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Pressed lightweight fly ash-OPC geopolymer concrete containing recycled lightweight concrete aggregate

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HIGHLIGHTS

- We studied lightweight fly ash-OPC geopolymer concrete containing recycled lightweight concrete block aggregate.
- Incorporation of OPC and temperature curing enhanced strength development.
- The use of OPC enhanced strength development with a slight increase in density.
- Density of 1200–1500 kg/m^3 and compressive strength of 4.5–17.5 MPa were obtained.

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ABSTRACT

In this paper, the density and strength of lightweight fly ash-OPC geopolymer concrete containing recycled lightweight concrete aggregate (RLCA) were studied. Waste lightweight concrete was crushed and used as lightweight aggregate. Geopolymer cement was produced from the blend of high calcium fly ash and ordinary Portland cement (OPC), sodium hydroxide and sodium silicate. The fly ash was replaced with OPC at the dosages of 0, 5, 10 and 15% by weight. The results showed that lightweight geopolymer concretes with densities between 1200 and 1500 kg/m^3 and 28-day compressive strengths between 4.5 and 17.5 MPa could be fabricated. The incorporation of RLCA reduced both density and strength of lightweight concrete. The addition of OPC enhanced the strength development of geopolymer concrete but also increased the density. The optimum OPC content for strength development was 10%. The NaOH concentration of 10 M, sodium silicate/NaOH ratio of 1.0, OPC content of 10% by weight of fly ash, liquid/solid binder ratio of 1.4, RLCA/solid binder ratio of 1.8 and curing temperature of 60 °C were recommended for the lightweight fly ash-OPC geopolymer concrete.

1. Introduction

Portland cement proofs itself as one of the main construction materials and is being used world-wide. Currently a large amount of concrete is utilized in the construction industry due to the suitable strength, durability, ease of construction and cost. The increase use of concrete is the main concern as the production of Portland cement involves emission of a large amount of greenhouse gas from the calcining of carbonaceous material and consumption of fuel [1]. In addition, the use of natural aggregates and the discarding of construction waste are putting a heavy load on environment [2–4]. The use of recycled aggregate is thus another mean to help the construction industry.

Other binder such as alkali activated cement or geopolymer serves as a good alternative binder [5] to reduce the increasing use of OPC. Fly ash is a good source material for making geopolymer as it is available worldwide. Activated with sodium hydroxide and sodium silicate and cured with moderate temperature, this fly ash geopolymer has good strength and durability [6]. At room temperature, the addition of 5–15% of OPC helps with the setting and strength development of fly ash geopolymer [7,8]. It has also been shown that both low and high calcium fly ash are suitable for use as source materials.

Currently, there is an increasing use of lightweight concrete in both residential and office buildings due to the reduced dead load and other added benefits such as improved heat and sound

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absorption properties [9]. Lightweight concrete is used extensively as partition and wall of which the volume is very large. It has been shown that lightweight concrete with sufficient high strength and low density could be made from waste or discarded lightweight concrete aggregate [10].

The use of lightweight concrete block is increasing and its waste is also increasing as the results of damage of blocks from manufacturing, transportation and handling as well as increased demolition of buildings. The use of recycled lightweight block as aggregate was therefore investigated with new binder namely fly ash geopolymer using workable mix and normal casting of sample [11]. The results indicated that the lightweight geopolymer block with recycled lightweight aggregate with strengths of 1.0–16.0 MPa and density of 860–1400 kg/m^3 could be fabricated. The previously published results indicated that slag, fly ash, silica sand and pumice could be used in making lightweight geopolymer concrete [12]. The geopolymer foam concretes have also been tested and found to have good thermal insulation as well [13]. In another investigation, the method of making pressed lightweight concrete with porous diatomite aggregate using a dry mix was found to be satisfactory. Pressed lightweight diatomite concretes with strengths of 7.8–12.9 MPa and density of 1000–1200 kg/m^3 were fabricated [14]. This pressing technique is attractive in terms of continuous pressing and making of blocks without conventional casting and demolding.

This research thus aims to develop lightweight fly ash-OPC geopolymer concrete using recycled lightweight aggregate from crushed waste lightweight concrete. The obtained data should be instrumental for the increasing use of both fly ash geopolymer and recycled lightweight concrete.

2. Experimental program

2.1. Materials

In this study, high calcium fly ash from Mae-Moh power plant in northern Thailand, ordinary Portland cement (OPC), sodium hydroxide (NaOH), sodium silicate and recycled lightweight concrete aggregate (RLCA) were the materials used. The chemical compositions of fly ash and OPC are shown in Table 1. The fly ash consisted of 45.23% SiO_2, 19.94% Al_2O_3, 13.15% Fe_2O_3, and 15.5% CaO with the loss on ignition (LOI) of 0.88%. It was, therefore, a class C fly ash as per ASTM C618 [15]. Three NaOH concentrations of 5, 10, and 15 M (M) and sodium silicate with 15.32% Na_2O, 32.87% SiO_2, and 51.8% water were used as alkali activators. The waste lightweight concrete block was autoclaved aerated concrete (AAC) type. This type of block is a popular commodity in the hot region especially Thailand and neighboring countries. The waste lightweight concrete block was crushed and classified into single size coarse aggregate (CA), medium aggregate (MA) and fine aggregate (FA) with particle sizes of 4.75–12.5, 1.18–4.75 and 0.01–1.18 mm, respectively as shown in Fig. 1. The RLCA was a graded aggregate with the ratios of CA:MA:FA of 30:30:40 by weight [11,16].

The physical properties of materials are shown in Table 2. The values of specific gravity of CA, MA and FA were 1.42, 1.96, and 2.61 respectively. The low S.G. of CA was due to the large amount of internal pore. This also resulted in the low unit weight of CA

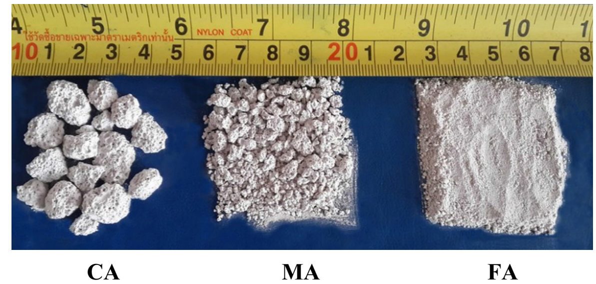

Fig. 1. Recycled lightweight concrete aggregate.

compared to those of MA and FA. The values of Blaine fineness of fly ash and OPC were 2409 and 3600 cm^2/g with the corresponding median particle sizes of 18.6 and 14.6 µm, respectively. This suggested that this batch of fly ash is relatively fine.

2.2. Mix proportion

The dry mixtures were designed and used for making pressed lightweight concrete block. To study the property of FA-OPC geopolymer, the FA replacement levels with OPC were limited to 0, 5, 10, and 15% by weight as previous researches indicated that the maximum OPC content should be around 10% [7,8]. The pressed lightweight concrete mixture is a dry mix and hence a dry aggregate was used. The density and compressive strength of lightweight geopolymer concretes containing RLCA were determined. In order to obtain adequate data, several series of mixes were tested as shown in Table 3.

Series A/S: To study the effect of aggregate content, the aggregate/solid binder (fly ash + OPC) ratios of 1.6, 1.8, 2.0 and 2.2 was tested.

Series T: To study the effect of temperature of curing, four curing temperatures viz., 25, 40, 60 and 90 °C were tested. The samples were kept at 25 °C for one hour and then temperature cured for 48 h.

Series NHC: Three NaOH concentrations viz., 5, 10 and 15 M were used to study the effect of NaOH concentration.

Series NS/NH: This series was used to study the effect of sodium silicate/NaOH ratios using NS/NH ratios of 0.33, 0.67, 1.0, 1.5 and 3.0.

Series L/S: This series was used to study the effect of liquid alkaline/solid binder ratio (L/S). The L/S of 1.2, 1.4, 1.6 and 1.8 were tested.

2.3. Details of mixing

In the first step, OPC and fly ash were mixed until uniform color was obtained. NaOH solution was then added and mixed for 5 min to obtain homogenous mixture. Sodium silicate solution was then added and the mixing was done for another 5 min. Next, the graded recycled aggregate was added and mixing was done for 1.5 min. The 50 × 50 × 50 mm lightweight geopolymer concrete blocks were fabricated with the aid of a pressing tool using a small pressure of 0.85 MPa [14]. The specimens were placed in a 25 °C controlled room for 1 h [17] and temperature cured for 48 h.

Table 1
Chemical composition of Fly ash and OPC.

Chemical compositions (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	Na_2O	MgO	SO_3	LOI
Fly ash	45.23	19.95	13.15	15.50	2.15	0.52	2.02	0.3	0.88
OPC	20.80	4.70	3.40	65.30	0.40	0.10	1.50	2.7	0.90