Foam Glass Production from Waste Glass by Compression

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Abstract. The authors have identified the impact of the glass mixture briquetting process parameters (milling method, dispersibility, particle size distribution, particle form and compression parameters) on the performance characteristics and the physical and chemical properties of foam glass. It was demonstrated that briquette density increasing contributes to achieving a lower average density of foam glass. It was proven that briquettes produced from multifractional powders are characterized by a higher density than those produced from powders with a limited range of particle size distribution.

Individual housing construction from environmentally friendly materials is gaining its pace thus triggering the development of new highly-efficient and cost-effective materials. High rates of industrial growth and increasing volumes of industrial waste drive the need for brand-new technological processes or improvement of the existing ones with regard to environmental safety and cost-effectiveness. One of the processes satisfying the above requirements is the production of foam glass from cullet or waste container glass using waste dolomite, limestone or other substances as foaming agents.

Foam glass is characterized by closed porosity and has all the advantages of existing heat insulating materials and none of their disadvantages. The strength of foam glass is sufficiently high (ranging from 0.8 to 3.5 MPa), while its density is quite low (100-300 kg/m$^3$) that demonstrates its high strength-density ratio. The foam glass heat transfer coefficient ranges between 0.045 and 0.085 W/m$^2$K. Another benefit of foam glass is its mineral composition. As any other type of glass, it does not rot, is frost-resistant, inflammable, non-toxic, resistant to microorganisms and most chemical agents. Foam glass is also distinguished by constant heat transfer coefficient as it does not absorb any moisture [1,2].

Porous glass materials are widely used in construction. However, these are quite expensive if produced from mixtures based on specially prepared granulated glass or cullet resulting directly from the production process.

The cost-effective way to produce such materials consists in using waste glass, since the glass color does not significantly impact the product quality. It should be noted that production of porous glass materials from waste glass did not get traction due to impossibility to collect large quantities of waste glass having similar chemical composition [3,4]. Mechanical compression (vibrating, pressing, rolling, etc.) of the glass batch significantly reduces the extent to which chemical composition of waste glass can impact the quality of porous glass produced.
The usage of general-purpose and industrial waste silicate glass in the production of foam glass solves the issues of health and environment protection and resource saving [5,6].

Currently there are several foam glass production methods:

- adding of substances emitting large volumes of gaseous products during the glass melting process to the glass batch;
- blowing of glass melt with air or gas;
- foaming of melted glass under vacuum as a result of expansion of air contained in it;
- mixing of fine glass powder with the glass foam and subsequent consolidation of the porous structure by fusing;
- fusing of glass powder mixed with a foaming agent (powder method).

Domestic manufacturers prefer the powder method whereby the fine glass powder mixed with a foaming agent is heated to the melting point in fire resistant (usually, steel) moulds and then foamed. The method allows to control and vary the product properties over a wide range [7].

Extensive use of foam glass is inhibited by its high price resulting from relatively high production costs that can be reduced by the preliminary briquetting of glass batch. This technology allows to stop using the moulds during the foaming process and, thus, decrease the metal consumption in the production of foam glass.

Glass batch compression enables not only to stop utilizing the steel moulds and granulated glass, but also, due to the high density of briquettes, achieve homogenous porosity of foam glass over the briquette cross-section and unify the size of pores. Gas generation in the preliminarily compacted glass batch allows to significantly improve the foam glass structure; the quantity of defects and their sizes decrease progressively as the initial density of the mixture increases. Besides, preliminary compaction of the glass batch contributes to homogenous distribution of pores during the heating, intensifies fusing at the initial heating stage and reduces the gas emission caused by the decomposition of the foaming agent [8].

The following materials were used in the experiment:

- Magnitogorsk glass factory waste (for chemical composition, refer to Table 1);
- dolomite from the Agapovka dolomite quarry (CaMg(CO₃)).

### Table 1. Chemical Composition of Glass.

| Oxides content, % | SiO₂ | Al₂O₃ | Fe₂O₃ | RO  | R₂O | SO₃ |
|-------------------|------|-------|-------|-----|-----|-----|
|                   | 70.5-73.5 | 1.4-3.4 | 0.1   | 9.7-12.3 | 13.0-15.0 | 0.5 |

The required quantity of the foaming agent was determined both by calculation and experimentally [9]. The actual quantity of the foaming agent exceeds the estimated one due to the fact that, as a rule, it is not completely decomposed during the foaming process that is also responsible for partial release of gas from the briquette.

Carbon-containing foaming agents are usually recommended for the production of heat insulating foam glass; soot is most popular, as it allows to achieve a significantly higher quality of glass as compared against carbonate foaming agents. However, the latter reduce the foaming temperature by 80-100°C. The toxic hydrogen sulphide (having offensive odour) that fills the pores of the foam glass produced using the carbon-containing foaming agents is replaced by the non-hazardous carbon dioxide.

The raw materials were treated in the centrifugal impact and ball mills until the specific surface value reached 500 m²/kg. Fine dispergation of the glass batch predefines the quality of the porous structure (the higher the specific surface value of its components is, the finer and more homogenous the porosity will be) and impacts the duration of fusing and gas generation processes that are accelerated by increasing the batch dispersibility. As the raw materials differ in terms of their
grindability, glass and foaming agent were milled separately. After that, the finish-grinding of the components mixed in a definite ratio was performed in the vibrating ball mill.

Unlike the ball milling, the centrifugal impact milling method allows to produce powder that consists of highly-defective particles uniform in shape and is characterized by a limited range of particle size distribution. However, under the constant compression conditions, briquettes of multifractional mixtures (typically resulting from ball milling) achieve maximum density (figure 1). In the latter case, the most part of the input energy is spent on movement and compaction of grains and not on their deformation which is characteristic of monofractional mixtures. Consequently, the wider the range of particle size distribution of the powder is, the easier it is compacted.

Figure 1. Relationship between milling method and range of particle size distribution.

Figure 1 shows that the batch prepared by the centrifugal impact milling method is characterized by a limited range of particle size distribution, with 30-63 micron particles prevailing, while the ball milling method ensures a wider range of particle size distribution, with 20-100 micron particles prevailing, that allows to achieve higher compaction during compression.

The body was formed by the two-stage double-action compression in the slide mould using the batch of thoroughly mixed components. The applied pressure ranged between 10 and 60 MPa [10,11]. The impact of pressure on the body density are shown in figure 2.

Compression not only causes the particles movement but also changes the range of particle size distribution: as a result of crushing, the quantity of particles increases and finer particles emerge. This is caused by high stresses at the contact points. Fine particles are small in size and have higher mobility that enables them to move more easily under the influence of the compression force, while large particles have limited mobility and degrade under the compression pressure [12,13].

According to figure 2, the optimum pressure ranges between 45 and 50 MPa. Further pressure increase is ineffective as it leads to the excessive mould wear. For every powder with a set of particular compression properties, there is a definite pressure that should not be exceeded: after it is achieved, almost no further compaction occurs.

The briquettes produced have the required initial strength of not less than 0.1-0.3 MPa that is important for the product removal from the semidry forming press by means of mechanical grips [13]. The strength required for charging to the furnace is ensured by thin water film.
Figure 2. Impact of compression pressure on body density.

It is apparent from the foregoing that the compression dynamics and properties of compressed briquettes depend on a range of factors: properties of the material particles (resistance to deformation, modulus of elasticity, plasticity); properties of the powder being compacted (milling method, dispersibility, particle size distribution and particles shape); compaction parameters (pressure, speed of its application, exposure time).

The briquettes were dried for 24 hours under the normal conditions. The body was annealed in the \((1+0.5+22) \text{ h}\) mode at the isothermal exposure temperature of 750 °C. These conditions allow to maintain uniform temperature profile over the entire briquette (Figure 3).

At the temperature of 750°C gas is emitted at an intensive rate. Increasing the exposure time causes the melt to emit the most part of the gaseous products of dolomite decomposition into the furnace atmosphere that, in its turn, results in the coalescence of pores, deterioration of the foam glass structure and significant density increase.

Figure 3. Briquettes before and after foaming.

To determine the foam glass properties, the workpieces foamed from the briquettes were filed round and polished with sand paper to achieve the plane-parallel surface.

The properties of foam glass produced are set out in Table 2.

The results obtained allow to conclude that a limited range of particle size distribution and larger quantity of surface defects allow to produce foam glass characterized by homogenous porosity distribution. This is due to the fact that fine particles cause reduction in the glass viscosity that results in the colmatation of pores. A wide range of particle size distribution in the batch complicates the annealing process. As a result, the heat transfer coefficient grows by 6.94% due to the convective heat transfer increase and the strength is reduced by 7.5% due to the increase in the pore size.

Limited range of particle size distribution in the batch allows to achieve higher performance characteristics of the foam glass produced.
Table 2. Performance characteristics of foam glass.

| Milling method         | Heat transfer ability, W/m·K | Density, kg/m³ | Ultimate compressive strength, MPa | Water absorption by weight, % |
|------------------------|-------------------------------|----------------|-----------------------------------|-----------------------------|
| Ball milling           | 0.072                         | 314            | 1.85                              | 12.10                       |
| Centrifugal impact milling | 0.067                       | 314            | 2.00                              | 11.30                       |

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