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High calcium fly ash geopolymer mortar containing Portland cement for use as repair material

Tanakorn Phoo-ngernkham [a], Vanchai Sata [b], Sakonwan Hanjitsuwan [c], Charoenchai Ridtirud [d], Shigemitsu Hatanaka [e], Prinya Chindaprasirt [b,*]

[a] Research Center for Advances in Civil Engineering and Construction Materials, Program in Civil Engineering, Faculty of Engineering and Architecture, Rajamangala University of Technology Isan, Nakhon Ratchasima 30000, Thailand
[b] Sustainable Infrastructure Research and Development Center, Dept. of Civil Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen 40002, Thailand
[c] Program of Civil Technology, Faculty of Industrial Technology, Lampang Rajabhat University, Lampang 52100, Thailand
[d] Dept. of Civil Engineering, Faculty of Engineering, Rajamangala University of Technology Isan, Khon Kaen Campus, Khon Kaen 40000, Thailand
[e] Dept. of Architecture, Faculty of Engineering, Mie University, Mie 514-8504, Japan

HIGHLIGHTS

- FA geopolymer mortars (GPM) containing PC could be used as alternative repair material (RM).
- GPM gave sufficiently high slant bond and bending strengths compared with RM.
- The interface zone of concrete and GPM was more homogeneous and denser than that of concrete and RM.

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ABSTRACT

This article investigated the utilization of high calcium fly ash geopolymer mortars (GPM) containing ordinary Portland cement (PC) for use as Portland cement concrete (PCC) repair material. The shear bond strength of PCC substrate and repair binder and bending strength of notched concrete beam filled with repair binder were used to evaluate the performances of GPM and commercial repair binders (RM). Test results indicated that the use of GPM gave sufficiently high shear bond and bending strengths compared with the use of RM suggesting that it could be used as an alternative product for concrete repair works. In addition, the results from scanning electron microscopy of fracture surfaces indicated that the interface zone of concrete and GPM was more homogeneous and denser than that of concrete and RM. The GPM with 14 M NaOH solution and 10% PC was the optimum mixture for improving the shear bond and bending strengths.

1. Introduction

Geopolymer is made from silica and alumina source materials activated with high alkali solutions such as sodium hydroxide (NaOH), potassium hydroxide (KOH), sodium silicate and potassium silicate [1]. A number of supplementary cementitious materials such as ground granulated blast furnace slag, metakaolin and fly ash are commonly used source materials in geopolymer for their availability and favorable mechanical properties [2–6].

Several researchers [7–10] reported that high calcium fly ash is also a suitable source material for making good geopolymer. The high calcium fly ash geopolymer mixture can be cured at room temperature as a result of the reaction of calcium in the system. However, the geopolymerization of high calcium fly ash without additives is still slow at ambient condition [10,11], therefore, low strength is normally obtained. The use of Portland cement to enhance the strength of high calcium fly ash geopolymer is very attractive [8,12–14]. In addition to the formation of calcium silicate hydrate, the heat from the reaction of Portland cement and water can assist the geopolymerization process and enhances the strength development [15]. High calcium geopolymer mortar with compressive strength of 65 MPa has been fabricated with the addition of Portland cement cured at 25 °C ambient temperature [8].

The commercial repair materials with good mechanical property and bonding strength are widely used for repair work in concrete. However, the costs of these products are rather expensive. Alternative repair material with comparable properties but less

* Corresponding author.
E-mail address: prinya@kku.ac.th (P. Chindaprasirt).

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expensive is, therefore, a subject of interest. A number of researchers [9,16–19] have tried to utilize geopolymer as a repair material by testing slant shear, pull-out and direct shear. Hu et al. [16] studied the bond strength between mortar substrate and geopolymer in sandwich specimens and reported that geopolymer exhibited higher bonding strength than that of comparable Portland cement mixture. Pacheco-Torgal et al. [17] determined the bond strength between concrete substrate and geopolymer mortar produced from tungsten mine waste containing calcium hydroxide and found that the geopolymeric binders had very high bond strength even at early ages compared with that of commercial repair products. In addition, Songpiriyakij et al. [18] also tested the bond strength between rebar and concrete substrate by using geopolymer paste as the bonding agent, and reported that the bond strengths of rice husk ash and silica fume geopolymer pastes were approximately 1.5 times higher than those of comparable repair epoxies. Therefore, the bond strengths of geopolymer materials are sufficiently high and should be used as an alternative bonding material for repair works.

The objective of this research is, therefore, to investigate the utilization of high calcium fly ash geopolymer mortars containing ordinary Portland cement as additive for use as a repair binder. The obtained knowledge would be very beneficial to the understanding and to the future application of geopolymer products as an alternative repair material.

2. Experimental details and testing analysis

2.1. Materials

2.1.1. Geopolymer mortars

The geopolymer mortar (GPM) was made from high calcium fly ash (HFA) from Mae Moh power plant in northern Thailand and local river sand with specific gravity of 2.63 and fineness modulus of 1.80. Sodium hydroxide solution (NaOH) and sodium silicate solution (13.89% Na_2O, 32.15% SiO_2, and 46.04% H_2O) were used as liquid activators. Four levels of HFA replacement by ordinary Portland cement (PC) of 0%, 5%, 10%, and 15% by weight and three NaOH concentrations of 6, 10, and 14 M (molar) were investigated. The chemical composition and physical properties of HFA and PC are shown in Tables 1 and 2, respectively. The mix proportions and strengths of GPM are shown in Table 3. For the mixing of mortars, NaOH and Na_2SiO_3 solutions were mixed together prior to the start of mixing. The HFA, PC and sand were dry mixed until a homogenous mass was obtained. The prepared liquid solution was then added and the mixing was done for 5 min. The setting time of mortar was also tested in accordance with ASTM C807 [20]. As shown in Table 4, the setting time of GPM was dependent on NaOH concentration and PC content. The final setting times ranged between 12 and 130 min and this could be used advantageously in adjusting the setting of repair material.

2.1.2. Ordinary Portland cement concrete

The mix proportions and strengths of ordinary Portland cement concrete (PCC) are shown in Table 5. The local river sand with specific gravity of 2.61 and fineness modulus of 2.40 was used as fine aggregate. While, crushed limestone with specific gravity of 2.71 and fineness modulus of 6.05 was used as coarse aggregate. The PCC was used for preparing two types of specimen viz., slant shear test specimens and bending test specimens. For the slant shear specimens, the fresh PCC was cast in 50 × 50 × 125 mm prism molds. They were cured in water for 28 days and then wrapped with vinyl sheet to protect moisture loss and cured for another 60 days. This long curing period was chosen to provide advanced hydration as in the old concretes in the construction field based on the previous research [21]. The PCC prisms were cut in the middle section with the interface line at 45° to the vertical (see Fig. 1) to provide the PCC substrate for the slant shear specimens. For the preparation of specimens for bending stress, the PCC was cast in 75 × 75 × 300 mm long beams. They were cured similarly to the slant shear specimens. A notch with height to beam depth (a_0/d) ratio of 0.4 and notch width to notch height (w_0/a_0) ratio of 0.4 was cut in the middle of beam (see Fig. 2).

Table 2
Physical properties of materials.

Materials	Specific gravity	Median particle size, d_{50} (μm)	Blaine fineness (cm^2/g)
HFA	2.61	8.5	4300
PC	3.16	14.6	3600

2.1.3. Commercial repair material products

Five available commercial repair material products (RM) were also tested. This was done so that the performance of GPM could be compared with those of commercial products. RM1 is general purpose non-shrink grout mortar; RM2 is high performance repair and finishing mortar; RM3 is fiber-reinforced non-shrink mortar; RM4 is multi-purpose non-shrink grout; and RM5 is polymer modified repair mortar. The amount of water in these products directly influences the compressive and flexural strengths including the bond adhesion; therefore, the recommended water/binder (W/B) ratios were strictly used. The obtained strengths of these repair materials are summarized in Table 6.

2.2. Testing and analysis

2.2.1. Shear bond strength between PCC substrate and GPM or RM

The shear bond strength was evaluated using the slant shear test of PCC substrate and GPM or RM as described in ASTM C882 [22] with stiffer slant shear angle of 45°. The slant shear angle of 45° is officially used for standard evaluation of epoxy bond with concrete [23] and was also used successfully in testing shear bond of concrete and geopolymer [6]. For casting of the specimens, the GPM was placed in two equal layers into a 50 × 50 × 125 mm prism mold, half-filled with slant PCC substrate. Each layer was tamped 25 times and vibrated for 45 s. The samples were covered with vinyl sheet and kept in the 25 °C controlled room. The specimens (as shown in Fig. 1) were tested in a constant loading rate of 0.30 MPa/s. The shear bond strength was the ratio of maximum load at failure and the bond area. The reported results of shear bond strength were the average of five samples.

2.2.2. Bending stress of PCC notched beam with filled GPM or RM

This test used the same type of specimens as in the test of fracture characteristics as shown in Fig. 2. For casting of specimens, the GPM or RM was mixed and filled in the notch to act as repair materials. The samples were covered with vinyl sheet to protect moisture loss and kept in the 25 °C controlled room until the testing age of 28 days. The specimens were tested by three point bending with deflection control using loading rate of 0.05 mm/min [24]. The reported results were the average of five samples.

2.2.3. Interface zone between PCC substrate and GPM or RM

The samples between PCC substrate and repair materials were broken and analysed by the scanning electron microscopy (SEM). The samples were cut, then coated with a layer of gold approximately 20–25 Å thick using a blazer sputtering coater. After that, they were placed on a brass stub sample holder with double stick carbon tape. A JEOL JSM-700IF scanning electron microscopy was used to study interface zone between PCC substrate and GPM or RM.

3. Results and discussion

3.1. Shear bond strength between PCC substrate and GPM or RM

The results of 45° slant shear load carrying capacity of PCC substrate and GPM or RM are shown in Fig. 3. The shear bond strengths increased with the increased PC content and NaOH concentration. The noticeable increase in shear bond strength was due to the increase in the reaction products. This is in line with the previous report [25]on the improved strength of fly ash based geopolymers with increased calcium content which the additional C–S–H and C–A–S–H gel co-existed with N–A–S–H gel of GPM. The increase in reaction products at the interface transition zone between PCC substrate and GPM enhanced the strength at contact

Table 1
Chemical composition of HFA and PC (by weight).

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	LOI
HFA	29.32	12.96	15.64	25.79	2.94	2.93	2.83	7.29	0.30
PC	20.80	4.70	3.40	65.30	1.50	0.40	0.10	2.70	0.90