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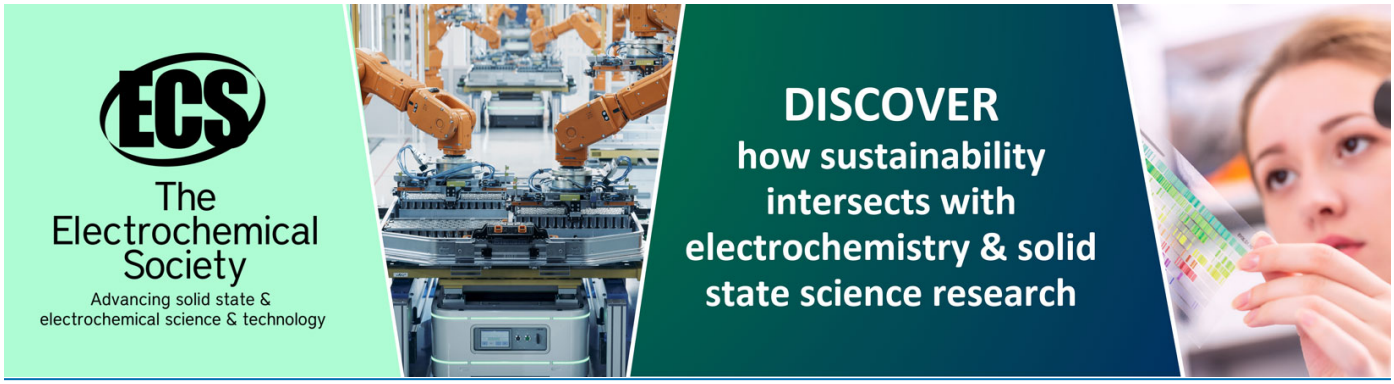

Foam glass from municipal waste as a lightweight aggregate for cement mortar

D Wattanasiriwech[1,3,4], S Nontachit[2,3], P Manomaivibool[1,3], and S Wattanasiriwech[2,3]
[1]Circular Economy for Waste-free Thailand Research Group, Mae Fah Luang University, Thailand
[2]Center of Innovative Materials for Sustainability, Mae Fah Luang University, Thailand
[3]School of Science, Mae Fah Luang University, Thailand

[4]E-mail: darunee@mfu.ac.th

Abstract. Municipal waste glass has long been a problem because of its difficulty in disposal. In Chiang-rai province alone, it was approximated that improperly treated glass waste amounts to 20,000 kg per annum. Foam glass is a porous insulating material which provides the advantage of low-thermal conductivity, low density and fire resistance. This research aimed to prepare foam insulating glass using waste glass collected from local municipality. The glass was first cleaned and then crushed using a hammer mill. Further grinding using ball milling technique was done until glass powder was obtained. With the use of proper amounts of foaming agent, calcium carbonate ($CaCO_3$), and binder, cassava gel, glass foams could be prepared at the temperature of 750 ℃. Microstructure was observed using an optical microscope, while density was measured using water replacement. The obtained foam glass has a bulk density of 0.535 g/cm^3 with approximated porosity of 77%. To observe ability as a lightweight aggregate, cement mortar with different amounts of glass foams was prepared. It was found that thermal conductivity linearly decreased while compressive strength increased when the amount of the foamed glass was increased. Compressive strength and thermal conductivity of the foam glass were estimated to be 2.43 MPa, of 0.23 W/m.K, making it a new economically promising lightweight aggregate for cement mortar.

1. Introduction

Municipal waste has long been a problem due to the limited nature of glass recycling. For example, only clean window glass, unbroken bottles, or colour-separated bottles were accepted in the recycling market in Thailand. Municipalities, then, collect and mark the rest as "dangerous waste stuff" and dump them into landfills without clear policy of a proper treatment.

Lightweight aggregate with a porous structure containing closed or open pores has been popular insulation materials for modern construction**.** Foam glass is a porous, fire-resistant material. The foam structure also provides excellent thermal resistance and is lightweight, making it attractive for modern construction where energy consumption and environmental friendliness is of great concern [1,2]. When compared to polymer foams, foam glass has less impact on the environment while having a much longer lifespan. The use of foamed glass aggregate in place of natural aggregates in concrete offered great thermal insulation and weight reduction [3]. Foam glass has demonstrated strength to density ratio, making it attractive as an eco-product.

Foam glass can be produced by mixing glass powder with a foaming agent and heat-treated until sintering and foaming. Sintering of viscous glass and foaming of glass must occur at the same time. The glass must have enough viscosity to sustain gas bubbles released from the foaming agent in the

structure [2]. Increasing time and temperature both led to expansion of the pore sizes, thus controlling of the firing regime to obtain desired structure is of utmost importance [4].

The types of common foaming agents such as carbon, calcium carbonate ($CaCO_3$), dolomite and silicon carbide determined the composition of released gases [5,6]. The gases produced were mainly CO_2 or SO_2, which were low-thermal conducting gases [7]. Foaming must decompose at the desired temperature, making retention of the foamed structure possible. To achieve low density and uniform pore structure, it is necessary to avoid collapses through coarsening of individually created bubbles. Coarsening of bubbles occur to reduce free surface energy.

Production of foam glass is quite expensive if they are produced from mixtures based on specially prepared granulated glass or cullet resulting directly from the production process [8]. The use of waste glass has been employed instead. Recycling waste glass in this scenario also allows the use of a diversity of glassware to make a high-value-added product [9]. This paper aims to prepare foam glass from municipal waste glass to use as a lightweight aggregate in cement concrete. Analysis of the waste glass and also the mortar is addressed in this paper.

2. Materials and methods

Waste glass was collected from Chiang-rai municipality (Figure 1a). Dangerous glass such as CRT tubes or fluorescent lamp envelopes was separated, so mainly soda-lime glass was used. Chemical analysis of the waste glass was first tested and its result is shown in Table 1. The glass was clean then crushed to obtain the desired size using sieve analysis. From the preliminary analysis, milling for 16 hrs was selected (Figure 1b). The glass powder was mixed with calcium carbonate at 1-4%. Tapioca starch gel was used as the binder in forming process.

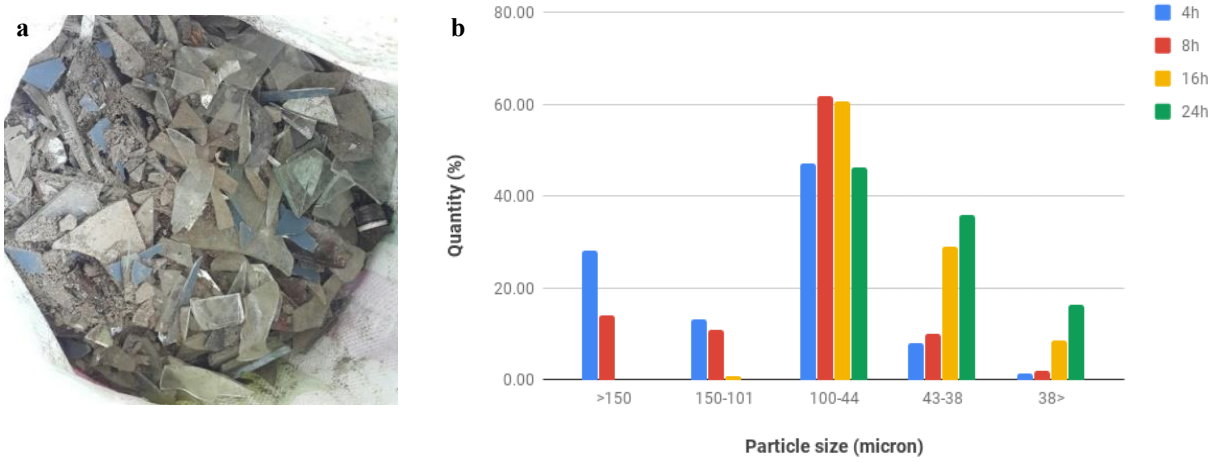

Figure 1. (a) Waste glass collected from Chiang-rai municipality and (b) sieve analysis result as a function of ball milling time.

Table 1. Chemical compositions of waste glass.

Components (wt%)	SiO_2	CaO	Al_2O_3	Na_2O	MgO	Fe_2O_3	K_2O	SO_3	Others
Waste glass	63.31	20.37	1.31	9.61	3.21	0.98	0.74	0.20	0.27

Dilatometry analysis of the compacted glass powder (Figure 2) showed that softening started around 600 ℃ with the highest shrinkage rate around 700-750 ℃. The glass was thus pelletised by hand and then fired in a furnace at 750 ℃ for 10 min.

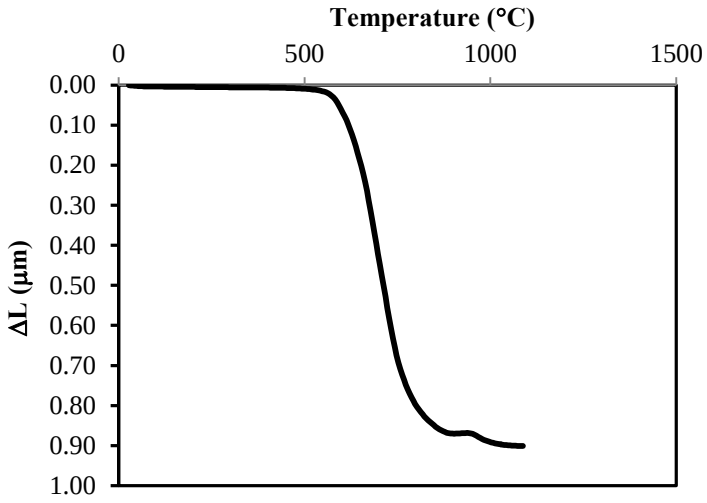

Figure 2. Dilatometry analysis of the compacted waste glass powder showing its softening temperature range.

The pore structure was investigated using a stereo microscope with an Image J software.The bulk density was determined based on the Archimedes' principle (water immersion method). Five samples were measured and averaged. [10]. The bulk density was calculated according to the Eq. 1;

$$\rho_{bulk} = \frac{m_1}{m_1 - m_2} \text{ x } \rho_{water} \quad (1)$$

where; ρ_{bulk} is bulk density of sample, ρ_{water} is density of the water, m_1 is mass of sample in air, and m_2 is mass of sample in water.

True density of the foam glass was measured following the Indian Standard Methods of sampling and physical tests for refractory materials (ISO 5016) using a Pycnometer with a capacity of 50 ml. The test material was ground and pass through the 75 µm-mesh sieve. The true density was calculated according to Eq. 2;

$$Q = \frac{m_1}{m_3 + m_1 - m_2} \times Q_{liq} \quad (2)$$

where: Q is true density of the sample, Q_{liq} is density of the liquid used at the temperature of the thermostatically controlled bath, m_1 is initial mass of test material, m_2 is mass of the pycnometer filled with a quantity of the test material and with test liquid, and m_3 is the mass of the pycnometer filled with the liquid used.

True porosity of the foam glass was measured following the same standard above. True porosity, π_1 is the ratio of the total volume of the open pores and the closed pores in porous body to its bulk volume. Percent true porosity, π_1, is given by the Eq. 3;

$$\pi_1 = \frac{\rho_t - \rho_b}{\rho_t} \times 100\% \quad (3)$$

where: ρ_t, and ρ_b are true and bulk density of the foam glass in g/cm^3.

Compressive strength of foam glass was measured indirectly by replacing foam glass to cement at 0- 60% by volume. Cement mortar was prepared in cubical shapes of 5 cm in each dimension by mixing cement to water ratio of 1:1. Specimen was cured for 7 days and the test was following ASTM C109.

Thermal conductivity of the mortar was tested on the square plates of 12 cm × 12 cm and 1 cm thick. The test was using PASCO scientific Model TD-8561 Thermal Conductivity Apparatus. The specimen was clamped between a steam chamber, which maintained a constant temperature of 100 ℃, and a block of ice, which maintained a constant temperature of 0 ℃ on the another side of specimen. The apparatus setup is schematically shown in Figure 3. A fixed temperature differential of 100 ℃

was thereby established between the surfaces of the specimen. The heat transferred was measured by collecting the water from the melting ice. The ice melts at a rate of 1 g per 80 cal of heat (the latent heat of melting for ice). Thermal conductivity, k (W/m.K), was therefore measured using the following equation:

$$k = \frac{\Delta Q \times h}{A \times \Delta T \times \Delta t} \quad (4)$$

where ΔQ is the total heat energy conducted (mass of ice melted × 80 cal/g), A is area through which conduction takes place, ΔT is temperature difference between two sides of the specimen, Δt is time during which the conduction occurred and h is thickness of the specimen.

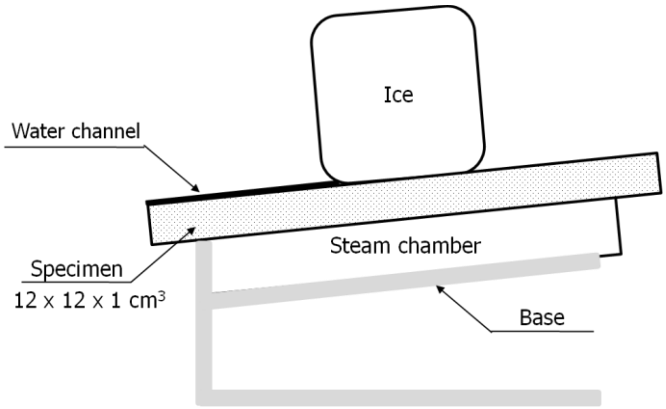

Figure 3. Schematic diagram of thermal conductivity measuring equipment.

3. Results and discussion

3.1 Effects of $CaCO_3$ content

Figure 4 shows foam glass prepared with 3 different $CaCO_3$ contents and sintered at 750 ℃ for 10 min. It was noted that the pictures are on different scale but roughly all foams were shaped to be 0.5 cm in diameter. The result suggested that foam glass produced with 4% $CaCO_3$ gave a satisfactory shell feature so this amount was selected for further experiment. However, observed pore structures of the glass beads were not uniform due to the agglomeration of $CaCO_3$ powder used. To solve this problem, $CaCO_3$ powder was sieved prior to mixing.

Figure 4. Foam glass prepared with various percentages of $CaCO_3$.

The bulk density, true density, and true porosity of foam glass is listed in Table 2. The foam glass contained porosity of almost 80% suggesting its potential use as a lightweight aggregate.

Table 2. Bulk density, true density, and true porosity of foam glass.

Properties	Value
Bulk density (g/cm^3)	0.535 ±0.07
True density (g/cm^3)	2.413 ±0.14
True porosity (%)	77.85 ±2.31

Pore size distribution of the foam glass as analysed using an Image J software equipped to an optical microscope is shown in Figure 5. The main distribution of size was between 10-400 μm, with the highest number at 50 μm.

3.2 Mortar properties

Compressive strength of mortars containing foam glass cured for 7 days in a controlled humidity compartment is shown in Figure 6a. The result showed that compressive strength of the mortars decreased linearly with increasing percent replacement from 17 MPa in the 20% replacement mortar. From this relationship, compressive strength of the foam glass was estimated to be 2.43 MPa. From literature, the strength of foam glass ranged from 0.8 to 3.5 MPa [8]. The obtained result in our present study fell in the reported range.

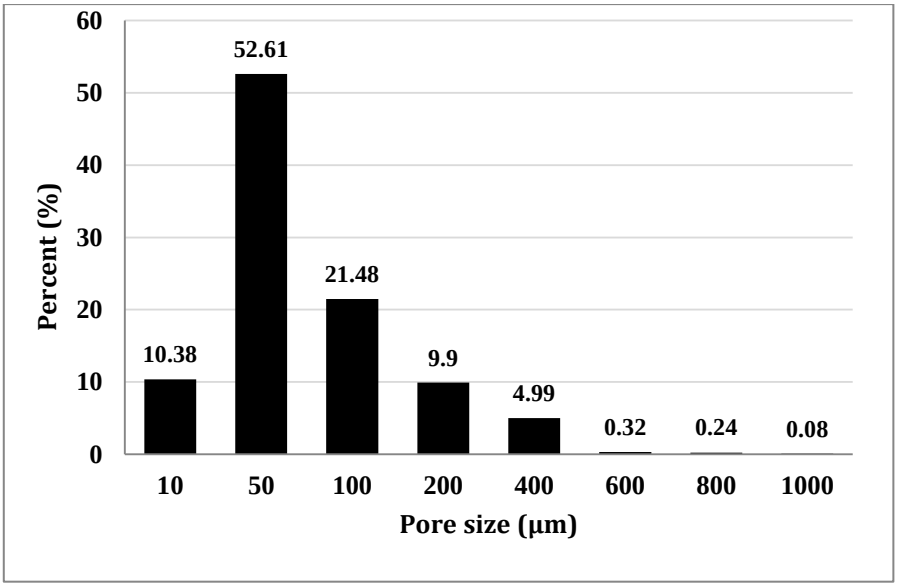

Figure 5. Pore size distribution of the foam glass as analysed using an Image J software.

Thermal conductivity measured at room temperature of mortars containing foam glass cured for 7 days in a controlled humidity compartment is shown in Figure 6b. Thermal conductivity of cementitious composites is affected by water–cement ratio (w/c) as the changes in w/c result in different densities thus leading to variations in thermal conductivity [11]. The result obtained in our study for the cement paste for the cement paste was closed to those reported in literatures [12,13].

Replacement of cement with foam glass and linear decrease of thermal conductivity suggests its ability to be used as the lightweight aggregate with an improved thermal resistance. Thermal conductivity of the foam glass was thus estimated from this relationship to be 0.31 W/m.K. The report by Zhu et al showed their foam glass prepared from coal fly ash and waste glass had thermal conductivity of about 0.36 W/m.K [6]. The energy saving effect using foam glass was evaluated in their study and it was shown that the prepared glass foams had good energy conservation for building thermal insulation materials.

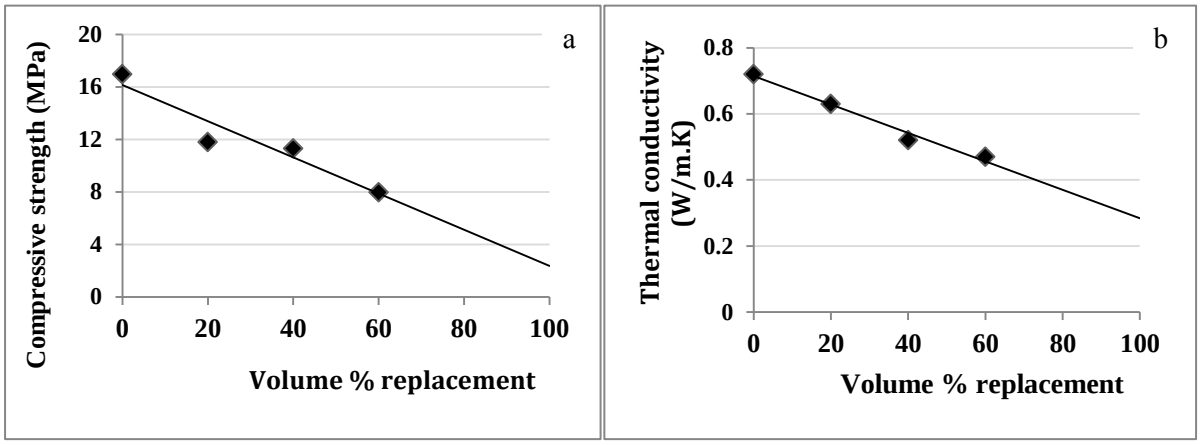

Figure 6. (a) Compressive strength and (b) thermal conductivity of cement mortar filled with foam glass as a function of the replacement volume.

4. Conclusions

Foam glass has been prepared from local waste glass, successfully using $CaCO_3$ as a pore former and tapioca starch as a binder. Sintering of the glass was selected based on the dilatometry analysis result. Pore size distribution of the foam was in the range between 10 to 400 mm with its majority size (>50%) of~ 50 mm. Estimated compressive strength of the foam was satisfactory while the thermal conductivity may need further improvement.

Acknowledgements

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