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Contributed Paper

Interfacial Transition Zone of Pervious Cement and Geopolymer Concrete Containing Crushed Clay Brick

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ABSTRACT

This research studies the interfacial transition zones (ITZ) of pervious geopolymer concrete and pervious cement concrete containing recycled coarse aggregate from crushed broken clay brick (RCB). Geopolymer and cement pastes were used as binder. Geopolymer was synthesized using fly ash, sodium hydroxide solution and sodium silicate. Physical observation, optical microscope (OM) and SEM, EDS techniques were used to characterize ITZ of both pervious concretes. XRD technique also used to characterize the crystalline phases of geopolymer pastes and cement paste. In addition, the compressive strength of geopolymer pastes, cement paste, pervious geopolymer concrete, and cement pervious concrete were also determined at the age of 7 days. The results showed that the ITZ of pervious geopolymer concrete and pervious cement concrete were totally different in shape. The ITZ of pervious cement concrete was wider than those of geopolymer system. It was also found that geopolymerization reaction occurred rapidly when fly ash was mixed with alkali activated solutions and it might not contribute to the network in ITZ while hydration reaction from cement paste and water had $Ca(OH)_2$ which had an opportunity to coat around the aggregates. Although cement paste presented the highest compressive strength as a binder, the compressive strength of cement pervious concrete was lower than those of geopolymer pervious concrete.

Keywords: pervious concrete, geopolymer, recycled aggregate, crushed clay brick

1. INTRODUCTION

Pervious concrete is special type of concrete with a high porosity compared to normal concrete. It made by coarse aggregates and used cement paste to coat the aggregates. This type of concrete allows water to pass through the concrete [1-3]. Basically, pervious concrete consists of binder, coarse aggregates, water and admixture. The binder volume can be composed of cement and water. Then, the binder consistency coats each aggregate particle and provides a good workability performance. Not only cement paste but also cementitious material such as geopolymer can be used as binder for pervious geopolymer. Geopolymer is an innovative material which was synthesized by mixing between aluminosilicate material such as fly ash and alkali activated solution such as sodium hydroxide (NaOH). Generally, there are three types of geopolymer products which are polysialate (Si-O-Al), polysialate siloxo (Si-O-Si-O-Al) and polysialate disiloxo (Si-O-Si-O-Si-O-Al). Geopolymer presented excellent mechanical properties such as high compressive strength, low shrinkage and acid resistance [4]. In addition, Sata et al. [5] crushed recycle structural concrete member and RCB can be used as an aggregate for pervious concrete instead of natural coarse aggregate. Pervious concrete have been applied to civil engineering field such as permeable pavement and thermal insulation.

There are at least three phase composite in concrete which are (1) bulk cement paste, (2) ITZ cement paste, and (3) rock and sand, collectively called aggregates [6]. Since pervious concrete had only binder coats around aggregate, the interfacial transition zone (ITZ) between binder and aggregates is very essential and should be discussed. It was found that ITZ is a weakness zone in the microstructure of concrete, but it is one of the most important factors influencing the performance of concrete. The ITZ is not a definite "zone", but a region of "transition" [7]. The characterizations of ITZ in concrete have been reported. Nevertheless, the ITZ of pervious concrete is complex and has not been fully understood yet.

Thus, this research aims to study ITZ microstructure of pervious geopolymer and pervious cement concrete containing recycled coarse aggregate from crushed broken clay brick (RCB). ITZ was described by using optical microscope (OM) and scanning electron microscope (SEM) in order to clearly observe fracture surface at ITZ. X-ray diffraction also used to characterize binder both cement paste and geopolymer pastes. Compressive strength of binder pastes and pervious concretes were investigated at the age of 7 days. The understanding of ITZ in pervious concrete was obtained.

2. MATERIALS AND MOTHOD

2.1 Materials

Fly ash was obtained from Mae Moh Electricity Power Plant Station, Lumpang province, Thailand. It had a median particle size of 50 μm, a Blaine fineness of 2250 cm^2/g, and 45% (by weight) retained on 45 μm sieve. Fly ash had sum of SiO_2, Al_2O_3 and Fe_2O_3 of 71.7% and high calcium content of 19.4% indicated Class C pozzolan according to ASTM C618 [8].

Two concentrations of sodium hydroxide (NaOH) at 15 and 20 molar, and a commercial grade sodium silicate solution (Na_2SiO_3) were used to be an alkaline activator for geopolymer pastes.

Recycled aggregate from crushed broken clay brick (RCB) with 4.5-9.5 mm diameter obtained from construction site. RCB was from local clay bricks with compressive strengths of 5.0-9.0 MPa. The specific gravity of RCB was 2.02 with dry-rodded density of 950 kg/m^3. RCB had high water absorption at 16.2% and high Los Angeles abrasion loss at 42.4%.

2.2 Synthesis Pervious Geopolymer Concrete and Pervious Cement Concrete

The mixing of geopolymer pervious concrete, fly ash was used to be starting material of geopolymer. A ratio of fly ash to RCB of 1 to 8 by weight was applied. The $Na_2SiO_3/NaOH$ was kept at 0.5 and NaOH concentration at 15 and 20 M were prepared for geopolymer pastes. The liquid to binder ratio was kept constant at 0.45.

The mixing of pervious geopolymer concrete, fly ash and NaOH were mixed in a pan-type mixer for 5 min. Then, RCB was added and mixed for 4 min. The last step mixing, Na_2SiO_3 was added and mixed for another min.

The mixing of pervious cement concrete, cement was mixed with water at liquid to binder ratio of 0.45 for 5 min, then, RCB was added and mixed for 4 min.

After mixing both two types of pervious concrete, they were cast in cylinder mold with 100 mm diameter and 200 mm height.

2.3 Study Property of Pervious Concrete

The cement specimens were cured in water until the testing age. For geopolymer specimens were cured at 60 °C for 48 hr. After that, they were wrapped with a thin plastic sheet and stored in the 25°C controlled. The compressive strength of both geopolymer and cement pervious concrete were determined at the age of 7 days in accordance with ASTM C39. The results were presented as the average value of three specimens.

2.4 Study Microstructure of ITZ

After the compressive strength test, a piece of geopolymer pervious concrete and cement pervious concrete were collected to study microstructure of ITZ as followed:

Optical microscope (OM) was used to observe surface of pervious geopolymer and pervious cement concrete containing RCB by visible light.

Scanning electron microscope (SEM) and Energy Dispersive Spectroscopy (EDS) technique were used to characterize ITZ zone of pervious geopolymer and pervious cement concrete containing RCB.

2.5 Characterization Binder by XRD Technique

X-Ray Diffractometer (XRD) was used to study the crystalline phase of cement paste, geopolymer pastes and RCB. X-ray diffractometer using D8000 with $CuK\alpha$ (k =1.54056 Å) radiation generated at 40 mA and 40 kV. Data collection was carried out in the 2q range 10° - 80°, with a step time of 0.1 sec.

3. RESULTS AND DISCUSSION

3.1 Physical Observation of Pervious Cement and Pervious Geopolymer Concretes Containing RCB

Figure 1 show physical observation of pervious cement and pervious geopolymer concretes containing RCB, respectively. Both pervious cement concrete and pervious geopolymer concrete had a surface that looks similar. It was clearly seen the color of materials by physical observation. RCB was red and binders (cement paste and geopolymer paste) were gray. It can be noticed that pervious cement concrete had ITZ wider than pervious geopolymer concrete and surrounded RCB. In order to clearly observe ITZ of pervious geopolymer and pervious cement concrete, OM technique have been used and discussed in the next session.

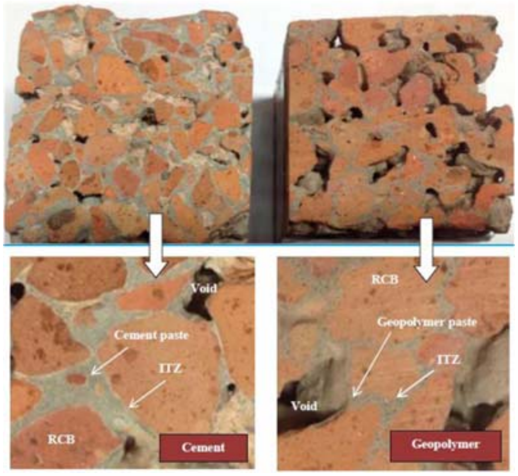
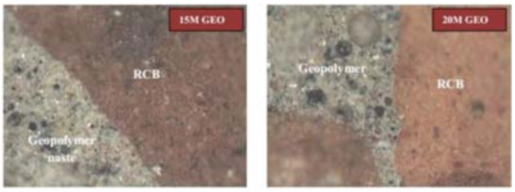


Figure 1. Physical observation of pervious concrete containing RCB.

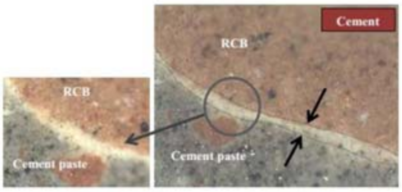
3.2 Characterized the Interfacial Transition Zone (ITZ) by OM Technique

Figure 2 shows ITZ between geopolymer pastes and RCB (Figure 2 (a) and Figure 2 (b)) and Figure 2(c) shows ITZ between cement paste and RCB. ITZ was characterized by optical microscope (OM) technique.

Geopolymer pervious concrete both 15 molar (15M GEO) and 20 molar (20M GEO) showed the same texture which were connected by without shape of ITZ. On the other hand, ITZ between cement paste and RCB had a large thickness. In addition, different color of geopolymer pastes, cement paste and RCB were clearly observed. It can be obvious that RCB were red, cement pastes were gray, geopolymer pastes were brown and the white-yellow color which was possible be reaction between cement paste and RCB was occurred at ITZ. After using high magnification in OM technique, it was clearly seen white-yellow color at ITZ.



(a) ITZ between 15M GEO and RCB (b) ITZ between 20M GEO and RCB



(c) ITZ between cement and RCB

Figure 2. ITZ of pervious concrete.

It can be mentioned that fly ash react with alkali solution quickly, ITZ zone between geopolymer and RCB hardly seen in the surface. On the other hand, hydration reaction from cement paste has product of calcium hydroxide (CH) which can form CSH gel when it had silica source to react with CH. It is possible that calcium hydroxide from hydration product react with silica from RCB and present ITZ zone as can be seen by OM technique. In order to deeply understand ITZ of geopolymer pervious concrete and cement pervious concrete, SEM and EDX techniques were investigated to characterize fracture surface and element composition on surface of pervious concrete as described in the next session.

3.3 Characterized the Interfacial Transition Zone (ITZ) by SEM and EDS Techniques

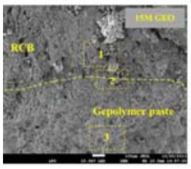
After study the ITZ zone of pervious concrete by OM technique, the results show the different shape of ITZ between pervious geopolymer concrete and pervious cement concrete containing RCB. Thus, SEM observations aim to characterize ITZ zone in high magnification. EDS analysis also investigated at binder, aggregate and ITZ zone in order to discuss the influence of the element with respect to aggregate.

ITZ between 15M GEO and RCB; 20M GEO and RCB are shown in Figure 3 and Figure 4, respectively. The reaction products in the ITZ grew and clearly observed in all samples. 15M GEO and 20M GEO had the similar ITZ morphology. The high percentages of silicon were found. Interestingly, the percentage of silica at ITZ (position 2) was slightly higher than that of geopolymer paste (position 1) which might be the results of leaching from RCB (position 3). The morphology of 20M GEO can be noticed that it hardly seen ITZ between geopolymer paste and RCB. Both of geopolymer and RCB had a tendency homogeneous.

ITZ between cement and RCB is shown in Figure 5. It is noticed that cement paste presented thickness of ITZ at most. It can be seen the different texture of each materials.

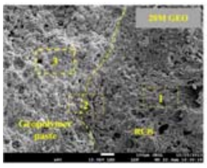
RCB had rough texture while cement paste had smooth texture. At ITZ zone, the long rough shape can be observed. It was found high percentage calcium element in position 2 as can be detected by EDS technique. A few researchers suggested that calcium hydroxide had rich in ITZ area and presented weakness point of concrete [9].

From EDS technique at 1000X magnification, it was found that ITZ morphology had high percentage of calcium and silicon. The product at ITZ might be from pozzolanic reaction between calcium hydroxide from cement hydration and silica in RCB. Scrivener et al. [7] suggested that ITZ depended on the microstructural feature being considered and the degree of reaction. At the early state of hydration, calcium silicate hydrate (CSH gel) and calcium hydroxide (CH) are formed through the solution.



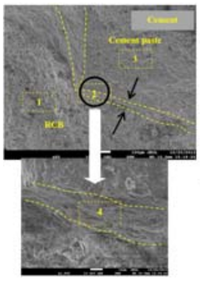
Element	Atomic %		
	Position 1	Position 2	Position 3
	RCB	ITZ	Geopolymer paste
Al	6.05	5.38	5.04
Si	21.37	18.24	12.56
Ca	0.30	0.61	2.25
Na	1.09	1.14	3.67

Figure 3. ITZ between 15M GEO and RCB.



Element	Atomic %		
	Position 1	Position 2	Position 3
	RCB	ITZ	Geopolymer paste
Al	5.22	5.13	4.14
Si	14.16	14.39	12.34
Ca	0.61	0.82	2.15
Na	1.10	6.44	4.75

Figure 4. ITZ between 20M GEO and RCB.



Element	Atomic %			
	Position 1	Position 2	Position 3	Position 4
	RCB	ITZ	Cement paste	ITZ (1000X)
Al	1.51	13.88	25.21	1.47
Si	68.06	32.78	119.33	17.01
Ca	11.51	46.48	18.07	53.06
Na	-	-	-	-

Figure 5. ITZ between cement and RCB.

3.4 X-ray Diffraction Analysis

Figure 6 shows XRD patterns of geopolymer pastes and cement paste. It was found that XRD patterns of both 15M GEO and 20M GEO had both amorphous phase and crystalline phases. The XRD pattern was changed slightly after the specimen had 20M NaOH concentrations. Nevertheless, both 15M GEO and 20M GEO found that amorphous hump of SiO_2 were observed at 2q between 20° - 40°. New crystalline phases of sodium aluminum silicate hydrate, calcium silicate hydrate and chabazite-Na were found which came from geopolymerization reaction of geopolymer. In addition, the remaining of unreacted fly ash which was crystalline of quartz (SiO_2) was also found.

In cement paste, The major products of phase hydration would be calcium silicate hydrate gel (CSH) and calcium hydroxide ($Ca(OH)_2$) [10]. XRD pattern of cement pastes had crystalline phases of katoite silicatian, cebollite and portlandite which occurred from hydration reaction.

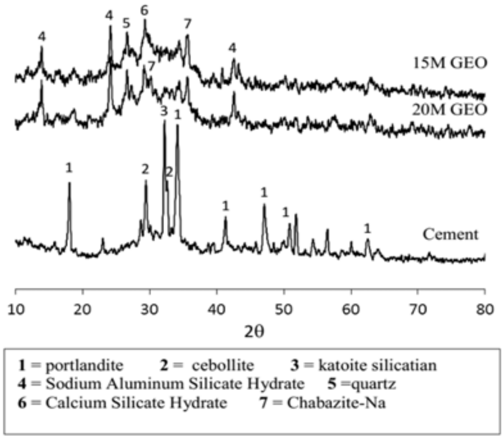


Figure 6. XRD pattern of geopolymer pastes (15M GEO and 20M GEO) and cement paste.

Figure 7 showed XRD pattern of RCB. It was found that RCB mainly composed of crystalline phases of quartz. Actually, RCB made from clay, lime, sand and concrete. Clay has high in silica content.

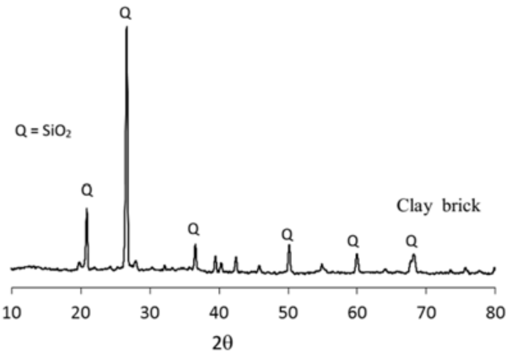


Figure 7. XRD pattern of RCB.

3.5 Mechanical Properties of Binder Pastes and Pervious Concretes

3.5.1 Compressive strength of pastes

Figure 8 shows compressive strength of cement paste and geopolymer pastes at the age of 7 days. Cement paste and geopolymer pastes were used to be binder which coated RCB in this research. The compressive strength of pastes was investigated in order to study effect of strength of pastes on ITZ of pervious concrete. The results showed that cement paste provided the highest compressive strength of 78.1 MPa. For geopolymer paste, compressive strength of 15M GEO was higher than that of 20M GEO. It can be described that the use of exceed concentration of sodium hydroxide leads to inhibit dissolution of the initial solid materials and decreased geopolymerization reaction and hence lower compressive strength was occurred [11-13].

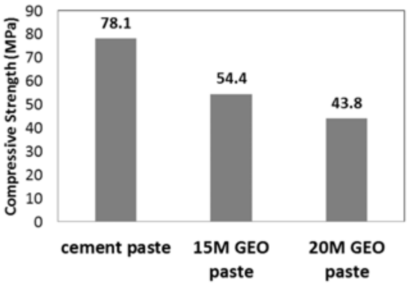


Figure 8. Compressive strength of cement paste and geopolymer pastes (15M GEO and 20M GEO) at the age of 7 days.

3.5.2 Compressive strength of pervious concrete

The compressive strength of pervious cement and pervious geopolymer concretes at the age of 7 days is shown in Figure 9. The results showed that 20M GEO was the highest compressive strength of 6.6 MPa while compressive strength of cement and 15M GEO were 4.5 and 4.0 MPa, respectively. Although pervious cement concrete had high compressive strength in term of binder paste, ITZ of pervious cement concrete was weak point and high porosity as shown in compressive strength of pervious concrete results. It was mentioned that the interfacial transition zone (ITZ) in cementitious composite is often considered as a weak phase, compared to aggregate and bulk paste [14-15]. On the other hand, 20M GEO paste presented the lowest compressive strength, but, 20M GEO concrete provided the slightly higher compressive strength than that of 15M GEO concrete. It might be described that the 20M GEO with high concentration NaOH solution increased the amount of silica and alumina ions and resulted in a high degree of geopolymerization. In addition, the silica and alumina in RCB aggregate could also leach out and assisted the geopolymerization which led to a strong bonding between geopolymer paste and aggregate causing the improvement of compressive strength [16].

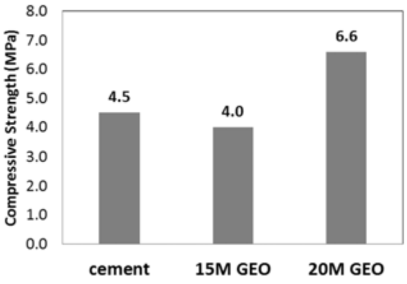


Figure 9. Compressive strength of pervious cement concrete and pervious geopolymer concretes at the age of 7 days.

4. CONCLUSIONS

The study of interfacial transition zone microstructure of pervious cement concrete and pervious geopolymer concrete containing RCB can conclude as follows:

1. ITZ of pervious cement concrete was totally different from ITZ of pervious geopolymer concrete due to difference on starting material and reaction mechanism.

2. ITZ of cement concrete had larger than ITZ of geopolymer concrete as can be seen by both OM and SEM techniques.

3. Although cement paste presented the highest compressive strength, pervious cement concrete provided the lowest compressive strength due to the different in ITZ.

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