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Properties of lightweight high calcium fly ash geopolymer concretes containing recycled packaging foam

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HIGHLIGHTS

- Lightweight geopolymer (LG) block was fabricated from high calcium fly ash and recycled foam aggregate.
- LG with NH = 5–15 molars, NS/NH = 0.33–3, liquid/ash = 0.5–1, curing at 25–60 °C, aggregate content = 0.85–1.05 %wt. were tested.
- Low densities of 1000–1300 kg/m^3 and 28-day compressive strengths of 4.0–11.2 MPa were obtained.

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ABSTRACT

In this research, the properties of lightweight geopolymer concretes containing recycled packaging foam were studied. The recycled foam was crushed to sizes of 2.35–4.75 mm and used as lightweight aggregate. Compressive strengths and densities with liquid alkaline/ash ratios of 0.5–1.0, sodium silicate/NaOH ratios of 0.33–3.0, NaOH concentrations of 5–15 molars, curing temperatures at 25 and 60 °C, and foam contents of 0.85–1.05 %wt. were tested. In addition, the thermal conductivities of geopolymer blocks were determined. Results showed that the lightweight geopolymer blocks of densities of 1000–1300 kg/m^3, with satisfactory strength and low thermal conductivity can be made. This gave a twofold advantageous viz. the use of low carbon footprint fly ash geopolymer and the reuse of packaging foam.

1. Introduction

The production of Portland cement is an energy intensive operation and releases a large amount of green house gas to the atmosphere, which accounts for about 5% of green house gas produced annually [1]. Therefore, new cementitious material using silica and alumina activated in a high alkali solution was developed to supplement Portland cement [2]. This new material is geopolymer or alkali-activated binder [3].

In Thailand, the lignite important coal mine and large power plant are located in Mae Moh district, Lampang province. The annual output of fly ash from this source is 3 million tons. A substantial amount is not utilized and is deposited at the landfill site. This fly ash contains high calcium content. It also contains high amount of silica and alumina and is used successfully in making geopolymer binder with adequate strength and excellent durability characteristics [4–6].

The construction of building and structures in Thailand and other countries relies heavily on Portland cement products. The structural members, walls and panels are made of Portland cement [7] and the problems of the weight of structural members and wall panels are of great concern [8]. In order to reduce the weight of structure, lightweight construction materials in the form of lightweight concrete block or wall using cast-in-place lightweight concrete have been developed. The purpose of this work is to reduce the dead load of structure resulting in lighter structures and also with reduced cement content.

Lightweight concretes (LC) is usually defined as concretes with unit weight less than 1840 kg/m^3 [9]. The low unit weights LC of 400–1200 kg/m^3 are for block production and the high unit weights of 1300–1840 kg/m^3 are for structural concrete [10]. The LC are classified into three types viz., LC with lightweight aggregate, LC with large voids, and LC with no fine aggregate [11]. LC with lightweight aggregate are mostly used for masonry due to high strength and good sound and thermal insulation properties from the air void in lightweight aggregate [12]. Both natural and synthesized lightweight aggregates are used in the manufacturing

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of LC. The common natural lightweight aggregates are pumice, perlite, and diatomite; and the synthesized ones are expanded clay and sintered fly ash [13].

Polystyrene foam (PSF) is a thermoplastic polymer with a closed cellular structure [14]. A large amount of PSF materials is now being used as food container and industrial product packaging. As a result, this foam in huge amount is now a waste and need special attention or proper disposal [15]. If burnt, they pollute the atmosphere or if discarded at landfill sites, it took a very long time to decompose.

PSF has interesting properties such as low unit weight (less than 300 kg/m^3), good thermal insulation, hydrophobicity, and chemical resistance [14,16]. There have been a number of studies on the use of PSF for making lightweight concretes [14–18]. The PSF dosage and water to cement ratio are important parameters affecting the density and strength of the lightweight concrete. The low density lightweight of 1050 kg/m^3 was successfully fabricated with the emphasis on strengthening the cement paste matrix with the aids of silica fume and plasticizer [16,17].

Thus, in this research, high calcium fly ash geopolymer paste was used as a new binder for making lightweight concrete containing used packaging foam as lightweight aggregate. This would give a twofold advantageous viz. the use of low carbon footprint fly ash geopolymer instead of Portland cement and the reuse of packaging foam to reduce the burden of waste disposal.

2. Experimental program

2.1. Materials

Materials used in this research consisted of lignite fly ash from Mae Moh power station in the north of Thailand, sodium silicate with 15.32% Na_2O, 32.87% SiO_2, and 51.8% water, and 5, 10, and 15 molars (M) NaOH and recycle packaging foam (RF). The RF was the discarded packaging foam from the household electricity appliances. The foam was broken into 3.0–4.0 cm pieces by hand and then crushed using a food blender. The crushed foam was sieved to obtain the size of 2.36–4.75 mm as shown in Fig. 1 and used as fine aggregate. Chemical compositions of fly ash determined using X-ray fluorescence (XRF) technique are shown in Table 1 and its X-ray diffraction (XRD) is shown in Fig. 2. The sum of SiO_2, Al_2O_3 and Fe_2O_3 was over 75% which was in accordance which ASTM C618 [18], however, the CaO content was high indicating a high calcium fly ash. The XRD analysis showed mainly amorphous phase with some peaks of crystalline phases of magnetite, magnesioferrite, dachiardite, and calcium aluminum oxide. The fly ash was 30% retained on sieve No. 325 (45 μm) with median particle size of 18.6 μm and Blaine fineness of 2800 cm^2/g. It consists mainly of spherical particles with smooth surface as shown in Fig. 3. The physical properties of materials are shown in Table 2. The RF has particle sizes between 2.36 and 4.75 mm with unit weight of 215 kg/m^3 and water absorption of 225%. River sand with specific gravity of 2.61 and fineness modulus of 2.65 was used as normal fine aggregate.

2.2. Mix proportion

2.2.1. Mix compositions

Five series of mixes were used to test the effects of liquid alkaline/ash ratios (series A), sodium silicate/NaOH ratios (series B), concentration of NaOH (series C), temperature of curing (series D), and volume of foam (Series E). The details of mixes are shown in Table 3.

Fig. 1. Lightweight aggregates from recycled foam.

Table 1
Chemical composition of materials (by weight).

Chemical compositions (%)	Fly ash
SiO_2	45.23
Al_2O_3	19.95
Fe_2O_3	13.15
CaO	15.50
K_2O	2.15
TiO_2	0.39
Na_2O	0.52
P_2O_5	0.81
MgO	2.02
LOI	0.88

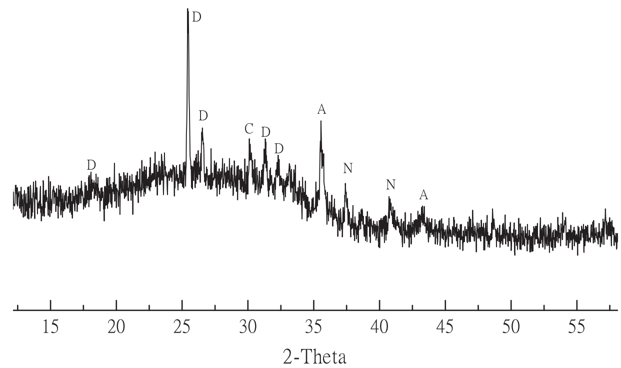

Fig. 2. XRD patterns of fly ash. A-Magnetite: Fe_3O_4; C-Magnesioferrite: Fe_2MgO_4; D-Dachiardite: $Na_{1.1}K_{.7}Ca_{1.7}Al_{5.2}Si_{18.8}O_{48}$ $(H_2O)_{12.7}$; N-Calcium Aluminum Oxide: $CaAl_2O_4$.

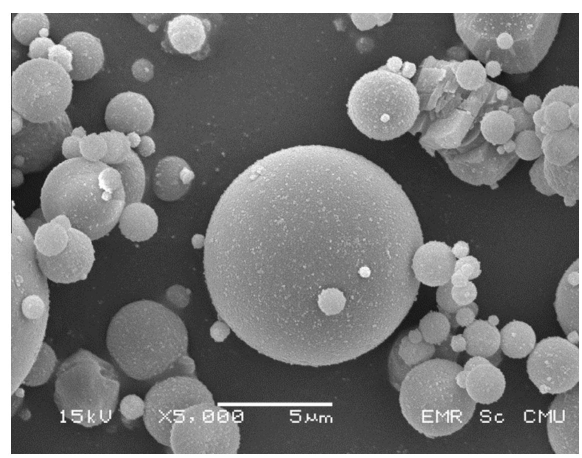

Fig. 3. SEM of fly ash.

Table 2
Physical properties of materials.

Materials	Fly ash	Sand	Recycled foam
Specific gravity	2.52	2.61	–
Median particle size (μm)	18.6	–	–
Particle size (mm)	–	–	2.36–4.75
Fineness modulus	–	2.65	–
Density (kg/m^3)	–	1360	215
Water absorption (%)	–	1.17	225

2.2.2. Details of mixing

Constant sand to fly ash ratio of 1.00 was used for all mixes. The mixing was done in a pan mixer with the following steps:

– NaOH solution and fly ash were mixed for 5 min.
– Sand was added and mixed for 5 min.