

INNOVATIVE WAY TO PRODUCE GLASS FOAM IN MICROWAVE FIELD

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ABSTRACT: The paper presents results of research conducted by the Romanian company Daily Sourcing & Research on the use of microwave energy in the manufacture process of glass foams. Compared to similar products manufactured by conventional heating techniques, the physical, mechanical and morphological features of the experimental samples are close and meet the requirements for materials used as thermal insulators. The apparent densities and thermal conductivities are low (0.16 – 0.24 g/ cm^3 and respectively 0.037 – 0.043 W/ m · K) and the compressive strength has acceptable values (1.14 – 1.25 MPa). The manufacturing technique of glass foam in microwave field, in experimental stage in the Romanian company Daily Sourcing & Research, has already confirmed its effectiveness in numerous tests conducted in the last two years.
KEYWORDS: glass foam, glass waste, microwave, oven, susceptible material.

1. INTRODUCTION

Currently, the world trend of waste recycling in order to protect the environment and to recover its valuable content is strongly highlighted. The consumed glass packaging offers important recycling opportunities due to the large quantities available and the possibility of producing materials, especially for construction, as substitutes for existing building materials on the market. They, as glass foams, are sintered porous materials obtained from a finely ground mixture of glass waste and one of the foaming agents (calcium carbonate, calcium sulfate, petroleum coke, silicon carbide, black carbon, graphite, etc.) at high temperatures of over 750 ºC. The foaming mechanism consists in releasing a gas (mainly, carbon dioxide) through a chemical reaction to decompose or oxidize the foaming agent. The sintering temperature of the powder mixture must be correlated with the temperature at which the chemical reaction mentioned above occurs, so that the release of the gas is produced under the conditions of a suitable viscosity of the sintered material. Thus, the gas bubbles that are developed inside its mass are blocked and by the cooling form a porous structure with low apparent density and thermal conductivity and acceptable mechanical strength [1].

Due to these characteristics, the glass foam is best suited as a rigid insulating material in construction. It has excellent fire resistant properties (unlike the polymeric materials) and it is rodent resistant, sound absorber, non-toxic and non-water absorbent [1]. Also, glass foam is used as floors and wall tiles, architectural panels, filters, absorbers, gas sensors. Glass foam with high compressive strength can be used as aggregate for lightweight concrete, in road construction, infrastructures foundation, sports grounds etc [1 – 4].

Technologies of manufacturing glass foam are currently applied industrially [1]. All technologies are based on conventional heating methods (fuels combustion or electric resistances). The main products industrially manufactured in the world are: "Technopor", made by Misapor Switzerland Company with branches in Germany, France and Austria and "Foamglas", made by Pittsburgh Corning Company with branches in United States, Europe (Belgium, Czech Republic) and China. The mentioned products have various physical and mechanical characteristics, which satisfy a wide range of qualitative requirements, especially for construction.

Lately, the Romanian company Daily Sourcing & Research adopted for the first time in Romania the technique of producing glass foam using the microwave energy. Previous experiments in other fields, generally in chemistry, have shown the advantages of this technical novelty. The microwave heating process is directly focused only on the material in the oven, facilitating fast, economical and environmentally-friendly heating. Although the microwave energy is currently used effectively in the household, the industrial application of this energy source is only achieved in a few isolated domains (vulcanization of rubber and manufacture of polymer-wood composites). Recent research has highlighted that the microwave energy can be effectively used for many other types of materials:

organics, ceramics, metals, polymers, composites etc. [5, 6].

The experimental results obtained by the Romanian company, published [7 – 9] in Romanian or international journals, have shown that, by the microwave heating, the physical, mechanical and morphological characteristics are almost similar to those manufactured by the conventional heating.

2. METHODS AND MATERIALS

2.1 Methods

According to the data from the literature [10] as well as the own previous experience, the use of calcium carbonate as a foaming agent in the manufacture process of foam glass in microwave field resulted to constitute one of the most economical available solutions due to at least two reasons: the relatively low temperature at which the foaming process takes place (a little over 800 ºC) and the very high weight proportion of recycling waste glass which can be processed (over 98%). For this reason the experiments have been focused to this goal.

The last research of the company Daily Sourcing & Research aimed to produce glass foam on the experimental installation in conditions that simulate them as accurately as industrial ones. The industrial manufacturing of glass foam involves a tunnel furnace with conveyor belt, which moves the material deposited on the conveyor along the furnace. The microwave power supply must be achieved through the sidewalls and the flat vault of the furnace, which must be covered inside with a layer of microwave susceptible material. The thickness of the susceptible material layer must ensure an optimal ratio between the microwave proportion absorbed and those that penetrate it, coming in direct contact with the material on the conveyor. According to the mechanism of producing the direct microwave heating of a material [2], the heating process is initiated at its core, the heat propagating to the peripheral areas. The indirect heating achieved in the case of microwave absorption in the susceptible layer occurs by its rapid and intense heating, the inner surface transferring the heat by thermal radiation. The double heating source of the material from inside and outside is optimal to achieve a fast and economical process, without affecting the macrostructure of the sample and obtaining an uniform pore distribution.

The simulation of these working conditions, specific to the microwave industrial furnace, was achieved by placing above the pressed powder mixture, disposed on a metal plate, of a cylindrical silicon carbide crucible with the wall thickness of 3.5 mm, placed with the opening down on ceramic fiber mats. Both the crucible and the metal plate containing the material are thermal protected with thick layers of ceramic fiber and are introduced into a 0.8 kW microwave oven adapted to high temperature operation (Fig. 1).

Figure 1. The experimental microwave equipment

A Pyrovar type pyrometer (measuring field: 600 – 2000 ºC) mounted above the oven in front of a viewing hole provided in the upper area of the heating equipment (see Fig. 1) was used to monitor the thermal treatment. The measurements were performed on a thermally unprotected surface of the silicon carbide crucible and the temperature of the foamed material was determined taking into account the relationship between the two measuring point.

The methodology of experimentation consisted in testing the six variants of the mixture composition formed by the waste of consumed colorless glass packaging and calcium carbonate as foaming agent. The glass waste granulation was below 100 µm. The mixture was wetted with 8.3% water addition as binder for the pressing process. The powder mixture composition corresponding to the tested variants are shown in Table 1. According to the data from this table, the weight ratio of glass waste had values between 98.0 – 99.0% and the weight ratio of calcium carbonate was between 1.0 – 2.0%. These weight proportion ranges are the result of previous experiments conducted in various other conditions in the company Daily Sourcing & Research. Therefore, the ranges adopted for the test were limited to the values specified above.

Table 1. Powder mixture composition

Variant	Mixture composition, wt.%		
	Glass waste	Calcium carbonate	Water addition
1	99.0	1.0	8.3
2	98.8	1.2	8.3
3	98.6	1.4	8.3
4	98.4	1.6	8.3
5	98.2	1.8	8.3
6	98.0	2.0	8.3

After the foaming experimental process, the glass foam samples were tested in laboratory for the physical, mechanical and morphological characterization. The main features (apparent density, porosity, thermal conductivity, compressive strength, hydrolytic stability and water absorption) were determined using current methods [6, 11 -14].

2.2 Materials

The raw material used in experiments was bottle colorless glass waste, having the following chemical composition: 71.8% SiO_2, 1.9% Al_2O_3, 12.0% CaO, 1.0% MgO and 13.3% Na_2O [4]. The glass waste was ground in a ball mill, the grain size being less than 100 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 powder mixture containing the dosed quantities of the two components, corresponding to the each experimental variant, was homogenized together with the amount of additional water added (8.3% over the amount of raw material) in a small laboratory installation.

Then, the wet mixture was loaded into a demountable mold and was pressed by mechanical methods up to about 2 – 3 MPa. After removing from the mold, the pressed material was placed freely on the metal plate.

3. RESULTS AND DISCUSSION

3.1 Results

The main functional parameters of the sintering/ foaming process of the powder mixtures containing glass waste and calcium carbonate in the six variants mentioned above, carried out in the microwave oven, are shown in Table 2.

Table 2. Parameters of the sintering/ foaming process

Parameter	Variant					
	1	2	3	4	5	6
Raw material quantity (g)	350.0	350.0	350.0	350.0	350.0	350.0
Foam glass quantity (g)	336.1	338.0	339.5	337.8	339.0	338.2
Sintering/ foaming temperature (ºC)	825	825	827	831	835	836
Average speed (ºC/ min) · heating · cooling	14.8 5.8	14.8 6.0	14.9 6.1	14.9 5.9	15.0 5.7	15.0 6.0
Index of volume growth	2.95	3.10	3.00	3.10	3.10	3.20
Specific consumption of electricity (kWh/ kg)	1.42	1.40	1.39	1.40	1.39	1.40

According to the data from Table 2, the range of the process temperatures is between 825 – 836 ºC, the highest value being reached at the weight proportion of calcium carbonate of 2.0% (variant 6). The index of volume growth is remarkable, being between 2.95 – 3.20.

The specific consumption of electricity is relatively high, between 1.39 – 1.42 kWh/ kg glass foam (or, taking into account the apparent density values shown in Table 3, 224.0 – 326.6 kWh/ m^3 glass foam). According to the own experimental determinations, the heat losses outside the system and those through thermal accumulation at the end of the process represent over 70%. Thus, the real energy consumptions are: 67.2 – 98.0 kWh/ m^3. The industrial furnaces operating with conventional heating systems, but in continuous regime, so with much lower heat losses, have energy consumptions of about 100 kWh/ m^3 [1]. Considering the working conditions significantly different, a comparison between the values of specific consumption of energy is not appropriate at this time.

The physical, mechanical and morphological features of the glass foam samples are shown in Table 3.

Table 3. Physical, mechanical and morphological features

Feature	Variant					
	1	2	3	4	5	6
Apparent density (g/ cm^3)	0.23	0.24	0.21	0.19	0.17	0.16

Porosity (%)	89.5	89.1	90.5	91.4	92.3	92.7
Compressive strength (MPa)	1.25	1.23	1.20	1.18	1.17	1.14
Thermal conductivity (10^3 W/ m · K)	43	43	41	40	39	37
Water absorption (%)	0.6	0.6	1.0	1.2	1.3	1.5
Pore size (mm)	0.6 – 1.0	0.5 – 1.0	0.7 – 1.1	0.9 – 1.3	0.9 – 1.5	1.0 – 2.5

The physical and mechanical characteristics of the glass foam samples obtained in microwave field are very close to those of similar products made by conventional heating methods. The low apparent density (0.16 – 0.24 g/ cm^3) and thermal conductivity (0.037 – 0.043 W/ m · K) as well as the acceptable compressive strength (1.14 – 1.25 MPa) are suitable features for materials used as thermal insulators in construction.

The longitudinal sections through the glass foam samples (shown in Fig. 2) are characterized by homogeneous pores structure. The calcium carbonate weight proportion in the mixture composition influenced the pores size, at lower proportions the sample macrostructure being finer (pores size around 1 mm) and at weight proportions of 1.6 – 2.0% the pores size exceeding 1 mm up to 2.5 mm (see Table 3).


Variant 1


Variant 2


Variant 3


Variant 4


Variant 5


Variant 6

Figure 2. The longitudinal section through the glass foam samples

Determining 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 31 - 57 µg, so that the stability joins in the hydrolytic class 2.

3.2 Discussion

Lately, the Romanian company Daily Sourcing & Research has researched the mechanism of heating the powder mixture based on glass waste to produce glass foams, using the microwave energy. The experimental results showed that the thermal process begins inside the sample, where the temperature increases rapidly, influenced by the microwave irradiation. The foaming process is developed rapidly from inside to the peripheral area of the sample. This heating mode (direct heating) is not suitable for the materials based on glass, because the very high heating speed generates major imbalances in the structure of the material (non-homogeneous structure characterized by high pore size, sometimes even containing very large goals.

From this raison, a solution for diminishing the effect of the microwave field on the material subjected to heating was adopted by placing a wall made of a microwave susceptible material in the way of microwave propagation. Silicon carbide was adopted and the wall thickness was determined experimentally at 3.5 mm in conditions of a relatively large area of the powder mixture. In this way, the electromagnetic waves are partially absorbed in the mass of susceptible material, which is rapidly heated and its inner surface seen by the material transfers heat through thermal radiation, contributing to the heating process. Also, some of the microwaves penetrate completely the susceptible material and irradiate the sample based on glass waste. Its heating is started from the inside to the outside. Thus, two high temperature centers that act in two opposite directions are formed. The heating speed is sufficiently diminished from over 26 ºC/ min to about 14 – 15 ºC/ min and the effect is favorable for the foaming process and the homogeneity of the porous material macrostructure.

4. CONCLUSION

The objective of the research was application of the own previous knowledge on the efficient materials heating in microwave field, aiming to produce glass foam with similar features to those of products made currently by conventional heating methods.

The experiments were conducted in the Romanian company Daily Sourcing & Research on a 0.8 kW microwave oven adapted to operate at high temperature.

The experiments aimed at creating working conditions specific to an industrial furnace with conveyor belt, the raw material being loaded (pressed) on a metal plate placed under a silicon carbide crucible with the opening down, in the direction of propagation of the microwave field.

The experimental results confirmed the obtaining porous products with the following characteristics: apparent density 0.16 – 0.24 g/ cm^3, porosity 89.1 – 92.7%, thermal conductivity 0.037 – 0.043 W/ m · K, compressive strength 1.14 – 1.25 MPa, water absorption 0.6 – 1.5%, pore size 0.5 – 2.5 mm.

The products are suitable for using as insulating material in construction.

In energy terms, the use of the microwave field is more efficient compared to the conventional heating methods currently used. In experimental conditions, of discontinuous operation regime, this conclusion is for now theoretical.

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