HEAT-INSULATING, FIREPROOF AND WATERPROOF MATERIALS PRODUCED BY RECYCLING GLASS WASTE IN MICROWAVE FIELD

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ABSTRACT

The paper presents experimental results obtained in the manufacture of glass foams from packaging bottle glass waste, using the microwave energy. The glass foam as insulating material for construction is an advantageous alternative to existing building materials (e. g. expanded polystyrene) due to its superior resistance to mechanical stress, fire and humidity. The results have shown that the manufacturing techniques of glass foams in microwave field lead to products with physical, mechanical and morphological characteristics similar to those of industrial products made by conventional methods (low apparent density and low thermal conductivity, acceptable mechanical strength, closed pores). The advantages of applying microwave energy are eliminating pollution as well as reducing the specific consumption of energy. The originality of research conducted in the Romanian company Daily Sourcing & Research consists in the use of microwaves as an unconventional source of energy, worldwide only conventional heating methods being currently applied.

Keywords: glass foam; glass waste; microwave energy; apparent density; thermal conductivity.

REZUMAT

Lucrarea prezintă rezultate experimentale obţinute la fabricarea sticlelor spongioase din deşeuri de sticlă de ambalaj, utilizând energia microundelor. Sticla spongioasă ca material izolator pentru construcţii constituie o alternativă avantajoasă faţă de materialele de construcţii existente (ex: polistirenul expandat) datorită rezistenţei ei superioare la solicitări mecanice, foc şi umiditate. Rezultatele au arătat că tehnicile de fabricare a sticlelor spongioase in câmp de microunde conduc la obţinerea unor produse cu caracteristici fizice, mecanice şi morfologice similare celor produse industrial prin metode convenţionale (densitate aparentă şi conductivitate termică reduse, rezistenţă mecanică acceptabilă, pori inchişi). Avantajele aplicării energiei microundelor sunt evitarea producerii noxelor, precum şi diminuarea consumului specific de energie. Originalitatea cercetarii efectuate de societatea românească Daily Sourcing & Research constă in utilizarea microundelor ca o sursă de energie neconvenţională, pe plan mondial fiind aplicate in mod curent doar metode de încălzire convenţionale.

Cuvinte cheie: sticlă spongioasă; deşeu de sticlă; energia microundelor; densitate aparentă; conductivitate termică.

1. INTRODUCTION

The packaging bottle represents a large amount of potential waste, constituting about 70% of all containers (including those of plastic and metal) (Meyer et al., 2001). In the case of glass, the recycling in closed circuit for producing the new glass is the most common form of recovery. Because this technique involves high costs, the re-use of glass waste as building material has become a practice of the last decades, so far at a not very large scale.

Excepting the dense glass foams with high mechanical strength (2–6 MPa), used as aggregate for lightweight concrete, in road construction, foundation infrastructure, sport ground etc., the glass foams with low apparent density are used as insulating material, filter, absorber, gas sensor etc. (Rawlings et al., 2006; Scarinci et al., 2005).

The foam glass is obtained by the thermal treatment at high temperature (750-1100 ºC) of a finely ground mixture composed of glass waste and one of the foaming agent (calcium carbonate, black carbon, graphite, silicon carbide etc. The softening process of the powder mixture must be correlated with the decomposition or oxidation process of the foaming agent, so the gas released from the chemical reaction to meet a viscous medium. After cooling, the gas bubbles remain blocked within the material, forming a porous structure (Scarinci et al., 2005).

According to the information in the literature (Hurley, 2003), manufacturing technologies of glass foam are currently applied industrially. All technologies are based on conventional heating methods (fossil fuels combustion or electric resistances). The main products industrially made are: "Technopor", produced by Misapor Switzerland Company with branches in Germany, France and Austria and "Foamglas", manufactured by Pittsburgh Corning Company with branches in United States, Europe (Belgium, Czech Republic) and China.

Also, the literature presents results obtained in the world at the experimental scale in the field of glass foam manufacture (Arcaro et al., 2016; Stiti et al., 2011). Like to the techniques applied industrially mentioned above, conventional heating methods are also used.

The microwave energy, as an unconventional energy source, is fast, clean and economical, being used for heating applications since World War II. But, the use of this energy source has long been delayed, the conventional forms of energy being preferred. Until ten years ago, the microwaves were used only to the food preparation, vulcanization of rubber and manufacture of polymer/ wood composites. Recently, it has been found that many other material types (organics, ceramics, polymers, glass, sol-gel, metals and composites) can be efficiently heated in the microwave field (Kharissova et al., 2010).

The ability to absorb the microwave radiation is not the feature of all materials, but only of those that are microwave susceptible, called dielectrics. Having very few free charge carriers (Jones et al., 2002), the dielectrics absorb volumetrically the microwave energy, turning it into heat. The mechanisms of the conventional heat transfer are not applicable in this case. The heating is initiated at the core of the material and propagates outward. Thus, the material itself generates heat and the heating process can be very fast (Menezes et al., 2018). Unlike the conventional heating, the massive components of the oven have not to be heated, the microwave energy being absorbed only by the material. In this way, the heating rate increases and the specific consumption of energy is diminished.

Lately, the research at the experimental scale of the Romanian company Daily Sourcing & Research Bucharest was focused on the production of glass foams using only the microwave energy and obtaining products with characteristics similar to those made by conventional methods.

It should be noted that previous experiments of the Romanian company have demonstrated that the direct heating of the powder mixture containing glass waste is not suitable, because the very high heating rate generates major imbalances in the structure of the material (non-homogeneous structure characterized by high pore size, sometimes even containing very large goals). The technical solution adopted for diminishing the heating rate is the placement of a ceramic microwave susceptible material on the microwave propagation path (as a crucible or cylindrical tube, for experimental testing or covering the walls surface of the oven, in the case of an industrial installation).

2. EXPERIMENTATION METHODOLOGY

2.1. Method

The adopted method consists in the mechanical pressing of the powder mixture (wetted at 8.5%), composed of packaging glass waste and calcium carbonate as foaming agent, in a metal tube with the wall thickness of

1 mm and the useful volume of about 600 cm^3, placed on a 5 mm thick metal plate. The plate is supported by means of a metal support on several ceramic fiber mats placed at the bottom of the oven. An outer ceramic tube made from microwave susceptible materials (silicon carbide and silicon nitride in the weight ratio 78/ 22), having the wall thickness of 3.5 mm, is placed concentrically on the same ceramic fiber mats. The ceramic tube has a cover made of the same material. To avoid the heat loss outward, the ceramic tube and the cover are protected with ceramic fiber mats. The entire construction containing the powder mixture described above is introduced into an adapted 0.8 kW domestic microwave oven (Fig. 1). The rotating mechanism of the oven is dismantled, so that the material is heated in a static position under the influence of the only microwave generator. The measurement of the powder mixture temperature during the process is made with a radiation pyrometer placed above the oven. The pyrometer visualizes the upper area of the mixture through openings provided both in the ceramic cover and in the upper ceramic fiber layers.

Fig. 1. The experimental microwave equipment

Compared to the conventional heating techniques, the microwave heating has the following main advantages: higher heating rate, selective heating, bigger control of the heating process, low equipment size. The selective heating is a characteristic which allows the heat only of the material. So, no energy is wasted for the heating of other components (generally massive) of the oven. The heating rate can increase, reducing the specific consumption of energy (Rahaman, 2007).

It should be mentioned that there are some peculiarities of the mixture based on glass used at the glass foam manufacturing which favor the microwave absorption. Thus, high concentrations of alkali (especially Na_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 (Kolberg and Roemer, 2001). The usual packaging bottle colorless glass, used as raw material in the experiments, contains over 13% Na_2O (Dragoescu et al., 2018).

The main raison why the unconventional heating technique has not yet been applied industrially in the glass foam manufacture process and also there are no concerns at the experimental scale, is that some components of the glass (SiO_2, Al_2O_3) are microwave transparent materials and theoretically the microwave heating of glass is inefficient at the room temperature due to its low electric conductivity, becoming effective at higher temperatures (below 500 ºC). Practically, due to the presence in the commercial glass composition of some contaminants (Fe_2O_3, Cr_2O_3 etc.) with microwave susceptibility (Rahaman, 2007), both massive glass cullet and the powder mixture, containing glass in very high ratio, used in foam glass manufacture, can be rapidly heated starting at the room temperature (Paunescu et al., 2017).

The experimental methodology provides for the testing of six variants of colorless glass waste and calcium carbonate, according to Table 1. The ranges of values adopted for the two materials are based on the results of previous experiments, being between 97.8 – 99.1 wt.% for glass waste and between 0.9 – 2.2 wt.% for calcium carbonate.

Table 1. Materials composition, wt.%

Variant	Colorless glass waste	Calcium carbonate
1	97.8	2.2
2	98.1	1.9
3	98.4	1.6
4	98.7	1.3
5	98.9	1.1
6	99.1	0.9

The glass foam samples, resulted after the sintering/ foaming experimental process, were tested in laboratory to determine the physical, mechanical and morphological characteristics. Apparent density, porosity, thermal conductivity, compressive strength, water absorption and hydrolytic stability were determined by the current methods ("Manual", 1999; Anovitz and Cole, 2015; "ISO", 2011; "Calculation", 2017).

2.2. Materials

The raw material used in experiments was packaging colorless glass waste, having the following chemical composition: 71.7% SiO_2, 1.9% Al_2O_3, 12.0% CaO, 1% MgO, 13.3% Na_2O, 0.05% Cr_2O_3 and 0.05% all other oxides (Dragoescu et al., 2018). The glass waste was broken, ground in a ball mill and sieved, the grain size of the powder having values between 32 – 80 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 two components of mixture, having successively the weight ratios shown in Table 1, were homogenized and then wetted with 8.5% water as binder to press the material prior to introduction into the oven.

3. RESULTS AND DISCUSSION

The parameters of the sintering/ foaming experimental process and the physical, mechanical and morphological features of the samples are shown in Tables 2 and 3.

Table 2. *Parameters of the sintering/ foaming process*

Variant	Raw material/ glass foam amount g	Sintering/ foaming temperature ºC	Heating duration min	Average rate, ºC/ min		Index of volume growth	Specific consumption of electricity kWh/ kg
				Heating	Cooling		
1	580/ 563	838	43	19.0	5.5	3.20	1.02
2	580/ 560	834	42	19.4	5.3	3.00	1.00
3	580/ 564	830	41	19.8	5.2	2.90	0.97
4	580/ 561	824	40	20.1	5.6	2.80	0.95
5	580/ 563	821	38	21.1	5.4	2.80	0.90
6	580/ 562	818	38	21.0	5.2	2.70	0.90

Table 3. Physical, mechanical and morphological features of the samples

Variant	Apparent density g/ cm^3	Porosity %	Thermal conductivity W/ m · K	Compressive strength MPa	Water absorption %	Pore size mm
1	0.14	93.6	0.034	1.1	0.6	1.3 – 2.5
2	0.15	93.3	0.035	1.1	0.5	1.0 – 1.7
3	0.16	92.7	0.037	1.1	0.3	0.8 – 1.4
4	0.17	92.3	0.038	1.1	0.2	0.5 – 1.0
5	0.18	91.9	0.040	1.2	-	0.4 – 0.8
6	0.19	91.4	0.040	1.2	-	0.4 – 0.7

In accordance with Table 2, the raw material amount was kept constant at the value of 580 g. The sintering/ foaming temperature of the powder mixture was in the range 818 – 838 ºC, the lowest value corresponding to the variant 6 (with the highest ratio of calcium carbonate). The process duration varied between 38 – 43 min, being influenced by the final temperature value of the process. The heating rate had relative high values, between 19 – 21 ºC/ min, being mainly influenced by the temperature level. The volume growth of the glass foam was very high, the material tripling its volume by foaming. The specific consumption of energy is very low (0.90 – 1.02 kWh/ kg) taking into account the specific working conditions: discontinuous operation regime, very small dimensions of the microwave equipment. Theoretically, industrial microwave equipment can be significant more efficiency due to the advantages of a high energy power source, the ability to use a unique internal protection feature, an uniform exposure to the microwaves and much-lower unit costs (Kharissova et al., 2010).

According to the data from Table 3, the glass foams obtained using the microwave energy corresponds qualitatively to the requirements of a building material. The apparent density has very low values (0.14 – 0.19 g/ cm^3). Also, the thermal conductivity, the main feature of a good insulating material, has very low values in the range 0.034 – 0.040 W/ m K. Practically, the material is non-absorbent of humidity (below 0.6%). The compressive strength value (1.1 – 1.2 MPa) is acceptable for applications in construction.

In Fig. 2 images of longitudinal section of the glass foam samples are shown.

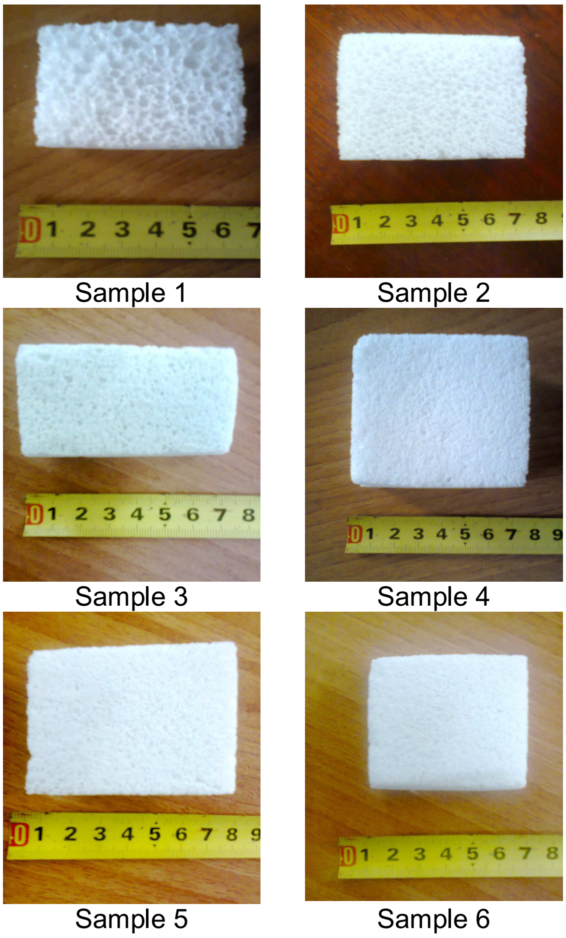

Fig. 2. Images of longitudinal sections of the samples

The pore size of the glass foam samples varies between 0.4 – 0.8 mm for the products obtained with 0.9 – 1.1% calcium carbonate as foaming agent (variants 5 and 6) and between 1.3 – 2.5 mm for the sample obtained with 2.2% calcium carbonate (variant 1).

The determination of the hydrolytic stability of samples involved the use of 0.15 ml of 0.01M HCl solution to neutralize the extracted Na_2O. The tests showed that the extracted Na_2O equivalent is in the range 38 - 53 μg, so that the stability joins in the hydrolytic class 2.

The fireproofing property of the glass foam was also tested by an open flame test, the result being negative.

4. CONCLUSIONS

The use of microwave energy in the manufacture process of glass foam from glass waste is a viable and efficiently solution, the products having features similar to those made by conventional methods.

The direct heating is not suitable due to the very high rate which generates major imbalances in the structure of the material (non-homogeneous structure characterized by high pore size, sometimes even containing very large goals), but the indirect or partially direct heating are optimal solutions.

The high concentrations of alkali (especially Na_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.

Although theoretically the heating process of glass is inefficient at the room temperature due to its microwave transparent components (SiO_2, Al_2O_3), practically the glass can be rapidly heated starting from the ambient temperature due to the presence in its composition of some contaminants (Fe_2O_3, Cr_2O_3 etc.) with microwave susceptibility.

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