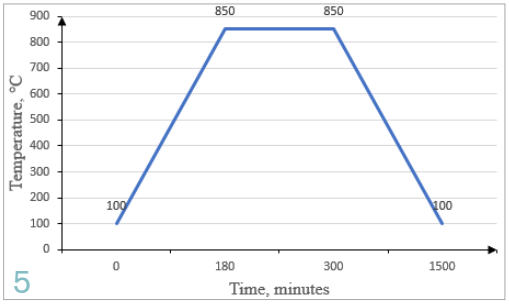


Fig. 6

Burning scheme with maximum temperature 850°C during 180 minutes

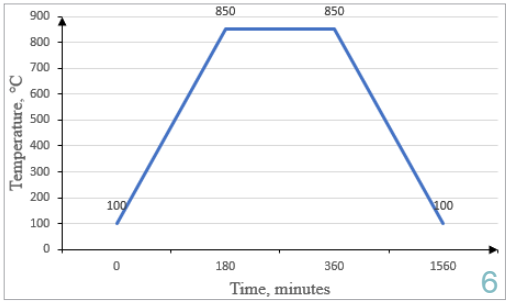


Fig. 7

Burning scheme with maximum temperature 900°C during 60 minutes

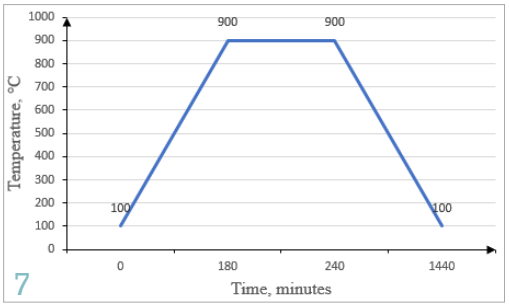
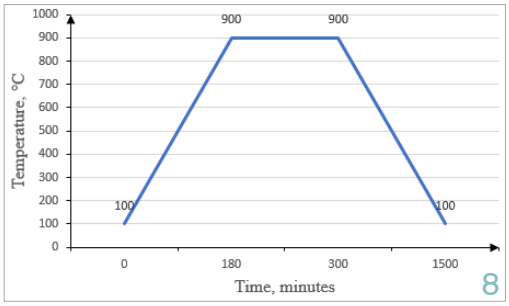


Fig. 8

Burning scheme with maximum temperature 900°C during 120 minutes



After burning finishing and forms cooling, the samples were demolded and prepared for testing. The compression strength tests and thermal conductivity tests have been performed by universal testing system Zwick 100 and FOX600. Density and water absorption have been measured in the framework of research. The porosity of the samples has been evaluated by Microscope Veho DX-3.

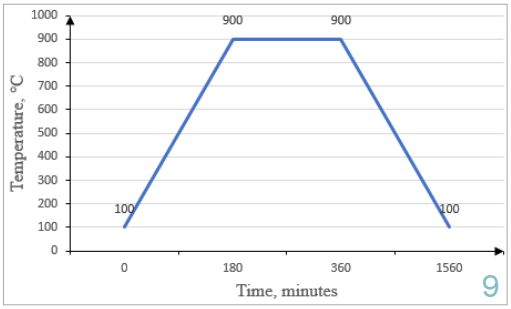


Fig. 9

Burning scheme with maximum temperature 900°C during 180 minutes

Fig. 10

Metal form

Fig. 11

Burning form made from metal

Two kinds of forms were used for burning the samples: metal for 50*50*50 mm samples (**Fig.10-11**) and metal for 300*300*30 mm samples.

Foil for 50*50*50 mm samples was used to let samples be taken out. Forms contain holes to evenly heat the samples. Some of the samples after burning can be seen in **Fig. 12-14**.

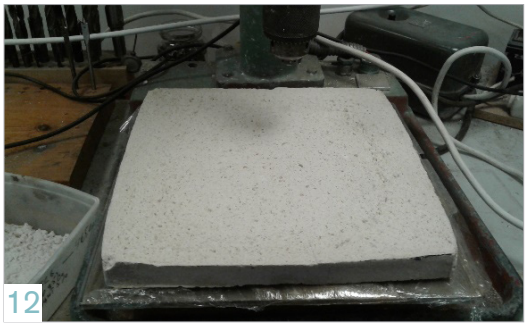
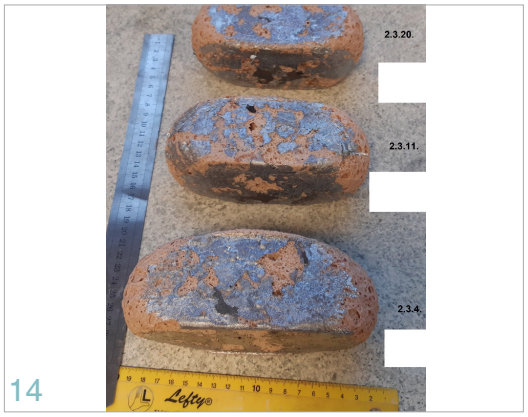


Fig. 12

Burning temperature 850°C 120 min

Fig. 13

Burning temperature 850°C 120 min



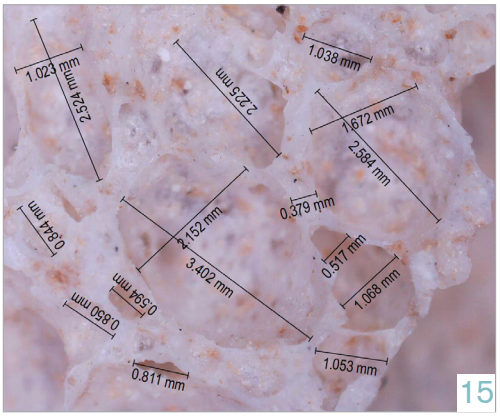


Fig. 14

Burning temperature 850°C 60 min

Fig. 15

Sample under microscope (850°C 120 min.) (sample from the plate form)

Results of water absorption tests of porous ceramic samples are shown in Table 4.

Table 4
Water absorption test results

Experiment sample Nr.	Weight after sintering, g	Volume density, kg/m³	Weight after 6 days, g	Water absorption, %
3-1	46.00	494.19	77.80	69.13%
3-1-1	31.10	259.60	89.60	188.10%
3-2	32.40	345.97	62.50	92.90%
3-2-1	46.90	358.20	85.80	82.94%
3-3	40.20	378.75	68.80	71.14%
3-3-1	33.30	376.70	59.50	78.68%
3-4	47.60	364.94	77.20	62.18%
3-4-1	37.00	341.44	70.10	89.46%

Results

The increase of samples volume and volume density of the ceramic samples were measured. Prepared samples were tested for compressive strength. The results of the experiment are shown in Table 5.

Table 5
Experiment results

Experiment Nr.	Volume increase after sintering, times	Compressive strength, MPa	Volume density, kg/m³
2.3.1. experiment	4.69	1.06	306.00
2.3.2. experiment	4.18	0.45	232.13
2.3.3. experiment	4.68	1.19	329.53
2.3.4. experiment	5.04	0.69	299.70
2.3.5. experiment	4.66	1.31	318.86
2.3.6. experiment	4.26	1.38	296.47
2.3.7. experiment	4.73	0.81	317.94
2.3.8. experiment	4.37	0.70	291.70
2.3.9. experiment	4.32	0.80	271.67
2.3.10. experiment	4.68	1.40	326.59
2.3.11. experiment	4.54	1.25	311.64
2.3.12. experiment	5.05	1.31	295.37
2.3.13. experiment	4.17	0.81	274.37
2.3.14. experiment	4.91	0.84	271.36
2.3.15. experiment	4.42	1.19	264.64
2.3.16. experiment	4.31	1.31	322.08
2.3.17. experiment	5.18	0.74	328.04
2.3.18. experiment	4.84	0.51	285.39
2.3.19. experiment	N/A	1.35	291.85

Experiment Nr.	Volume increase after sintering, times	Compressive strength, MPa	Volume density, kg/m³
2.3.20. experiment	5.13	1.20	310.13
2.3.21. experiment	3.99	1.22	320.78
2.3.22. experiment	4.45	0.73	285.24
2.3.23. experiment	4.06	1.41	310.62
2.3.24. experiment	4.26	0.72	255.24
2.3.25. experiment	4.09	0.90	310.17
2.3.26. experiment	4.90	1.11	326.71
2.3.27. experiment	3.68	1.31	329.64

Volume density of the obtained samples is in the range from 232.13 to 329.64 kg/m³ (**Table 5**) with minimal value for experiment Nr. 2.3.2. Volume density of the obtained ceramic depends on content of the raw materials– more volume of clay increases the density in the final product. The density depends on the sintering temperature as well.

The compressive strength of the obtained samples is in the range from 0.45 MPa to 1.41 MPa depending on the burning temperature and composition (**see Table 5**).

The obtained thermal conductivity for samples from experiment Nr. 2.3.2. is 0.088 W/(m K) with a sample thickness 51 mm.

Volume of expanded samples increase from 3,68 till 5,18 times from the initial volume.

Measured water absorption of the porous ceramic samples is in the range from 62.18% till 188,10%, which may be evaluated as high. Sizes of the pores are in the range 0.12 -3.40 mm (**see Fig. 15**). By analysis of obtained experimental results of elaborated compositions by software Statistica the optimal parameters of porous ceramics, such as volume density of 249 kg/m³ can be achieved by temperature 852°C with a sintering period of maximum temperature 124 minutes.

Discussion

During previous researches according to made experiments, it was found that the range of the melting temperatures is from 850°C to 1200°C depending on the composition of the raw materials. After the specified temperature limit, the solid phase increases, and the gas phase in the material decreases, as a result of which the sample becomes dense and ineffective as insulation porous ceramic material.

The process of forming the ceramic structure is created in the following stages of coagulation-> sintering -> pore formation. The coagulation structure is formed by the action of intermolecular forces between the clay particles at the interlayers of the liquid medium, forcing the filler from the substance onto the surface layer during granulation. During drying, a condensation structure forms after the removal of the liquid phase. As a result of heating, the amorphous structure is formed by burning the glass-ceramics with intermediate pores forming a solid uniform system.

In the general case, as the volume density increases, the compressive strength also increases. The density and size of the pores depend on the sintering temperature and the amount of the gasifier. As the sintering temperature increases, the volume density decreases, the number of pores increases, and the mechanical strength decrease. The strength of a ceramic product is affected by various modified additives that are used to form the structure of the ceramic product.

The duration of foaming also affects the pore structure and accordingly also to the compressive strength. At the longer foaming time, the gas pressure in the pores increases, in result the pore's size increases and makes the pore partitions more fragile, which leads to a decrease in compressive strength.

Achieved thermal conductivity of 0.088 W/(m K), which is similar to the performance of porous construction products in this group of construction materials.

Water absorption depends on the shape of the pores, the amount of opened pores and sizes of the pores. The shape and size of the pores depend on the composition, amount of gasifier, temperature, and time of burning. To achieve the lowest water absorption results, it is necessary to elaborate compositions with a larger number of closed pores.

Conclusions

It was obtained experimentally that the sintering temperature of a porous ceramic material can be reduced to 800-850°C by creating a ceramic composition with a glass content of 89% -90% and using soot as a gas generating agent in amount 0.179-0.200%.

By analysing water absorption results (from 62.33% to 188.10%) it can be concluded that all the tested samples have a large number of open pores, therefore the water absorption is high.

The obtained thermal conductivity result is 0.088 W/(m K) for composition 850°C during 120 minutes indicates that the obtained tested samples are close to diatomite thermal insulation materials (0.115 - 0.162 W/(m K)).

The obtained increase in volume during the sintering process in comparison to the initial volume is from 3 to 5 times, which corresponds to other researches (Rautanen, 2020).

References

Chen Y., Wang N., Ola O., Xia Y., Zhu Y. Porous ceramics: Light in weight but heavy in energy and environment technologies. Mater. Sci. Eng. R Reports, vol. 143, p. 65, Jan. 2021, https://doi.org/10.1016/j.mser.2020.100589

Dorokhova E. S., Zhernovaya N. F., Bessmertnyi V. S., Zhernovoi F. E., Tarasova E. E. Control of the Structure of Porous Glass-Ceramic Material. Glas. Ceram., vol. 74, no. 3, pp. 95-98, 2017, https://doi.org/10.1007/s10717-017-9936-x

Luckham P. F., Rossi S. Colloidal and rheological properties of bentonite suspensions. Adv. Colloid Interface Sci., vol. 82, no. 1, pp. 43-92, 1999, https://doi.org/10.1016/S0001-8686(99)00005-6

Monich P. R., Romero A. R., Höllen D., Bernardo E. Porous glass-ceramics from alkali activation and sinter-crystallization of mixtures of waste glass and residues from plasma processing of municipal solid waste. J. Clean. Prod., vol. 188, pp. 871-878, Jul. 2018, https://doi.org/10.1016/j.jclepro.2018.03.167

Rautanen J., Jääskeläinen T. Process for producing foam glass. EP 3 656 747 A1, 2020.

Rawlings R. D., Wu J. P., Boccaccini A. R. Glass-ceramics: their production from wastes. A review. Springer Science and Business Media LLC, 2006; [Online]. Available: https://core.ac.uk/download/pdf/294576.pdf.

Rincón A., Desideri D., Bernardo E. Functional glass-ceramic foams from ‚inorganic gel casting' and sintering of glass/slag mixtures. J. Clean. Prod., vol. 187, pp. 250-256, 2018, https://doi.org/10.1016/j.jclepro.2018.03.065

Yakub I., Du J., Soboyejo W. O. Mechanical properties, modeling and design of porous clay ceramics. Mater. Sci. Eng., vol. A 558, pp. 21-29, 2012. https://doi.org/10.1016/j.msea.2012.07.038

Апкарьян А.С., Абакумов Е. П., Христюков В. Г. Способ изготовления пеностеклокерамики [Method of making foam glass ceramics]. РФ 2374191, 2009.

Дамдинова Д. Р., Анчилоев Н. Н., Павлов В. Е. Пеностекла системы стеклобой - глина - гидроксид натрия:составы, структура и свойства. Строительные материалы, no. 8, 2014, Accessed: May 05, 2021. [Online]. Available: https://cyberleninka.ru/article/n/penostekla-sistemy-stekloboy-glina-gidroksid-natriya-sostavy-struktura-i-svoystva.

Дятлова Е. М. Химическая технология керамики и огнеупоров [Chemical technology of ceramics and refractories]. 2012.

Капустинский Н. Н., Кетов П. А,. Кетов Ю. А. Способ получения пеностеклянных изделий [Method of obtaining foam glass products]. RU 2453510, 2010.

Можегов В. С., Ли Чи-Тай, Суворов С.А., Шевчик А.П., Способ получения пеностекла [Method of obtaining foam glass]. RU2187473C2, 2000.

Погребенский Г. М., Искоренко Г.И., Канев В.П. Способ изготовления гранулированного пеностекла из стеклобоя [Method of manufacturing granulated foam glass from cullet]. РФ 2162825, 2001.

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