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Investigating the effects of solarcure curing method on the compressive strength, microstructure and polymeric reaction of fly ash based geopolymer

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HIGHLIGHTS

- Solarcure curing method is a clean technique for achieving high compressive strength of geopolymer binders.
- High calcium fly ash performed better than the low calcium fly ash as the geopolymer base material.
- Increasing the molarity of alkaline solution increase the compressive strength of geopolymer binders.

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ABSTRACT

This paper presents the effects of the specially designed solarcure method on the properties of geopolymer binders. The solarcure method is composed of the box-shaped chamber that works on the principles of trapping solar radiations to regulate the adequate amount of heat and temperature inside the box. Two sets of geopolymer binder mix containing low-calcium fly ash (LCFA) and high-calcium fly ash (HCFA) as a base material was developed. One part of sodium hydroxide (5 M and 10 M) solution mixed with two parts of sodium silicate was used as an alkaline activator. Mortar cubes of 50 mm size were cast and cured in three different regimes; continuous oven (CO) curing, intermittent oven (IO) curing and solarcure (SC) curing were used for the compressive strength test. For constant curing; temperature was maintained at 60 °C 24-h, whereas in intermittent conditions (IO and SC), samples were cured in three cycles; each cycle was composed of 8 h curing then 16 h cooling. For IO curing, the oven temperature was maintained at 60 °C, however for SC curing; the solar-box chamber has achieved maximum inside temperature up to 90 °C for each curing cycle. Specially designed SC technique caused up-to 56% increase in compressive strength as compared to the compressive strength of CO cured samples. SC curing also improved the microstructure properties and geopolymer reaction product.

1. Introduction

Among various construction materials, environmental impacts of Portland cement have been debated a lot by many researchers [12,31]. Production of one ton of Portland cement consumes 1.6 tons of raw material and 6.5 million BTUs of energy, which resulted in approximately one-ton carbon dioxide emission [23]. Therefore, the annual production of more than two billion tons of cement emits a considerable amount of CO_2. Researchers are making significant efforts to change the profile of traditional concrete towards environmental friendliness. Development of geopolymer (GP) binders is another form of high-performance concrete [15]. GP binders are formed as a result of continuous reaction occurred in alumina-silica rich precursor in the presence of alkaline solution [10].

In the early development stage of GP binders, after mixing and casting exposure to heat regime is identifies as the essential requirement, however, developing the green heat curing conditions is always discussed as the missing gap in the literature. Hardjito [14] observed an increase in compressive strength of LCFA geopolymer concrete with the rise in curing temperature from 30 °C to 90 °C; the optimum curing time was obtained as 24 h. Whereas Adam and Horianto [1] have achieved highest compressive strength by curing at120 °C for 20 h, the results were obtained by curing of samples into three different heat regimes at 80 °C, 100 °C, and 120 °C. In another research, Okoye et al. [26] used five different curing regimes varied from 40 °C to 120 °C at an interval of 20 °C, for 72 h, the maximum strength was achieved at 100 °C.

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Memon et al. [20] developed self-compacting geopolymer concrete; the maximum strength was obtained using curing regime of 70 °C for 48 h. Through a wide range of research on GP binders, it is mostly accepted that the increase in curing temperature and time accelerates the rate of reaction and decreases the early set time, which often caused the enhancement of mechanical properties [27,29]. Outcomes of the previous research studies summarized that GP binders achieved high compressive strength when curing temperature was maintained 60 °C to 120 °C and the curing period was prolonged from 20 to 72 h, which may be questioned from sustainability viewpoints if the source of heat is non-renewable.

Solar is a natural source and identified as the renewable form of energy. Therefore, to answer the question of sustainability regarding heat curing, solar energy can be the possible input of a dedicated heat curing system for geopolymer binders. During last two decades, successful efforts have been made in developing solar ovens for domestic purposes [24,17]. The principal aim of this research study was to develop environmental friendly curing regime for producing high-performance GP matrix. Mahavar et al. [19] have designed a box-shaped solar oven capable of achieving inside temperature of 90 °C within 4 h duration; it traps solar radiation and works on the greenhouse mechanism. Referring to the concept of the solar box of Mahavar et al. [19] a solarcure (SC) technique was designed and used in this research study for heat curing of geopolymer binders. To investigate the effects of SC technique on the properties of GP matrix; two other curing regimes called continuous oven (CO), and intermittent oven (IO) was also used for comparison. For comparative analysis, effects on compressive strength development as well as their microstructures were investigated.

2. Materials and methods

2.1. Material properties

Two types of fly ash LCFA and HCFA obtained from local sources in Malaysia was used as base material for this research. LCFA was acquired from Tanjung Bin 21,00 MW coal-fired power plant located in Johor, Malaysia, while HCFA was collected from the Manjung power plant, Perak, Malaysia. Elemental composition, loss on ignition (LOI) and surface area of the two sources of fly ash were determined using X-ray fluorescence (XRF) and Brunauer Emmet Taller (BET) method; the results are given in Table 1. Both types of fly ashes showed almost similar surface area. However, it is well noted that the CaO content was more than 10% of the total oxides in case of HCFA. Further, the summation of the amount of SiO_2, Al_2O_3, and Fe_2O_3 was less than 70%. Hence the acquired fly ash fulfilled the classification requirements of high calcium fly ash as per ASTM 618-10. Furthermore, Si/Al ratio of HCFA was calculated as 2.49; whereas, it was measured 2.22 in case of LCFA. Fig. 1 shows the micrograph of LCFA and HCFA samples used in this study. The samples were characterized using variable pressure field emission scanning electron microscope (model; VPFESEM Zeiss, supra55 VP). Silica sand with a maximum particle size of 710 μm and fineness modulus of 2.04 was used as aggregates; gradation is given in Table 2. Mineralogy of micro silica sand, LCFA and HCFA were examined by X-ray diffraction (XRD) using Siemens D 501 diffractometer. Fig. 2 is showing that the silica sand was pure quartz (ICSD: 98-016-2490), and no other mineral was found. Mullite (ICSD: 98-009-9328) and quartz were observed in LCFA, whereas HCFA consisted of calcium, sodium, aluminum, silicon oxide (ICSD: 98-010-0222), hematite (ICSD: 98-015-4192), iron nitrate (ICSD: 98-004-4612) and quartz. Sodium hydroxide (NaOH) with 99% purity in mixed with sodium silicate (Na_2Sio_3) was used as an alkaline solution to develop geopolymer reaction.

2.2. Fabrication of solarcure chamber

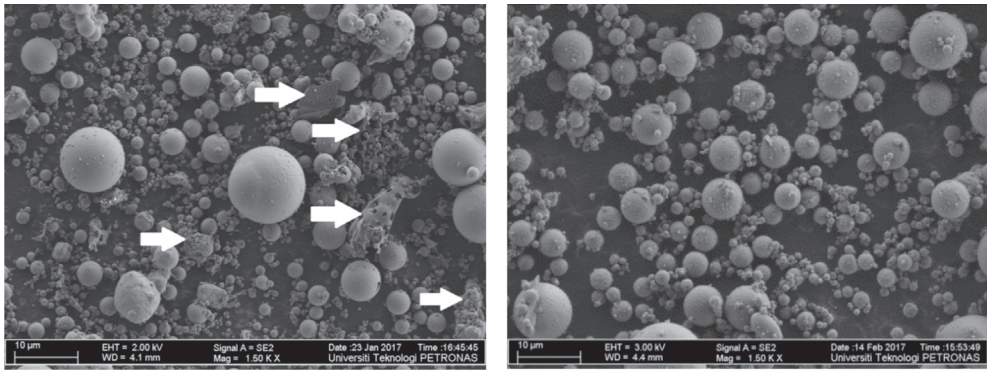
Solarcure (SC) chamber works on the principle of trapping solar radiation to regulate the inside temperature [11]. In the first step; a 3-D frame with the triangular arch at the top to support box-top was fabricated, the inclination angle of the head was kept 30°. After manufacturing the 3-D structure, 12 mm thick thermocol sheets were pasted on the outer walls of the frame, which can maintain an internal temperature of for the long duration and aluminum foil was applied at the inner walls of the box; it can facilitate the solar radiation within the chamber and increase the internal temperature. For avoiding the effects of rain, the outer side of thermocol was laminated with plastic sheets. Bubble wrap was used to make a pad for the solar box. SC chamber was placed at 04°23′13″ N latitude and 100°58-′23″ E longitude with the inclined phase in southern direction refer to Fig. 3. No solar tracking was considered, and the solar box was left in one direction (south) during the whole curing period. Chromel alumel 6 mm Stripped Lead thermocouple (temperature range −50 °C–+200 °C with a ±0.75 °C accuracy) were used to measure the surface temperature of geopolymer cubes. For measurement of inside air temperature of the solar box as well as ambient and external air temperature,100 mm length K type probe with temperature measuring range from −50 °C to +900 °C with maximum error only ±0.75 °C were used.

3. Experimental program

Twelve GP mortar mixes were prepared; the details of mix proportion (by weight) are shown in Table 3. Effects of three curing

Table 1
Elemental composition, loss on ignition (LOI) and surface area of fly ashes.

Chemical composition of fly ash											Average BET surface area
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	SO_3	TiO_2	P_2O_5	LOI	m^2/g
LCFA (%)	50.8	19.6	10.4	8	0.753	2.32	0.596	2.41	2.02	0.6	0.9985
HCFA (%)	34.5	11.8	23.6	19.0	2.27	2.08	1.49	1.46	1.27	2.8	1.0812



a) LCFA b) HCFA

Fig. 1. Micrographs of fly ashes (arrows pointing Conglomerates).