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Designing water resistant lightweight geopolymers produced from waste materials

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ABSTRACT

In the present work, percentage of water absorption and pore structure of lightweight inorganic polymers (geopolymers) produced by fine fly ash, rice husk bark ash and palm oil clinker (POC) aggregates has been investigated. Different specimens, made from a mixture of waste materials, were subjected to permeability and porosimetry tests at 2, 7 and 28 days of curing. The specimens were oven cured for 36 h at 80 °C and then water cured at room temperature until 2, 7 and 28 days. The results showed that high amount of POC particles improve the percentage of water absorption at the early age of curing. In addition the ratio of "the percentage of water absorption" to "weight" of the POC-contained specimens at all ages of curing was much higher than that of POC-free specimens which make them suitable for lightweight applications. The total specific pore volume of the POC-contained specimens was smaller than POC-free specimens at early age of curing. Some empirical relationship was found to predict the total specific pore volume of the specimens by means of their percentage of water absorption at early age of curing with an acceptable approximation. The obtained results from Fourier transform infrared spectroscopy also confirm those results from permeability and porosimetry tests.

1. Introduction

Geopolymer is an inorganic material developed by Davidovits. The materials containing both silica and alumina can be used as a binder to produce geopolymer. Various alkali activators also play a major role in producing geopolymers by dissolving silica and alumina from the raw material and forming aluminosilicate structures. Geopolymer has been used for various works such as for sculpture, building, repairing, and restoration. Numerous research publications relating to geopolymers have been released, with some reporting on chemical composition aspects or reaction processes while others present results relating to mechanical properties and durability [1].

Several waste materials containing silica and alumina sources like fly ashes could be used as a source material to produce geopolymer because of their suitable chemical composition along with favorable size and shape [2,3]. Fly ash is a solid, fine-grained material resulting from the combustion of pulverized coal in power station furnaces. The material is collected in mechanical or electrostatic separators. The term fly ash is not applied to the residue extracted from the bottom of boilers. Fly ashes capable of reacting with $Ca(OH)_2$ at room temperature can act as pozzolanic materials. Their pozzolanic activity is attributable to the presence of SiO_2 and Al_2O_3 in amorphous form. Fly ashes are particularly rich in SiO_2, Al_2O_3 and Fe_2O_3, and also contain other oxides such as CaO, MgO, MnO, TiO_2, Na_2O, K_2O, SO_3, etc. Fly ash with a high content of CaO (15–40%) may be regarded as potentially hydraulic and capable of causing unsoundness in mortars and concrete [4].

One of the suitable silica-reach source is rice husk–bark ash (RHBA) which is a solid waste generated by biomass power plants using rice husk and eucalyptus bark as fuel. The power plant company providing RHBA for this research reported that about 450 tons/day of RHBA are produced and discarded. The major chemical constituent of RHBA is SiO_2 (about 75%) [5,6]. Therefore, blending FA and RHBA can adjust the ratio of Si/Al as required.

In the previous work [7], the properties of geopolymeric specimens with seeded FA and RHBA was studied. It was shown that the finer ashes particles results in higher compressive strength. In addition, that mixture contained the SiO_2/Al_2O_3 ratio equal to approximately three had the best properties. In the present work, experiments were conducted to decrease the weight of the produced specimens using lightweight aggregates. Palm oil clinker (POC) is a by-product in the incineration of palm oil shell. It is a light solid fibrous material which when crushed has the potential to be used as aggregate in lightweight concrete. The density and the strength of POC falls within the requirements of the structural lightweight concrete. This is anticipated to grow further with the global increase in vegetable oil demand. However, it is also the main contributor to the nation's pollution problem, which includes the annual production of 2.6 million tonnes of solid waste in the form of oil palm shells [8].

The aim of this study is to investigate the physical properties of lightweight geopolymers produced by FA, RHBA and POC. Fine FA

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and RHBA were mixed by different amount of POC and subjected to permeability and porosimetry tests. As indicated in the previous work [7], the advantage of using a mixture of ashes is to control the SiO_2/Al_2O_3 ratio to achieve a suitable combination of waste materials result in improved properties. Properties of the produced specimens were investigated after specific times of curing. In addition, the obtained results from permeability tests were supplied by Fourier transform infrared spectroscopy (FT-IR).

2. Experimental procedure

The cementitious materials used in this work were FA and RHBA. Their chemical composition has been illustrated in Table 1. In addition, Fig. 1 shows SEM micrograph of the cementitious materials, respectively. The as-received ashes were sieved and the particles passing the finesses of 33 μm were grinded using Los Angeles mill 180 min. The average particle size obtained for FA was 3 μm with the BET specific surface of 38.9 m^2/g. The average particle size obtained for RHBA was 7 μm with the BET specific surface of 33.1 m^2/g. Fig. 2 shows the particle size distribution of the two produced samples.

Table 1
Chemical composition of FA, RHBA and WG (wt.%).

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	Na_2O	Loss on ignition
FA	35.21	23.23	12.36	20.01	2.36	0.36	0.24
RHBA	81.36	0.4	0.12	3.23	0.85	–	3.55
WG	34.21	–	–	–	–	13.11	–

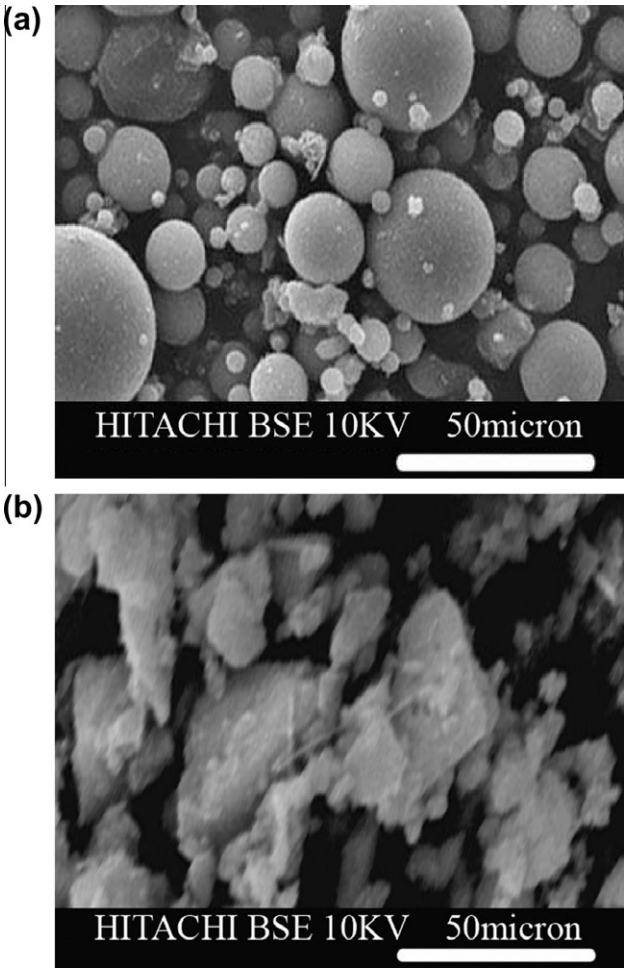

Fig. 1. SEM micrograph of (a) FA and (b) RHBA used in this study.

POC particles less than 7 mm and 7–18 mm size were used as fine and coarse aggregate. The density of fine and coarse POC was 1015 and 693 kg/m^3 respectively.

Sodium silicate solution or water glass (WG) and sodium hydroxide (NaOH) were used as the solution part of the mixture. WG was used without following modification, but the sodium hydroxide was diluted to different concentrations before using. The chemical composition of the utilized WG is also given in Table 1.

Totally two series of geopolymer specimens each contain different mixture of FA, RHBA and POC as illustrated in Table 2 were prepared for the tests. The mixture of FA to RHBA had a constant ratio of 70:30 and a bulk density of 2318 kg/m^3 to achieve SiO_2/Al_2O_3 ratio equal to approximately three [7]. The mixed alkali activator of sodium silicate solution and sodium hydroxide was used. Sodium hydroxide was diluted by tap water to have concentrations of 12 M since this concentration was found to produce the best properties [7]. The solution was left under ambient conditions until the excess heat had completely dissipated to avoid accelerating the setting of the geopolymeric specimens. The sodium silicate solution without preparation was mixed with the sodium hydroxide solution. The ratio of the sodium silicate solution to sodium hydroxide solution was 2.5 by weight for all mixtures because this ratio demonstrated the best properties for fly ash-based geopolymer [9,10]. For all samples, the mass ratio of alkali activator to FA-RHA mixture was 0.4. Pastes were mixed by shaking for 5–10 min to give complete homogenization. The mixtures were cast in ∅30 mm × 60 mm polypropylene cylinders. The mixing was done in an air-conditioned room at approximately 25 °C. The molds were half-filled, vibrated for 45 s, filled to the top, again vibrated for 45 s, and sealed with the lid. The mixtures were then precured for 24 h at room temperature (this precuring time has been found to be beneficial to strength development and hence improved properties [11]). Precuring time before application of heat induces significant dissolution of silica and alumina from fly ash and formation of a continuous matrix phase, increasing, therefore, the homogeneity of the geopolymeric materials [11,12]. After the precuring process, the samples and molds were placed in a water bath to prevent moisture loss and the carbonation of the surface. The batches were put in the oven at the elevated temperatures of 80 °C for 36 h. Again this temperature and time was found to have the best effect on the properties of the specimens [7]. The percentage of water absorption results of the produced specimens were measured on the cylindrical samples at 2, 7 and 28 days of curing (including oven curing). Three tests were carried out on each mixture and the average values were reported.

To prepare the water permeability testing specimens, 1 cm from the top and bottom of the samples from each mixture were removed to avoid any effects caused by surface paste. Hence, the samples having ∅30 mm × 40 mm were used as representative specimens for each mixture. Non-shrinking epoxy resin was cast around all specimens with a thickness of 25 mm to prevent water leakage. These specimens were installed in housing cells to test their water permeability. In this work, to evaluate the water permeability of the specimens, percentage of water absorption is an evaluation of the pore volume or porosity of concrete after hardening, which is occupied by water in saturated state. Water absorption values of the samples were measured in accordance to the ASTM C642 [13] after 7 and 28 days of moisture curing adapted to the method done for concrete specimen.

In this study, the pore structure of concrete is evaluated by using mercury intrusion porosimetry (MIP). There are several methods generally used to measure the pore structure, such as optics method, MIP, helium flow and gas adsorption [14]. MIP technique is extensively used to characterize the pore structure in porous material as a result of its simplicity, quickness and wide