NONCONVENTIONAL HEATING METHOD USED TO OBTAIN GLASS FOAM FROM CLEAR FLAT GLASS WASTE

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ABSTRACT: Results of the research conducted by the Romanian company Daily Sourcing & Research Bucharest to obtain glass foams from clear flat glass waste with good macrostructural homogeneity are presented in the paper. The favourable influence of the microwave heating was proved experimentally on a 0.8 kW-microwave oven. The most significant achievement was obtaining good macrostructural homogeneity, which is difficult to obtain under conditions of conventional heating methods. The pores of the samples are uniformly distributed and their size varies between 0.6 - 2 mm (foaming with calcium carbonate) and 0.9 - 3 mm (foaming with silicon carbide).
KEYWORDS: flat glass waste, glass foam, microwave, contaminant, macrostructural homogeneity.

1. INTRODUCTION

In the last decades, materials recycling and especially of those hazardous to health and the environment, is one of the world's main concerns. The glass waste constitutes an important resource through the size of available quantity and the annual growth rate, especially in the developed countries, but also in other countries of the world. If initially the glass waste was industrially used in the manufacturing process of the new glass, currently, thermal processing technologies of this waste were developed to obtain glass foams, porous materials with physical, mechanical and morphological characteristics suitable for their use mainly as insulating materials in constructions. The most common glass waste used in this processes is the consumed packaging bottle due to the very low contaminants content in its chemical composition [1, 2]. Numerous researchers' concerns in the world are known from the literature aiming processing different glass types with special features, which affect the manufacturing process of glass foam (cathode ray tube glass, borosilicate glass etc.) [2, 3] or to obtain porous products with characteristics which allow their use in different specific fields (high-strength exterior panels, infrastructures foundation, sports grounds, drainage, road construction, lightweight aggregate etc.) [2, 4]. It must be mentioned that all processing technologies of glass waste are based on conventional heating methods (fuel combustion or electric resistances).

In the last two years, the Romanian company Daily Sourcing & Research Bucharest tested experimentally the glass foam production using the microwave energy [5, 6], as a nonconventional heating source. This is a fast, clean and economical energy source, currently used in too few fields of activity, the best known being the domestic sector [7]. The products experimentally obtained by the Romanian company, using different glass waste types and mineral additives for foaming have physical, mechanical and morphological features similar to those produced by conventional methods. It has not yet achieved a technological installation operating in continuous regime having a significant production capacity, to highlight the economic advantages of this modern technique. The latest research of the company Daily Sourcing & Research aimed the particularities of the manufacturing process of glass foam in microwave fields using clear flat glass waste as raw material [8]. Due to the presence in its chemical composition of some contaminants (mainly, Fe_2O_3), the sintering and foaming temperature of the powder mixture of raw material and foaming agent trends to increase significantly, having as effect, under the conditions of processing by conventional methods, obtaining a macrostructural inhomogeneity of the material. From this reason, the flat glass waste is preferentially used as raw material, by re-melting, in the industrial manufacturing process of the new flat glass [9]. However, concerns of research in this domain exist and are presented in literature. The heating methods are also conventional. The most known achievement is the obtaining a new insulating material with drainage features, using uncontaminated flat glass waste together other domestic glass waste. The product has low apparent density, high mechanical strength, being highly water-absorbing and flame-retardant, the technology being applied in Switzerland, Germany and other European countries [10]. Another bibliographic source [11] refers to experiments in this area, the flat glass waste being used in association with other silicate wastes (consumed packaging bottle, cathode ray tube glass, computer monitor glass, fritted glass, glazes, steel slag etc.), foaming agents (2% silicon carbide), colouring oxides and other additives. The product has high mechanical strength and is used as lightweight aggregate.

2. METHODS AND MATERIALS

2.1 Methods

Results of the previous experiments on producing glass foam in microwave field led to the conclusion that the direct heating of the powder mixture containing glass waste and foaming agent is totally contraindicated. The very high heating speed (over 45 ºC/ min) generated by microwave irradiation and initiated in the core of the sample, causes very large inner voids, even if the shell of the sample is not affected. The adopted solution was the use of a cylindrical tube Ø 125 mm (Fig. 1b) made by a microwave susceptible ceramic material (silicon carbide), inside of which being loaded the pressed powder mixture, placed on a metal plate. The tube has the height of 100 mm and the wall thickness of 3.5 mm, experimentally determined for an optimal heat transfer. Thus, it is estimated that two hot poles emitting thermal radiation are generated. One is developed in the core of material due to the direct heating and the second is the inner surface of the ceramic enclosure, which absorbed the heat and transfers it inward by thermal radiation (indirect heating). To avoid the heat loss towards the outside of the tube (in the unprotected microwave oven), a suitable thermal protection with ceramic fibber mats (Fig. 1c) were ensured. The protected tube containing the pressed mixture is introduced into the adapted 0.8 kW-microwave oven (Fig. 1a). The rotating mechanism of the oven was dismantled, the position of the loading during the heating process being static. The heating process in the microwave oven was monitored with a Pyrovar type pyrometer (measuring field: 700 – 2000 ºC) mounted above the oven in front of a viewing hole provided in the upper area of the heating microwave equipment.

a b c

Figure 1. The microwave experimental equipment

a – adapted 0.8 kW domestic microwave oven; b – the silicon carbide cylindrical enclosure; c – thermal protection with ceramic fiber.

The glass foam samples, resulted after the sintering and foaming experimental process, were tested in laboratory to determine the physical, mechanical and morphological characteristics. Apparent density, porosity, thermal conductivity, compressive strength, hydrolytic stability and water absorption were determined by the current methods.

2.2 Materials

The experimentation of producing glass foam from clear flat glass waste was carried out using both foaming by thermal decomposition (with calcium carbonate as foaming agent), and foaming by oxidation (with silicon carbide as foaming agent and coal ash). The two foaming types were tested previously at the microwave heating in the same technological conditions described above, but using consumed packaging bottle waste as raw material, in all cases being obtained a very good macrostructural homogeneity of the foamed products.

The clear flat glass waste was selected, cleaned, broken, finely ground in a ball mill and sieved between 63 – 130 µm. The coal ash, brought from Paroseni thermal power station at grain size between 63 – 80 µm, was ground in the ball mill and sieved below 63 µm. Calcium carbonate as foaming agent was used without other mechanical processing such as it was purchased from the market, having a very fine granulation below 40 µm. The chemical compositions of clear flat glass waste [8] and coal ash [12] are shown in Table 1.

Table 1. The chemical composition of flat glass waste and coal ash, wt.%

Component	Flat glass waste	Coal ash
SiO_2	71.5	46.5
CaO	7.9	7.9
MgO	3.6	3.2
$Na_2O + K_2O$	15.6	10.1
Al_2O_3	1.2	23.7
Fe_2O_3	0.2	8.6

3. RESULTS AND DISCUSSION

3.1 Results

The distribution of the components of wet mixture is presented in Table 2. The first three variants correspond to the tests with calcium carbonate as foaming agent and the last variants correspond to the tests with coal ash and silicon carbide.

Table 2. Distribution of wet mixture, wt.%

Var.	Flat glass waste	$CaCO_3$	Coal ash	SiC	Water addition
1	98.6	1.4	-	-	8.0
2	98.6	1.4	-	-	6.5
3	98.8	1.2	-	-	8.0
4	87,9	-	8.5	3.6	9.5
5	85.9	-	10.5	3.6	9.0
6	86.0	-	10.5	3.5	9.0

The main functional parameters of the sintering and foaming process of the wet powder mixtures containing clear flat glass waste and calcium carbonate, respectively coal ash and silicon carbide in the six variants mentioned above, carried out in the microwave oven, are shown in Table 3.

Table 3. Parameters of the sintering/ foaming process

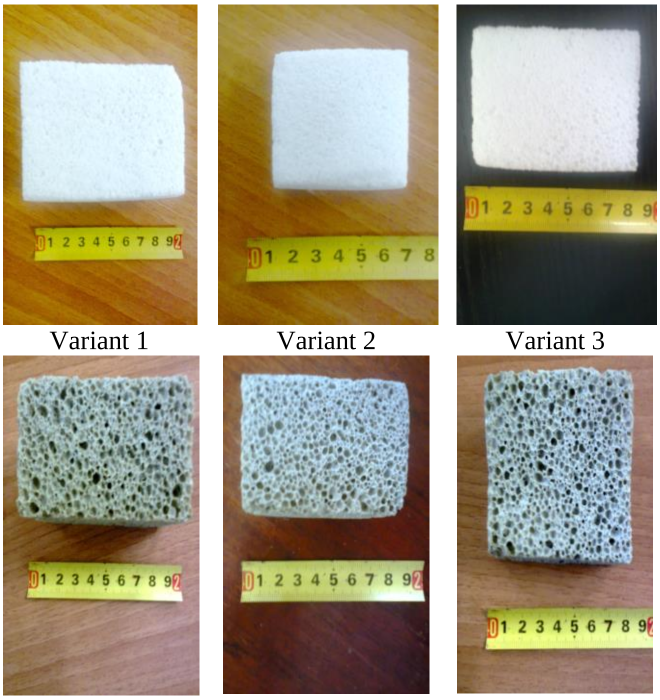
Parameter	Var. 1	Var. 2	Var. 3	Var. 4	Var. 5	Var. 6
Sintering/ foaming tempera-ture ºC	820	831	833	980	990	995
Average speed (ºC/min) · heating · cooling	16.0 8.3	14.4 8.9	14.5 8.1	12.0 6.8	11.6 6.8	11.2 5.0
Process duration (min)	50	56.5	56	80	85	89
Index of volume growth	2.70	2.00	2.20	2.50	2.75	2.50
Specific consumption of electricity (kWh/kg)	1.57	2.08	1.63	2.55	2.76	2.80

The physical, mechanical and morphological features of the six experimental samples are shown in Table 4.

Table 4. Physical, mechanical and morphological features of the samples

Var.	Appa-rent densi-ty g/cm^3	Porosity %	Com-pressive strength MPa	Thermal conduc-tivity W/m·K	Water ab-sorp-tion %	Pore size mm
1	0.32	85.5	1.2	0.040	2.8	0.7-2.0
2	0.39	82.3	1.3	0.055	2.4	0.7-1.4
3	0.38	82.7	1.3	0.053	2.2	0.6-1.3
4	0.32	85.4	2.1	0.042	2.6	0.9-3.0
5	0.42	80.9	1.8	0.060	2.9	1.0-2.0
6	0.36	83.6	1.4	0.048	3.6	1.0-2.5

Images of the longitudinal section through the samples are shown in Fig. 2.



Variant 1 Variant 2 Variant 3

Variant 4 Variant 5 Variant 6

Figure 2. Images of the longitudinal section through the samples

The tests for determining the hydrolytic stability of samples, using 0.15 ml of 0.01M HCl solution to neutralize the extracted Na_2O, showed that the stability joins in the hydrolytic class 2, the extracted Na_2O equivalent being in the range 36 - 54 μg.

3.2 Discussion

The results of the six experimental variants should be seen separately on the two test groups characterized by different foaming modes (by the decomposition of calcium carbonate and respectively by oxidation of silicon carbide). The manufacturing process of glass foam involves correlating between the softening temperature of raw material and that of decomposition or oxidation reaction of the foaming agent, so that the released gases (in the both cases , carbon dioxide and/ or carbon monoxide) to remain blocked in the viscous mass of the material. According to Table 3, the temperature of the sintering/ foaming process is between 820 - 833 ºC in the first case (variants 1 - 3) and in the range 980 - 995 ºC in the second case (variant 4 - 6), the differences being explained by the presence of Fe_2O_3 brought by the coal ash, which is a major chemical contaminant. Compared to the manufacturing processes in microwave field of glass foams from consumed packaging bottle, in the same technological conditions, the temperature values do not differ significantly, although the durations of the process (50 - 56 min in the first case and 80 - 89 min in the second) are, generally, 35 - 40% longer than the processing of the packaging bottle waste. The index of volume growth by foaming the material is same as in the reference situation, i.e. 2 - 2.75. The specific consumption of electricity, experimentally determined, is high (1.53 - 2.08 kWh/ kg for variants 1 - 3 and 2.55 - 2.80 kWh/ kg for variants 4 - 6), but the own experimental determinations on the heat losses outside and those through thermal accumulation at the end of the process represent over 70%. The industrial furnaces operating with conventional heating systems, but in continuous operation regime, have energy consumptions much below 1 kWh/ kg [13]. Considering the working conditions significantly different, a comparison between the values of specific consumption of energy is not appropriate at this time. Compared to the glass foams obtained from packaging bottle waste, the ones manufactured with flat glass waste have apparent densities higher, both at the use of calcium carbonate (0.32 - 0.39 g/ cm^3, compared to 0.20 - 0.30 g/ cm^3) and at the use of silicon carbide (0.32 - 0.42 g/ cm^3, compared to 0.25 - 0.35 g/ cm^3). Also, the values of thermal conductivity (0.040 - 0.060 W/ m·K) are slightly higher compared to the reference samples. The compressive strength of the samples corresponding to variants 1 - 3 (1.2 - 1.3 MPa) do not differ from the reference situation, but those obtained with silicon carbide (1.4 - 2.1 MPa) are higher with 15 - 20%. According to the data from Table 4, the glass foams obtained from flat glass waste are much more water-absorbent (2.2 - 3.6%) compared to the values, generally, below 1% of samples obtained from packaging bottle waste.

The most important conclusion is that of macrostructure homogeneity of the glass foam products. The pore size is between 0.6 - 2 mm at the samples foamed with calcium carbonate and between 0.9 - 3 mm at the samples foamed with silicon carbide. The macrostructural homogeneity obtained at the manufacturing glass foams from packaging bottle waste is achieved also in the case of using flat glass waste (see Fig. 2) and this result is due to the favorable influence of the nonconventional heating method. In addition, it should be mentioned that the experimental heating method with an only microwave generator, maintaining the static position of the material throughout the process as well as the relatively large amount of loaded material (over 450 g) compared to the dimensions of the microwave oven do not constitute an advantage for achieving uniformity of heating. The macrostructural homogeneity of the glass foam samples, as effect of an uniform heating and with a speed corresponding to the process (between 11 - 16 ºC/ min) is due to the use of the tube made from ceramic microwave susceptible material (silicon carbide) with the optimal wall thickness of 3.5 mm, which allows a tempering waves distribution, achieving partly a direct heating (as a result of the microwaves penetrating the silicon carbide layer, contacting the material) and partly an indirect heating (as result of the absorption of microwaves by the silicon carbide layer, which is heated becoming a thermal radiation source to the material). This tempered heating (the very high speed are avoided) as well as the creating two hot poles which transfer simultaneously the heat constitute the explication of obtaining the macrostructural homogeneity of the samples. The experiments described above aimed the practical simulation of the working conditions in a tunnel furnace with conveyor belt powered with microwaves, where the coating of the sidewalls and the flat vault of the furnace with a layer of ceramic microwave susceptible material corresponds to the use of the cylindrical silicon carbide tube in experiments. It should be mentioned that there are some particularities of the mixture based on glass used at the glass foam manufacturing which favors the microwave absorption. Thus, high concentrations of alkali (Na_2O and K_2O) in the glass mixture allow the effective heating in microwave field due to the correlation between the electric conductivity of material and the microwave absorption [14].

4. CONCLUSION

The aim of the research conducted by the Romanian company Daily Sourcing & Research Bucharest is to obtain glass foams in microwave field from clear flat glass waste with physical, mechanical and morphological characteristics appropriate for using as insulating material in construction.

The glass foams were obtained by two techniques of foaming with calcium carbonate and respectively silicon carbide.

The favourable influence of the microwave heating was proved experimentally on an adapted 0.8 kW-microwave oven.

The physical, mechanical and morphological characteristics of the two glass foam groups are suitable for using as insulating material in construction.

The most significant achievement presented in the paper was obtaining good macrostructural homogeneity of the glass foam from flat glass waste, which is difficult to obtain under conditions of conventional heating methods. The pore size varies between 0.6 - 2 mm (foaming with calcium carbonate) and 0.9 - 3 mm (foaming with silicon carbide), the pores being uniformly distributed.

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