COMPOSITION, SYNTHESIS AND PROPERTIES OF COLOR ARCHITECTURE BUILDING FOAM GLASS OBTAINED FROM WASTE PACKING GLASS

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ABSTRACT

The foam glass is known mainly as an insulation material. It is less popular for the production of industrial colored foam glass. This material is for the application as coatings for building, architectural and artistic elements, especially in interior design. The synthesized compositions contain different coloring and foaming components. New foaming agents are characterized with dual function, both for foaming and coloring. By present study some environmental problems are solved for utilization of waste glasses to obtain a color foam glasses for use as heat and sound insulation. The obtained results are a part of a more general project for the development of technologies and special equipment for production of foam glasses.

Keywords: foam glass, heat and sound insulations, waste glasses.

INTRODUCTION

The foam or cellular glass is a modern alternative of the well known and widely used materials for thermo insulation and energy saving. This material is successfully applied in insulation of roofs of various configurations or walls, both internal and external engineering equipment as well as for sound insulation, but there are not data for the industrial manufacture of colored foam glasses [1, 2]. In Table 1 are summarized some of the classical applications of the foam glasses [1].

In the last years new directions for the development and applications of foam glass are registered [3-7] (GLAPOOR, ZES, FOAMGLAS®). According to our opinion this positive tendency will continue to grow faster in the future. This motivated us to search new technology and compositions using our previous experimental experience as well as the data of other Bulgarian scientists [8-11].

Currently the high-quality foam glass is obtained almost exclusively using carbon containing foaming agents although the pure CaCO₃ can be considered the “classical” type of foaming agent also [1] since almost all researches in the area of manufacturing foam glass use this agent as a beginning. The use of CaCO₃ in the batch for colored foam glass leads to some difficulties in obtaining products of low density [8, 9] since as a whole the short reaction time is not sufficient to ensure much quantity of the gas phase and to allow developing of the processes of foam generation. The reaction between CaCO₃ and SiO₂ that begins at about 600°C accelerates with the temperature increase and proceeds vigorously at temperature about 800°C. The process of homogenization of the initial compositions of batches is very important. The other important parameter is the size of the particles. In order to obtain high quality foam glass the specific area of the batch has to be about 6000 cm²/g corresponding to particle size about 10 µm.
The aim in this study is to obtain color foam glasses applying several combinations of coloring and foaming agents and appropriate regimes of heat treatment.

EXPERIMENTAL

As a main starting component we selected a waste glass, thus solving some economical and environmental problems. Chemical composition of the collected waste glass was determined in a certified laboratory. The content of the oxides is shown in Table 2. It is seen, that glass composition corresponds to a typical industrial silicate glass.

The composition of the batches is very important for the chemical processes taking place during the foaming (Table 3). The batches are prepared in a conventional manner. The coarsely grinded glass prepared is processed in ball-crusher and a sieve analysis is made subsequently.

Table 1. Types of foam glasses [1].

<table>
<thead>
<tr>
<th>Type</th>
<th>Function</th>
<th>General features and characteristics of material</th>
<th>Assortment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal insulating</td>
<td>Insulation of walls of residential, public and industrial buildings; thermal insulation for deep and moderate cold; thermal insulation of hot spots and pipelines</td>
<td>Closed pores, low coefficient of heat transfer, temperature range of application – 260 + 400°C</td>
<td>Panels of dimensions up to: - width 200 – 500 mm - length 200 – 1000 mm - thickness 80, 100, 120 mm Segments for pipes of various dimensions Lumps of random shape and dimensions 10 - 100 mm</td>
</tr>
<tr>
<td>Acoustic (sound absorption)</td>
<td>Acoustic improvement of buildings</td>
<td>Impenetrable pores, high coefficient of sound absorption</td>
<td>Panels of various dimensions</td>
</tr>
<tr>
<td>Filtering</td>
<td>Filtration of liquids and gases</td>
<td>Penetrable pores of dimensions up to 100μm; water-acid- and alkaline resistance except for hydrofluoric acid</td>
<td>Panels of various dimensions</td>
</tr>
<tr>
<td>Technical (non-alkaline, high silicate)</td>
<td>Thermal and electric insulation of devices and apparatuses</td>
<td>Improved mechanical strength, radio penetration, high thermal resistance; temperature range of application: non-alkaline up to 600°C, silicate – up to 1200°C</td>
<td>Plates of various dimensions; products with complex shapes</td>
</tr>
</tbody>
</table>

The aim in this study is to obtain color foam glasses applying several combinations of coloring and foaming agents and appropriate regimes of heat treatment.

Various starting batches are developed for manufacture of colored foam glass and its application for architecture building and artistic purposes, mainly in interior design and also for acoustic and thermal insulation. In Table 3 are shown the content of the main foaming agents, coloring additives and conditions of the heat treatment.

Several experimental schemes are investigated depending on the foaming and coloring agents. The preparation of various 28 foam glass batches containing the basic glass with the same foaming agent CaCO$_3$ but with different coloring additives (Table 4). When Cr$_2$O$_3$ is mixed with CaCO$_3$, the foaming takes place at 1000°C for about 15 min. In the case of pure CaCO$_3$, as well as CaCO$_3$ together with 3CoCO$_3$, 2Ca(OH)$_2$·H$_2$O or Fe$_2$O$_3$, the temperature of foaming is lower - 900°C for 15 min. As it was mentioned previously, the abrupt decrease from the maximal temperature of foaming, i.e. to the

Table 2. Chemical composition of collected waste glass.

<table>
<thead>
<tr>
<th>Oxides</th>
<th>Content, mass %</th>
<th>Oxides</th>
<th>Content, mass %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al$_2$O$_3$</td>
<td>1.77</td>
<td>P$_2$O$_5$</td>
<td>0.05</td>
</tr>
<tr>
<td>CaO</td>
<td>8.67</td>
<td>SiO$_2$</td>
<td>72.31</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>0.27</td>
<td>TiO$_2$</td>
<td>0.06</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>0.48</td>
<td>SO$_3$</td>
<td>&lt;0.03</td>
</tr>
<tr>
<td>MgO</td>
<td>2.77</td>
<td>Moisture</td>
<td>0.11</td>
</tr>
<tr>
<td>MnO</td>
<td>&lt;0.01</td>
<td>3X</td>
<td>0.026</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>13.26</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
softening of the glass mass (650 – 600°C), leads to the increase of the viscosity. This is an important condition for retaining the obtained pore structure.

On Fig. 1 is shown the general view of the selected samples, that have been colored with different agents at selected experimental conditions presented in Table 4.
It was noticed during the examination of the samples that the size of pores varies from 0.25 to 1 mm depending on the duration of the experiment and temperature of the heat treatment. Consequently the rate of heating has the impact on the properties of the products. The presence of open porosity observed means that the materials can be used for acoustic insulations.

The compression strength of the sample foam glass is tested on hydraulic press Alfred J. Amsles & Co No 599/545 and is loaded uniformly with pressure effort applied perpendicularly to the surface. The sample usually is shaped as a cube with dimension 4–5 cm. The necessary conditions for adequate test results are to have well tempered sample free of any defects, with strictly parallel surfaces. At least 10 measurements are made for each sample and the average compression strength is taken. The rate of loading 30 kg/mm² s was used for all tests. The tensile strength or the compression strength is determined according to:

\[ \sigma = \frac{P}{S} \]  

where \( \sigma \) is tensile strength, [MN/m²]; \( P \) is tensile or pressure effort applied, [MN]; \( S \) is cross section of the sample, [m²]. For determining the strength of foam glass, several samples were subjected to pressure testing and the results obtained are shown in Table 5.

Bending strength is determined by the equation.

\[ \sigma_b = \frac{M_y}{W_y} \]  

where \( \sigma_b \) is bending strength, (MPa) or (MN/m²); \( M_y \) is bending moment; \( W_y = W_y \) is inertia (resistance) bending moment; \( M_y = PL_o / 4 \)

\[ P \] – maximal loading, [N]; \( L_o \) – distance between the supporting rollers, (m)

\[ W_y = \frac{bh^2}{6} \]  

\( W_y \) is inertia moment during bending the cross section of the sample; \( b \) and \( h \) are dimensions of the cross section.
The thermal energy is transferred from the body with higher temperature to that with lower temperature. The process continues until the temperatures of the bodies of the system become equal. The heat conductivity of different materials is characterized with coefficient of heat conductivity \( \lambda \). It depends on their chemical composition and structure and varies with the temperature. The coefficient of heat conductivity \( \lambda \) [W/(m K)] is determined in steady heat of the sample, (m).

The bending strength is determined with accuracy of 0.1 MPa [MN/m²] and is shown in Table 6.

The heat-conductivity characteristic is also important for the thermal and acoustic foam glasses. The heat-conductivity is a process of heat transfer that takes place between bodies of different temperatures that are in direct contact with each other. The thermal energy is transferred from the body with higher temperature to that with lower temperature. The process continues until the temperatures of the bodies of the system become equal. The heat conductivity of different materials is characterized with coefficient of heat conductivity \( \lambda \). It depends on their chemical composition and structure and varies with the temperature. The coefficient of heat conductivity \( \lambda \) [W/(m K)] is determined in steady heat

<table>
<thead>
<tr>
<th>No</th>
<th>Sample</th>
<th>Composition, Temperature, duration</th>
<th>( \frac{a}{m} )</th>
<th>( \frac{b}{m} )</th>
<th>( h )</th>
<th>( S \cdot 10^{-4} )</th>
<th>( P \cdot 10^6 )</th>
<th>( \rho_{rel} )</th>
<th>( \sigma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>2% CaCO(_3); (T = 830 °C, t = 10 min)</td>
<td>0.018</td>
<td>0.017</td>
<td>0.016</td>
<td>3.6</td>
<td>89</td>
<td>420</td>
<td>8.72</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>2% CaCO(_3)+ 1% 3CoCO(_2),2Co(OH)(_2)H(_2)O (T = 900 °C, t = 5 min)</td>
<td>0.015</td>
<td>0.02</td>
<td>0.017</td>
<td>3.0</td>
<td>55.5</td>
<td>454</td>
<td>5.44</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
<td>2% CaCO(_3)+ 10% Fe(_2)O(_3) (T = 900 °C, t = 10 min)</td>
<td>0.015</td>
<td>0.018</td>
<td>0.014</td>
<td>2.7</td>
<td>76.5</td>
<td>494</td>
<td>7.99</td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>2% CaCO(_3)+ 1 % Cr(_2)O(_3) (T = 900 °C, t = 15 min)</td>
<td>0.016</td>
<td>0.018</td>
<td>0.018</td>
<td>2.8</td>
<td>29</td>
<td>720</td>
<td>2.74</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No</th>
<th>Sample</th>
<th>Composition, Temperature, duration</th>
<th>( P \cdot 10^6 )</th>
<th>( a \cdot m )</th>
<th>( b \cdot m )</th>
<th>( S \cdot 10^{-4} )</th>
<th>( L_o \cdot m )</th>
<th>( M_b \cdot m^3 )</th>
<th>( W_b \cdot m^3 )</th>
<th>( \rho_{rel} \cdot kg/m^3 )</th>
<th>( \sigma_b \cdot MN/m^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>2% CaCO(_3); (T = 830 °C, t = 10 min)</td>
<td>17.26</td>
<td>0.0127</td>
<td>0.0116</td>
<td>1.470</td>
<td>0.032</td>
<td>13.80</td>
<td>0.2848</td>
<td>420</td>
<td>6.06</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>2% CaCO(_3)+ 1% 3CoCO(_2),2Co(OH)(_2)H(_2)O (T = 900 °C, t = 5 min)</td>
<td>26.00</td>
<td>0.0153</td>
<td>0.0293</td>
<td>4.483</td>
<td>0.032</td>
<td>20.80</td>
<td>2.1890</td>
<td>454</td>
<td>1.19</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
<td>2% CaCO(_3)+ 10% Fe(_2)O(_3) (T = 900 °C, t = 10 min)</td>
<td>32.90</td>
<td>0.0132</td>
<td>0.0218</td>
<td>2.878</td>
<td>0.032</td>
<td>26.32</td>
<td>1.0455</td>
<td>494</td>
<td>3.15</td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>2% CaCO(_3)+ 1 % Cr(_2)O(_3) (T = 900 °C, t = 15 min)</td>
<td>4.92</td>
<td>0.0130</td>
<td>0.0130</td>
<td>1.690</td>
<td>0.032</td>
<td>3.936</td>
<td>0.3662</td>
<td>720</td>
<td>1.34</td>
</tr>
</tbody>
</table>
flux by measuring the temperatures on two opposite surfaces of the selected foam glasses sample (Table 7). The measurements were made using C-Therm TCI™, which is a flexible, prompt and highly precise tool that can measure directly the heat conductivity of the sample.

CONCLUSIONS

The possibilities for obtaining coloring foam glass from waste glasses for insulation and for building architectural and artistic elements using various coloring agents (green color by \( \text{Cr}_2\text{O}_3 \), red brown by \( \text{Fe}_2\text{O}_3 \), blue by \( \text{CoO} \)) was proved. Cobalt basic carbonate \( 3\text{CoCO}_3 \cdot 2\text{Co(OH)}_2 \cdot \text{H}_2\text{O} \), was successfully applied, which not only well foams the starting waste glass mass but also colors it in blue, after decomposition. The obtained experimental results show that the colored foam glasses also have very good strength and thermo physical properties.

The best results for colored foam glasses are obtained in the case of heat treatment at 900°C at burning time 10 and 15 min and for the composition of the foam agents is \( 2\% \text{CaCO}_3 + 10\% \text{Fe}_2\text{O}_3 \).

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REFERENCES