RESOURCE RECYCLING OF WASTE GLASS AS GREEN BUILDING MATERIALS

Qing Chi Xu, Antony Prince, Gurdev Singh
Environmental & Water Technology Centre of Innovation, Ngee Ann Polytechnic, 535 Clementi Road, Singapore 599489

ABSTRACT

In this work, we report an energy saving and eco-friendly method for the production of foam glass which can be used as a building material. Foam glass prototypes (40 × 40 × 10 cm) and foam glass bricks (7.5 × 7.5 × 25 cm) with high open porosity (85-95%), low density (0.15-0.25 g/cm^3), high compressive strength (1.0-2.0 MPa) were successfully produced. Foam glass samples show uniform pore size, low thermal conductivity (0.067 W/m^{o}K) and relative high sound absorption coefficient (0.5). This foam glass material has potential application as partition wall in building structures due to their low thermal conductivity and high sound absorption coefficient. In addition, their high porosity implies that they are light and will significantly reduce the load on the building. They are also fire-proof and could have anti-bacterial property. The foam glass is also non-toxic, which adds to the eco-friendly nature of the product.

INTRODUCTION

In Singapore, the amount of solid waste generated has increased over the decades from 0.74 million tons in 1972 to 6.89 million tons in 2011. The waste generation per capita was approximately 3.64 kg/day in 2011. The existing landfill, Pulau Semakau landfill which was built in 1999, is estimated to last till 2045.
In addition, with the increasing trend of waste generation, more incineration plants would be needed to be built every 7-10 years. This is not feasible for a land-scarce country like Singapore, and the costs of building and operating waste disposal facilities is very expensive. The capital construction costs of Semakau landfill is about \$610 million and the fourth incineration plant, the Tuas South incineration plant, is about \$890 million. [1] Hence, it is necessary for Singapore to develop alternative ways for managing its solid waste.
In 2011, 59% of the solid waste generated in Singapore was recycled. However, materials like glass have a low recycling rate of only 29%. This is due to the lack of glass recycling plants in Singapore. Hence, the waste glass is collected locally, then are sorted and exported overseas. [1] The glass recycling technologies available (i.e. the conventional glass bottle recycling, the float process & fiberglass manufacturing) are energy-consuming and pollution-causing. Also, the glass recycling process may not be profitable as the glass product may not be much cheaper than the virgin glass in addition to the high initial construction, recurring operation and maintenance costs. [3-5]
If the glass waste is contaminated, it may be rejected by glass recycling plant. [5, 6] These glass wastes would be incinerated and landfilled, which would result in energy consumption and occupying valuable landfill space as they are non-biodegradable. [4]
To improve the glass recycling capabilities, foam glass technology is studied. Foam glass is a glass product with bubble-like cellular structure and high porosity of 80-97%, making it an ideal material for thermal insulation and acoustic insulation purposes. [1, 4, 7, 8] It is created with the gas expansion in a glass melt at temperatures between 700 to 900 ^{o}C. Injected gases maybe used, but a commonly method is the use of gas-producing substances from thermal decomposition called foaming agents. The gases from the foaming agents bubble out to create the porous body of the foam glass. [3]
Foam glass first commercialized in 1930's, was limited to the use of virgin glass as feedstock. However, with technological development, manufacturers succeeded in producing foam glass products with post-consumer glass. Generally, the specifications of the foam glass in the market are mainly its size, thermal conductivity, sound insulation ability, water absorption ability and mechanical strength. [9] Currently, the reported maximum size of foam glass block produced is of 1.2 m long by 0.6 m wide by 0.16 m thick. [10] The ideal density and thermal conductivity is between 0.13-0.30 g/cm^3 [10] and 0.037-0.058 W/m^{o}K respectively [11].
An independent study by the UK government initiated group – WRAP (Waste and Resources Action Programme) has shown that the use of foam glass in the construction of domestic and commercial buildings would greatly reduce the energy consumption and hence the carbon dioxide footprint of newly built structures.
It has been reported that any pore sizes larger than 4 mm is not suitable for construction application. [12] This is because the pore size determines the mechanical strength; larger pores will reduce the strength of the foam glass due to the thinness of the cell walls between the pores. [13] In 2008, Shutov et al proposed to conduct a more detailed analysis in determining the optimum pore size. [14]
Formulation and heating process are the most important parameters, which can affect the properties

Proceedings of the SB 13 Singapore — Realising Sustainability in the Tropics

ISBN: 978-981-07-7377-9

of foam glass. In 2009, Alejandro et al reported that by adjusting the foaming temperature and the holding time, the porosity and the microstructure of the foam glass can be controlled. [15] In 2010, Pokorny et al reported that the foaming process was not only affected by the foaming agents but also by the heating process. [16] A higher heating rate will increase the expansion of the glass, which creates a product with low density. [16]
Hence, it is necessary to develop a simple and eco-friendly method for the production of foam glass using low-grade waste glass as raw material. In this work, the formulation and heating parameters will be also optimized. The potential application of the obtained foam glass as lightweight partition wall will be studied.

EXPERIMENT

MATERIALS

As shown in Figure 1, a simple and energy saving method has been developed to produce foam glass with low density. Briefly, appropriate amount of glass powder, foaming agents ($CaCO_3$ and/or carbon black) and other additive (Na_2HPO_4) were ball-milled at speed of 350 rpm for 30 min to get fine powder. Then 12.0 wt% of binder (sodium silicate solution, 24%) was added into the fine powder and mixed unformly. After that, the mixture was put into a steel mould and compressed at high pressure using a hydraulic compressor. Finally, the samples were de-moulded before being sintered, which saved the energy consumption and the cost of steel moulds.

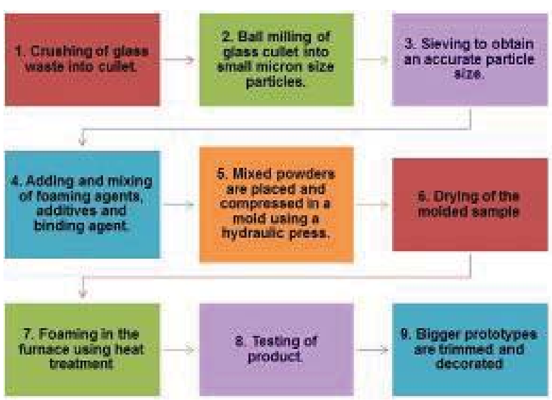


Figure 1. The flow diagram of the production process of foam glass prototype

HEATING PROCESS

A 3-segment heat treatment process shown in Figure 2 was designed to produce foam glass. In this work, the pre-heating temperature and foaming temperature were optimized. The sample was pre-heated to 450 °C at a heating rate of 15 °C/min and kept at this temperature for 30 min. Subsequently, it was heated to the foaming temperature of 900 °C at a heating rate of 10 °C/min and dwelled at 900 °C for 30 min. Afterwards, the sample was cooled down to annealing temperature of 600 °C naturally and dwelled at this temperature for another 30 min. Finally, the sample was cooled down to room temperature naturally.

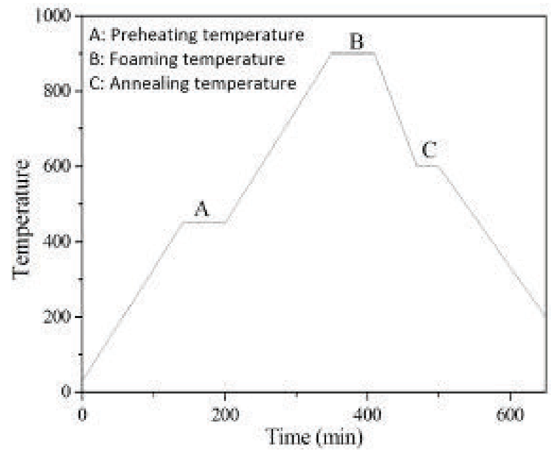


Figure 2. 3-segment heat treatment process

CUTTING & DECORATION

The foam glass prototypes were cut to rectangular shape using a milling machine and then decorated with different wall papers or hard papers.

CHARACTERIZATION

The properties of the product will determine its application. Hence the following output parameters will be tested:

1. Density
2. Porosity
3. Pores sizes
4. Compressive strength
5. Thermal conductivity
6. Sound adsorption coefficient

Density is determined by the formula:

$$Density = \frac{\text{mass of product}}{\text{volume}}$$

The mass of product was weighed using a mass balance (A&D company: Fz- 2000i model) and volume V_1 measured and calculated. A pycnometer was used to determine the porosity of the products (Quantachrome instrument: Ultrapyc 1200e model). Its uniformity of pores structure and the pore sizes was determined using a stereoscopic zoom microscope (Nikkon: SMZ 745 T model). The compressive strength of the foam glass was tested using a compressive strength testing equipment (FT-50). The thermal conductivity was done by an external company, Setsco Service Pte. Ltd, according to the ASTM C518 : 10 testing standard. The sound adsorption coefficient of the foam glass prototype was tested by East Notice Certification Service Co., Ltd, according to testing standard of ISO 354 : 2003 Acoustics.

RESULTS AND DISCUSSION

Firstly, the heating parameters including pre-heating temperature and foaming temperature were optimized. All other parameters (foaming temperature: 900 °C, foaming agent: 3% $CaCO_3$, binder: 12%) were fixed and the pre-heating temperature was changed in the range of 400 – 600 °C. Because density is the most important parameter to evaluate the quality of foam glass, the densities of foam glass samples are discussed. The results of the foam glass prepared at different pre-heating temperatures are shown in Figure 3. It can be seen that the foam glass exhibits the lowest density of 0.37 g/cm^3 at 450 °C.

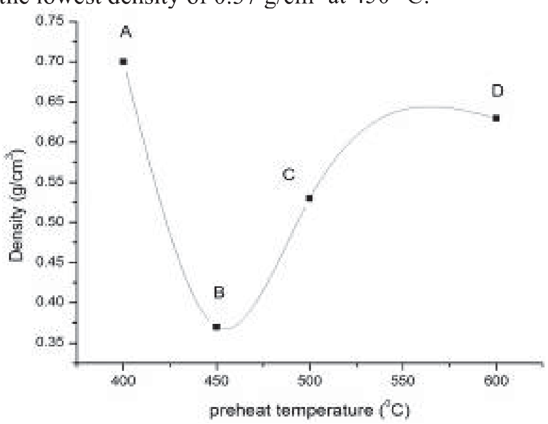


Figure 3. Densities of the foam glass samplese produced at different pre-heating temperatures

Then the pre-heating temperature was fixed at 450 °C and other parameters are remaining the same, except the foaming temperature. The foaming temperature was changed in the range of 850-925 °C. The densities of the foam glasses produced at different sintering temperatures are shown in Figure 4. It is obvious that the foam glass exhibits the lowest density of 0.37 g/cm^3 at the sintering temperature of 900 °C.

After optimizing the heating process (preheating temperature: 450 °C and foaming temperature: 900 °C) is used in the following experiments. The mixture of glass powder with 3% $CaCO_3$, 12% sodium silicate solution, and different amounts of carbon (0-5%) are used as raw material. The densities of the obtained foam glasses are shown in Figure 5. The results show that the addition of carbon can decrease the density of the foam glass and the lowest density is around 0.31 g/cm^3 when the content of carbon is 2%.

After optimizing the amount of carbon as foaming agent, the effect of different contents of Na_2HPO_4 has been studied. The mixture of glass powder with 3% $CaCO_3$, 12% sodium silicate solution, 2% carbon and different amount of Na_2HPO_4 (0-5%) are used as raw material. The densities of the obtained foam glasses are shown in Figure 6. The results show that the addition of Na_2HPO_4 can greatly decrease the density of the foam glass and the lowest density is around 0.18 g/cm^3 when the content of Na_2HPO_4 is 2%.

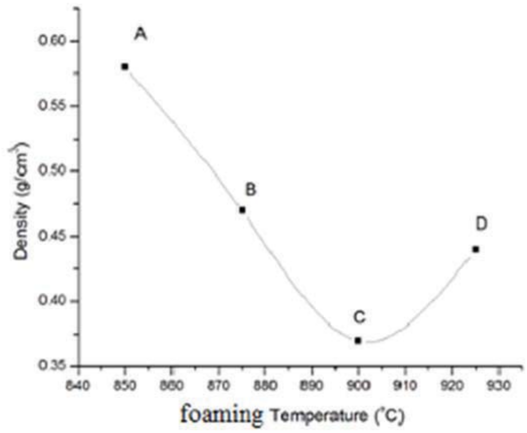


Figure 4. Densities of the foam glass produced at different foaming temperatures

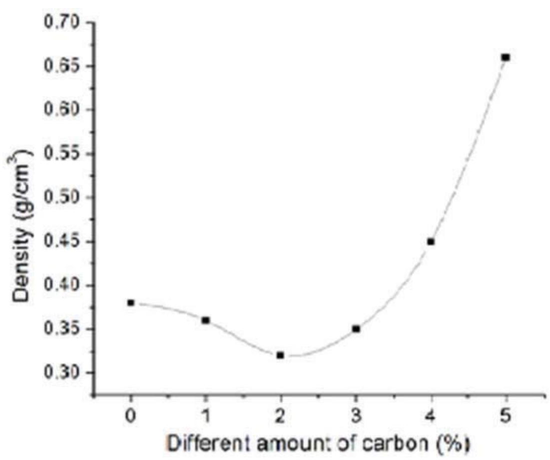


Figure 5. Densities of the foam glass produced at different amounts of carbon

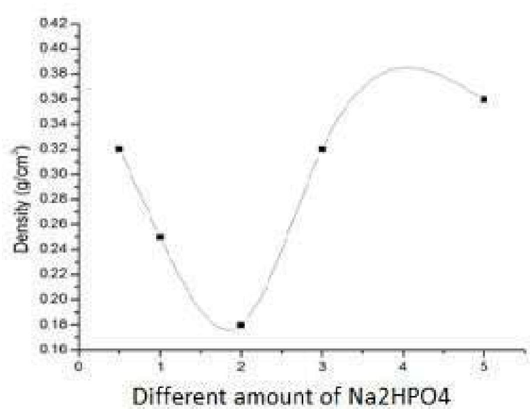


Figure 6. Densities of foam glass produced with different amount of Na_2HPO_4

The main objective of this project is to produce lightweight foam glass using mixed color waste glass as raw material. Herein, after developing and optimizing the sample preparing method, heating process and formulation, mixed color waste glass is used as raw material to produce foam glass. The mixture of 3% $CaCO_3$, 12% sodium silicate solution, 2% carbon, 2% Na_2HPO_4 and various mixture of different color waste glass are used as raw material. The densities of the obtained foam glasses are shown in Figure 7. The results show that the densities of foam glasses produced using different mixed color waste glass as raw material are around 0.17-23 g/cm^3, which prove that mixed color waste glass also can be used as raw material to produce foam glass. The pictures and microscope images of the obtained foam glass are shown in Figure 8. The pore sizes are small and uniform, which are in the range of 0.05 to 0.2 mm.

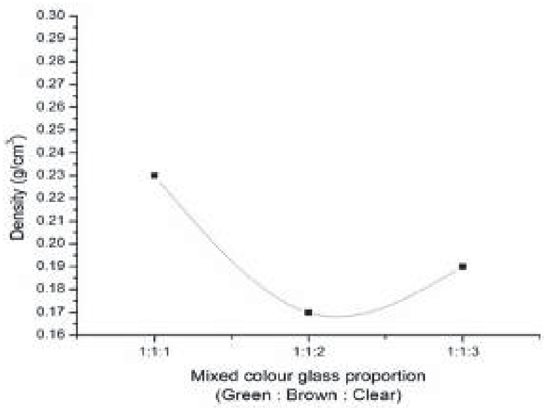
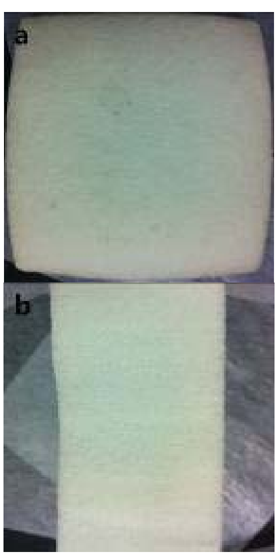


Figure 7. Densities of foam glass produced with different amount mixed color waste glass



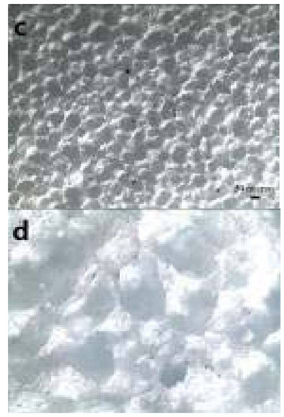


Figure 8. The pictures (a. top view & b. cross view) and microscope images (c. 1×50 & d. 3×50) of the obtained foam glass

The feasibility of industrial production is very important for this project. Herein, the foam glass scale up production has been studied. Bigger and thicker samples (300 g, 7.0 × 7.0 × 3.0 cm, and 1.8 Kg, 20.0 × 20.0 × 2.0 cm) are produced. However, there are unusual big holes (Figure 9) present in the middle of the big samples, which are attributed to non-uniform temperature in the samples. To solve this problem, a steel tray with many small holes is designed and the samples are put on the tray during the heating process. The temperatures of the bottom and top parts of the samples should be uniform.

Figure 9. Photographs of bigger and thicker foam glass samples

Additionally, the heating rate from pre-heating temperature to foaming temperature is further optimized to make the temperature uniform in the big samples. Normally, the big holes disappear and pore sizes become more uniform using low heating rate (1 – 2 °C), but the densities of the foam glasses become higher. Based on the results, the heating rate of 3 – 4 °C is suitable to produce big and thick foam glass samples with uniform pore size and low density (Figure 10).

Figure 10. Photograph of thick foam glass sample

The energy consumption is the main cost of foam glass production. It is very important to reduce the foaming temperature and energy cost. In this project, we have reduced foaming temperature by adding a special additive. Adding 1.5% of this additive can reduce the foaming temperature from 900 °C to 800-825 °C. The pore sizes of the big foam glass prototypes are uniform and the densities (0.2 – 0.3 g/cm^3) are low. Figure 11 shows some photographs of big foam glass prototypes produced at 800-825 °C. The big foam glass prototypes have been cut to regular shape using a milling machine. After cutting, the foam glass samples are decorated with wall papers or hard papers, which probably can be used as celling board or partition wall (Figure 12).

Figure 11. Big foam glass prototypes produced at 800-825 °C

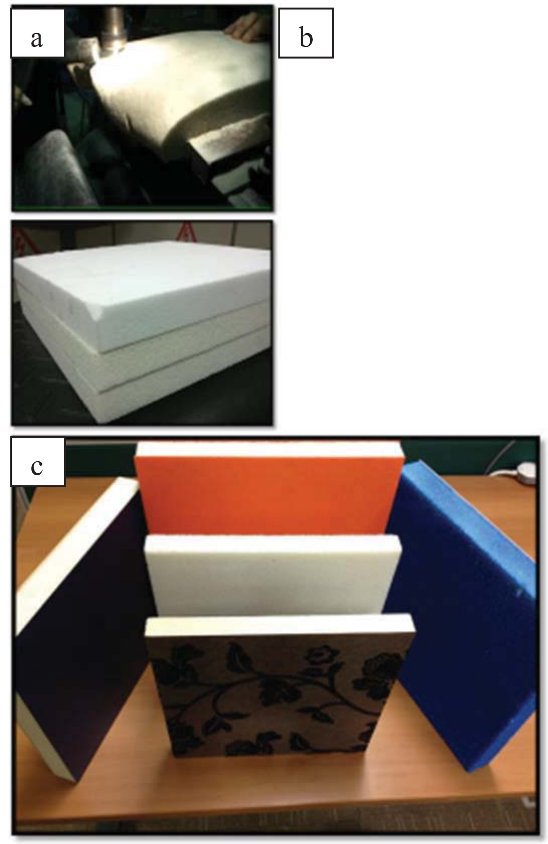


Figure 12. Photographs of (a) sample shaping process, (b) shaped samples and (c) samples after decoration

The big foam glass prototypes are tested after all the parameters have been optimized. The big foam glass prototypes show high porosity (85 – 93%), small pore size (0.05 – 0.5 mm), low density (0.18 – 0.25 g/cm^3), low thermal conductivity (0.068 W/m°K), relative high sound adsorption coefficient (0.5) and high compressive strength (1.5 – 2.0 MPa), which are comparable with commercial foam glass.

CONCLUSION

In this project, an eco-friendly and energy saving method has been developed to produce foam glass using waste glass as raw material. After optimizing the formulation and processing parameters, high quality foam glass is produced at relative low temperature (800 - 825 ºC). The possibility of using mixed-colour waste glass as the raw materials to produce high quality foam glass is also investigated. The results prove that low-grade mixed-colour waste glass can be used to produce high quality foam glass. Scale-up production trials are conducted to produce foam glass prototypes with dimensions of bigger than 40 × 40 × 10 cm. The obtained foam glasses show small pore size (0.05 – 0.5 mm), high porosity (88 - 93%), low density (0.18 – 0.25 g/cm^3), low thermal conductivity (0.068 W/m°K), relative high sound adsorption coefficient (0.5) and high compressive

(1.5 – 2.0 MPa) & flexural strength (0.8 – 1.2 MPa), which are comparable with commercial foam glass. The recycle of waste glass as foam glass would help to increase the solid waste recycling rate in Singapore and extend the lifespan of the Pulau Semakau landfill.

ACKNOWLEDGMENT

Financial support from MOE (IF10104) and other supports from Ngee Ann Polytechnic, EWT COI is acknowledged.

REFERENCES

1. (2002) Singapore waste management and recycling industry: Market survey. Singapore: Waste management and recycling association of Singapore (WMRAS), http://www.wmras.org.sg/
2. (2012) NEA website. Singapore: http://app2.nea.gov.sg/topics_wastestats
3. Hurley J. (2003). A UK Market Survey for Foam Glass. UK: The Waste and Resources Action Programme (WRAP).
4. Taylor & Francis Group, LLC. Waste Management Practices: Municipal, Hazardous and Industrial (2005)136-141
5. Siegle L., McCorquodale D. and Hanaor C. (2006). Recycle, the essential guide. Canada: Black Dog Publishing.
6. Limbachiya M., Meddah M. S. and Fotiadou S. (2012). Performance of granulated foam glass concrete. Construction and Building Materials 28 759–768.
7. Colombo P., Brusatin G., Bernardo E. and Scarinci G. (2003). Inertization and reuse of waste materials by vitrification and fabrication of glass-based products. Current Opinion in Solid State and Materials Science 7, 225–239.
8. Bernardo E. (2007). Micro- and macro-cellular sintered glass-ceramics from wastes. Journal of the European Ceramic Society 27, 2415–2422
9. Gellert R. (2010). Materials for energy efficiency and thermal comfort in buildings. Chapter 8: Inorganic Materials for insulation in buildings. UK: Woodhead Publishing Limited and CRC Press LLC.
10. Scheffler M. and Colombo P. (2005). Cellular Ceramics. Federal Republic of Germany: Weiley-Vch Verlag GmbH & Co. KGaA.
11. Lyons A. (2004). Materials for Architects and Builders, second edition. Great Britain: Elsevier Butterworth-Heinemann.
12. Shutov A. I., Alekseev S. V. and Yashurkaev T. V. (2006) Effect of pore size on heat flows in thermal treatment of foam glass. Glass and ceramics 63, (7 – 8), 213-214.
13. Fernandes H. R., Tulyaganov D. U., Ferreira J. M. F. (2009). Preparation and characterization of foams from sheet glass and fly ash using carbonates as foaming agents. Ceramics International 35, 229–235
14. Shutov A. I., Yashurkaeva L. I., Alekseev S. V. and Yashurkaev T. V. (2008), Determination of practical properties of heat-insulating foam glass. Glass and Ceramics 65 (1-2), 3-5.UDC 691.618.92.
15. Alejandro S. L., María J. O. T., Francisco J. G. T., Enrico B. and Colombo P. (2008) Foaming of flat glass cullet using Si_3N_4 and MnO_2 powders. Ceramics International 35 1953-1959.
16. Pokorny A., Vicenzi J. and Bergmann C. P. (2010). Influence of heating rate on the microstructure of glass foams, Waste Management & Research 29, 172-179.
17. Bjørn Berge & Howard Liddell (2005).The Ecology of Building Materials. Great Britain: Architectural Press.
18. D. Feldman (2010). Materials for energy efficiency and thermal comfort in buildings. Chapter 10: Polymeric foam materials for insulation in buildings. UK: Woodhead Publishing Limited and CRC Press LLC.