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Use of coal ash as geopolymer binder and coarse aggregate in pervious concrete

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HIGHLIGHTS

- Waste from coal ash was used to produce pervious geopolymer concrete (PGC).
- Fly ash was used as geopolymer binder and bottom ash as coarse aggregate.
- NaOH concentration, level OPC replacement, and curing temperature were varied.
- The obtained PGCs are suited for use as an environment friendly concrete.

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ABSTRACT

Fly ash (FA) and bottom ash (BA) are wastes from coal combustion power plant. Due to its coarse and porous particle, BA is usually disposed of at landfill sites. While, as-received FA can be used as pozzolanic material and source material to produce geopolymer binder. This study focused on the use of FA as geopolymer binder and BA as coarse aggregate to produce pervious concrete. The effect of NaOH concentration, partial replacement of FA with ordinary Portland cement (OPC), and curing temperature on the properties of pervious geopolymer concrete (PGC) were investigated. The results showed that the strengths of PGC increased with both NaOH concentration and level of OPC replacement. The curing at elevated temperature (90 °C) was a significant factor for the strength development. The PGCs containing BA had the thermal conductivity of 0.30–0.33 W/m K, density of 1466–1502 kg/m^3, and compressive strength of 5.7–8.6 MPa and are suited for use as an environment friendly concrete.

1. Introduction

The coal fired thermal power plant produces a large amount of ash. Fly ash (FA) is the major waste ash and is used as a pozzolan for partial replacement of Portland cement in concrete work. Due to its aluminosilicate composition and fine particle size, FA is also used as a source material to produce geopolymer binder with excellent early age compressive strength, sulfate resistance, and chloride resistance [1–3]. Apart from FA, a significant quantity of bottom ash (BA) is also produced. As-received BA is low in pozzolanic property as a result of its coarse particle size and is generally dumped in a disused mine. With similar chemical compositions to FA and ground to a proper fineness, BA can be used as a pozzolan [4] and can also be utilized as a source material for making geopolymer [5]. In addition, BA can be used as a lightweight aggregate for making lightweight concrete due to its high porosity and low density [6–8].

Pervious or permeable concrete has interconnected voids as a result of lacking in fine aggregate. It can be used for green pavement design [9–11] because of various environmental benefits such as reducing storm water runoff rates, protecting water supplies, and adjusting temperature and humidity of earth's surface. In a framework of pervious concrete, coarse aggregates are bound together with a binder. Using Portland cement as a binder can make pervious concrete with sufficient strength for porous pavement applications [10,12]. However, cement production uses significant amounts of natural resources and has a large environmental footprint. The previous studies [13,14] showed that fly ash-based pervious geopolymer concrete gave the compressive strength within the ACI 522 [11] recommended range. Therefore, the utilization of geopolymer binder in the production of pervious concrete offers an alternative environment friendly material.

This research aimed to study the properties of pervious geopolymer concrete (PGC) made from FA geopolymer binder

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Table 1
Chemical composition of OPC, FA, and BA.

Chemical compositions (%)	OPC	FA	BA
SiO_2	14.4	35.9	31.8
Al_2O_3	2.7	15.1	12.1
Fe_2O_3	3.4	17.3	18.0
CaO	70.4	17.2	25.3
MgO	0.9	2.3	2.4
Na_2O	0.2	0.9	0.9
K_2O	0.6	3.2	2.5
SO_3	4.3	5.9	3.7
TiO_2	0.3	0.9	0.5
LOI	2.4	1.1	2.6

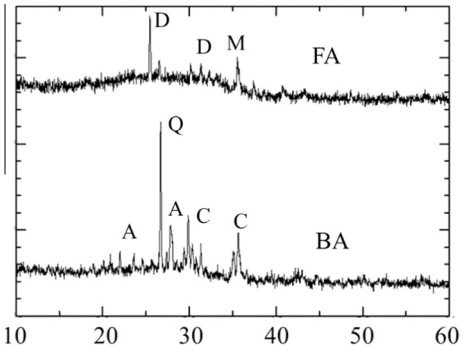

Fig. 1. XRD patterns of FA, and BA. D = Dachiardite, M = Magnetite, Q = Quartz, A = Anorthite, C = Diopside.

and BA as coarse aggregate. The effects of NH concentration, partial replacement of FA with OPC, and curing temperature were investigated. The obtained knowledge and data should help to promote the use of waste from coal fired thermal power plant for producing an environment friendly concrete.

2. Experimental details

2.1. Materials

The fly ash (FA) and bottom ash (BA) were from Mae Moh power station in the north of Thailand. FA was used as a source material for making geopolymeric binder and BA was used as a coarse aggregate. The results of the XRF analysis of the coal ashes are shown in Table 1. FA can be classified as high calcium fly ash according to ASTM C618 [15]. The XRD patterns of FA showed higher amorphous phase than BA as indicated by the hump between 20° and 30° 2-theta as shown in Fig. 1. BA with specific gravity of 2.40, unit weight of 1230 kg/m^3 (in saturated surface dry condition), water absorption of 3.83%, and Los Angeles abrasion resistance of 39.4% was crushed and sieved to obtain particle size range of 4.75–9.50 mm. BA was angular in shape with high porosity and rough surface as shown in Fig. 2. Sodium hydroxide (NH) (10 and 15 M), and sodium silicate (NS) with 13.8% Na_2O, 31.8% SiO_2 and 54.4% H_2O by weight were used as alkaline activators. In addition, Portland cement type I (OPC) was used as an additive to replace of FA at the levels of 5%, 10%, and 15% by weight of binder. The use of OPC to partially replace FA results in the reduction of setting time and increase in the strength of fly ash geopolymer paste [16].

2.2. Mix proportions

The designed void ratio of 32% and the paste volume of 22% were used for all PGC mixes to avoid the variation. This condition provided appropriate thickness of paste covering of aggregate without dripping of paste. NS/NH ratio of 0.6 and liquid/binder ratio of 0.3 were selected to control a suitable flow value of paste between 150 and 230 mm [17,18]. The first series was designed to study the effect of concentration of NH and replacement of FA with OPC on the properties of PGC. Two NH concentrations of 10 and 15 M were used. FA was replaced with OPC at 0%, 5%, 10%, and 15% by weight of binder. The second series was designed to study the effect of curing temperature on the properties of PGC. Three curing temperatures of 60, 90 and 120 °C were selected.

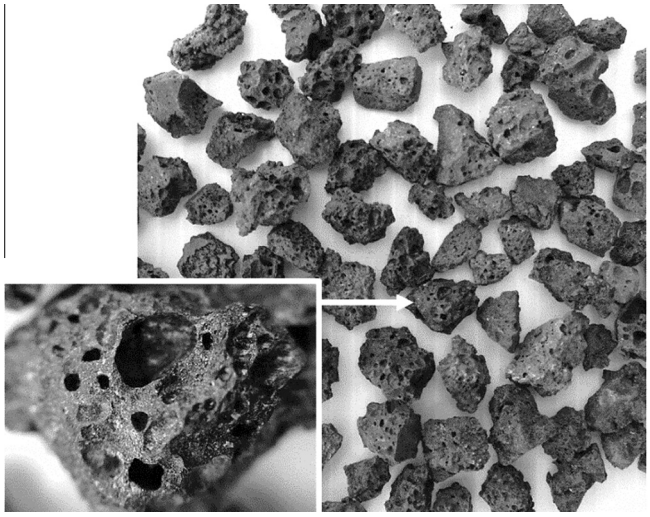

Fig. 2. BA particles.

Table 2
Mix proportions per m^3 and curing temperature of PGCs.

Mix	BA (kg)	Geopolymer paste					Curing temperature (°C)
		FA (kg)	OPC (kg)	NH (kg)		NS (kg)	
				10 M	15 M		
Effect of the concentration of NH and the replacement of FA with OPC							
10M0C90T	1175	320	–	60	–	36	90
10M5C90T	1175	304	16	60	–	36	90
10M10C90T	1175	288	32	60	–	36	90
10M15C90T	1175	272	48	60	–	36	90
15M0C90T	1175	327	–	–	61	37	90
15M5C90T	1175	311	16	–	61	37	90
15M10C90T	1175	294	33	–	61	37	90
15M15C90T	1175	278	49	–	61	37	90
Effect of the curing temperature							
10M10C60T	1175	288	32	60	–	36	60
10M10C90T	1175	288	32	60	–	36	90
10M10C120T	1175	288	32	60	–	36	120

Note: In all mixes, the designed void ratio = 32% and paste volume = 22%.

The names of PGCs were given by NH concentration (M), level of the replacement (C), and curing temperature (T). For example, 10M5C90T is PGC with 10 M NH, 5% OPC replacement and 90 °C curing temperature. The mix proportions of PGC are shown in Table 2.

2.3. Mixing and preparation of samples

For mixing, FA and OPC were mixed in the mixer to obtain a homogenous blend. NH was added and mixed for 5 min, and NS was then added and mixed for another 2 min. In the last step, BA in saturated surface dry condition was added and mixing was continued for 1 min.

The mixture was molded using the standard tamping rod and vibrating table. The cast samples were covered with plastic sheet, cured at temperature of 60, 90, and 120 °C for 48 h, demolded and stored in a 25 °C moist room until the testing ages. The 100 × 200 mm cylindrical samples were used for density, total void ratio, water permeability, compressive strength, splitting tensile strength, and ultrasonic pulse velocity tests and the 150 × 150 × 60 mm prism samples for the thermal conductivity and surface abrasion resistance tests.

3. Testing

The properties of PGCs were tested at the age of 7 days. The samples for compressive strength tests were capped at both ends with sulfur capping compound in accordance with ASTM C39 [19] to fill the voids and level both ends of concrete cylinder. The splitting tensile strengths were tested in accordance with ASTM