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Geopolymer Development by Powders of Metakaolin and Wastes in Thailand

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Abstract

Geopolymer has been developed as an alternative material to Portland cement. Geopolymer is based on the polymerization of alkaline activation and oxide of silicon and aluminium. These oxides can be found in many pozzolanic materials such as metakaolin and the wastes from industries and agricultures in Thailand, e.g., fly ash, bagasse ash and rice husk ash.

Pozzolanic materials were selected as source materials for making geopolymers into 4 different types. Sodium hydroxide concentration of 10 Molar (10MNaOH) and sodium silicate (Na_2SiO_3) solutions were used as alkaline activators by the mass ratio of Na_2SiO_3/NaOH at 1.5. The mixtures were cast in 25×25×25 mm. cubes. After casting, the geopolymers were cured at 80°C for 24 hrs. in an oven and then at room temperature for 7 days. The pozzolanic materials effects, the Si/Al molar ratio and the Na/Al molar ratio were studied and characterized.

An X-ray fluorescence (XRF) was chosen to determine the percentages of silica and alumina in order to verify the proper ratio of the fly ash, Rice husk ash, Bagasse ash and Metakaolin.The study also included the impact on mechanical and physical properties such as compressive strength, water absorption, density and porosity.

1.Introduction

Geopolmer was first originated by Davidovits (1979) to designate a new class of three dimensional silico-aluminate materials[1]. The geopolymer is produced by totally replacing the ordinary Portland cement. Hence, the use of geopolymer concrete to replace the cement is to reduce the CO_2 emissions by the cement industries [2]. Geopolymerization can be applied to utilize solid wastes and by-products containing silica and alumina which are called 'Pozzolans'. A geopolymer is environmentally friendly [3] which is attractive to increase attention in various research fields as a construction material[4]. Pozzolans from industrial and agricultural by-products such as fly ash, bagasse ash and rice husk ash were used to produce geopolymers in this research.

An industrial by-product, from power plants, which is now being used quite extensively as a pozzolan for replacing cement is fly ash. Bagasse ash is a by-product from sugar refinery whereas rice husk is a by-product from rice mill. When they are burnt both bagasse ash and rice husk ash contain around 80% of silica, silica in amorphous form suitable for use as a pozzolan[5]. Furthermore, the geopolymerization can be reacted with metakaolin, obtained by burning kaolin from Ranong province in Thailand, normally, at temperature higher than 600°C[6].

The main alkali solutions activated with pozzolans were sodium silicate and sodium hydroxide. In this research, the fly ash, bagasse ash, rice husk ash and metakaolin were used as the starting materials. They were studied the effects of pozzolanic materials, the Si/Al molar ratio, the Na/Al molar ratio and Na/Si molar ratio for mechanical and physical properties such as compressive strength, water absorption, density and porosity.

2. Experimental

2.1. Characterization of initial materials

Fly ash (FA) was lignite fly ash from Mae Moh power plant in the northern part of Thailand. Rice husk ash (RHA) was obtained from rice mill in the central part of Thailand. Bagasse ash (BA) was a by-product from sugar refinery at Kaset Thai Co., Ltd., in Nakhon Sawan province. Washed kaolin was obtained from Mineral Resources Development Co., Ltd., Ranong province in southern part of Thailand. FA, RHA and BA were ground by a ball mill until the mass of the fine particles retained on sieve size No.325 (aperture of 45 μm) was 1-3%. Metakaolin (MK) was subsequently produced by burning kaolin clay at 1000°C, for 6 hr. Table.1 shows the chemical compositions of FA, RHA, BA and MK as determined by X-ray fluorescence (XRF) analysis. X-ray diffraction (XRD) pattern of MK, in Fig.1, present mainly MK composed of α-quartz, metakaolinite and silicon oxide.

Tables 1 Chemical compositions of FA, RHA, BA and MK as determined by XRF (mass%)

Chemical composition (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3
FA	39.88	22.36	13.22	12.85	2.56	1.72	3.09	2.97
RHA	94.25	0.52	0.22	0.70	0.40	0.05	2.26	0.82
BA	75.39	5.44	3.42	7.89	1.50	0.30	3.32	0.39
MK	53.48	44.08	0.63				1.65	

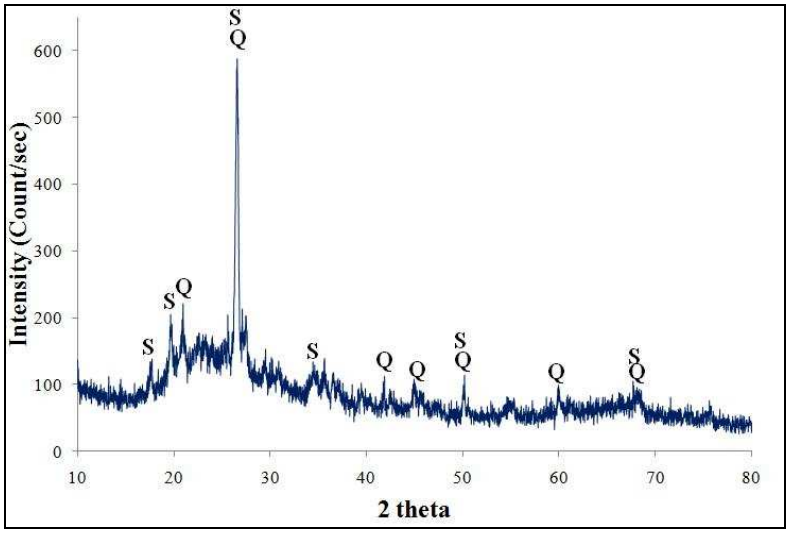

Fig. 1 XRD pattern of Metakaolin. Q = Quartz and S = Silicon oxide.

2.2. Alkali activators

Sodium silicate solutions (Na_2SiO_3) (13.8%Na_2O, 32.2% SiO_2 and 54.0%H_2O) and 10M NaOH solutions (commercial grade) were used as the alkali activators.

2.3. Methodology

2.3.1. Mixed proportions of geopolymer paste

FA, RHA, BA and MK were individually pre-mixed in a beaker. The mixed proportions of FA to RHA, FA to BA and FA to MK were prepared by variation to five ratios as; 0:100, 20:80, 50:50, 80:20 and 100:0 by weight. The ratios of solid to liquid (Na_2SiO_3 and 10MNaOH) were 80:20, 70:30, 60:40 and 50:50 by weight as geopolymer pastes. These proportions have difference of the Si/Al and Na/Al as shown in Table 2 and Fig.3

2.3.2. Mixing of geopolymer paste

The solution of Na_2SiO_3 and 10M NaOH were prepared at least 1 day prior to its use. The solution was poured into a beaker and mixed with solid homogeneously. Consequently, the pastes were poured into 25 × 25 × 25 mm^3 acrylic moulds. The specimens were wrapped with plastic film and then cured at room temperature for 24 hrs, further removing the mold and, finally, the specimens were cured at room temperature for 7 days.

2.4. Test of specimens

2.4.1. Compressive strength

The test was done in according to the ASTM C 618. The reported results are the average of four samples at 8 days age.

2.4.2. Water absorption, Density and Porosity

In order to determine the water absorption, density and porosity of mortar specimens, 7 days age of four cubes from each series were oven dried at a temperature of 85°C for 24 hrs and their weight were determined as the initial weight (W_d). A sample was then immersed in water for 24 hrs and weighed the sample in water as W_w. Finally, the saturated weight was weighed in air as W_a.

The water absorption was calculated using Eq.1

$$\%\text{Water absorption} = (W_a - W_d)/(W_a) \times 100 \quad (1)$$

The density was calculated using Eq.2

$$\text{Density} = (W_d)/(W_a - W_w) \times 100 \quad (2)$$

And the porosity was calculated using Eq.3

$$\rho = (W_a - W_d)/(W_a - W_w) \times 100 \quad (3)$$

where

ρ is vacuum saturated porosity (%),
W_a is weight in air of saturated sample (g),
W_d is dry weight after 24 hrs in oven at 85 ± 5 °C (g) and
W_w is weight in water of saturated sample (g)

The reported results are the average of four samples.

3. Results and Discussion

3.1. Effect of quantity of alkali liquid on compressive strength

The compressive strength of geopolymer specimens curing at room temperature and 8 days age were shown in Fig.2.

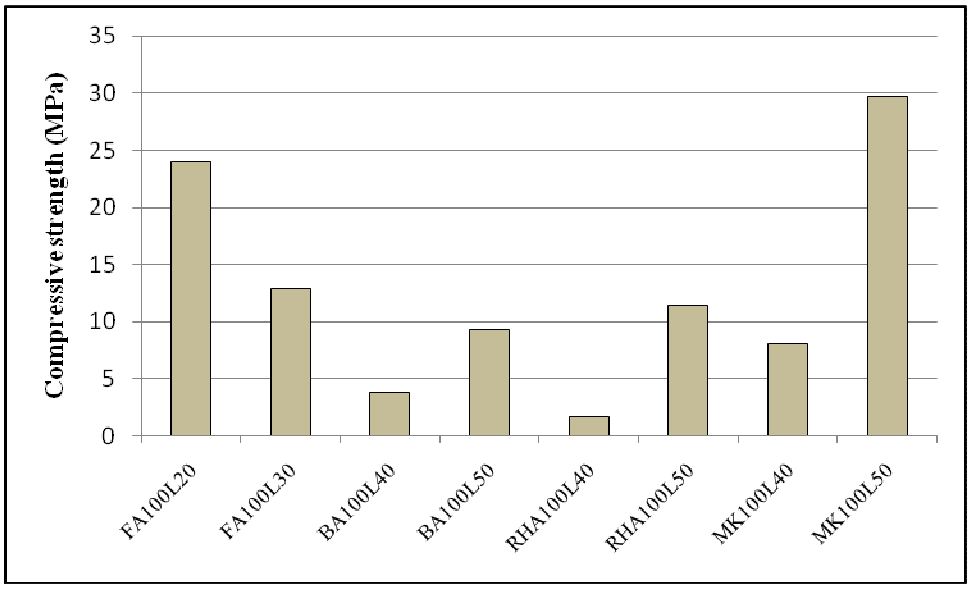

Fig. 2 Compressive strength vs. quantity of liquid alkali

From Fig. 2, the maximum compressive strength (31.57 MPa) was obtained from the specimens of MK100L50 (100% metakaolin and 50% liquid alkali) while the minimum strength (1.66 MPa) was from RHA100L40 (100% rice husk ash and 40% liquid alkali), therefore, the metakaolin would be focused in its activity. In additional, it was found that the compressive strength of geopolymer with FA obviously dropped when the percentage of alkali liquid exceeded 30%, whereas with BA, RHA and MK, the strength increased as the quantity of alkali liquid increased.

However, the 100% RHA and 100% BA were inappropriate to produce geopolymers because of their low compressive strength results. The reasons of low strength, probably, arise from the high Si/Al molar ratio as the percentage of SiO_2 contents of RHA and BA were 94.25 and 75.39, respectively, shown in Table 1. Therefore, it was thought to mix RHA and BA with FA in order to increase amount of Al_2O_3 which was brought from FA mainly and the Si/Al molar ratio would be implied to decrease. The percentage of alkali liquid for geopolymer was suitably used between 30-40%.

3.2. Effect of Si/Al molar ratio and Na/Al molar ratio on compressive strength

Table 2 Compressive strength, Si/Al molar ratio and Na/Al molar ratio

Formulae	Compressive strength (MPa)	Si/Al molar ratio	Na/Al molar ratio
FA20BA80L40	3.01	7.47	1.14
FA20RHA80L40	2.63	16.2	2.06
FA20MK80L40	25.09	1.27	0.25
FA50BA50L40	16.16	4.06	0.73
FA50RHA50L40	5.07	5.66	0.88
FA50MK50L40	31.89	1.41	0.30
FA80BA20L40	11.13	2.48	0.53
FA80RHA20L40	12.28	2.80	0.56
FA80MK20L40	21.37	1.62	0.38

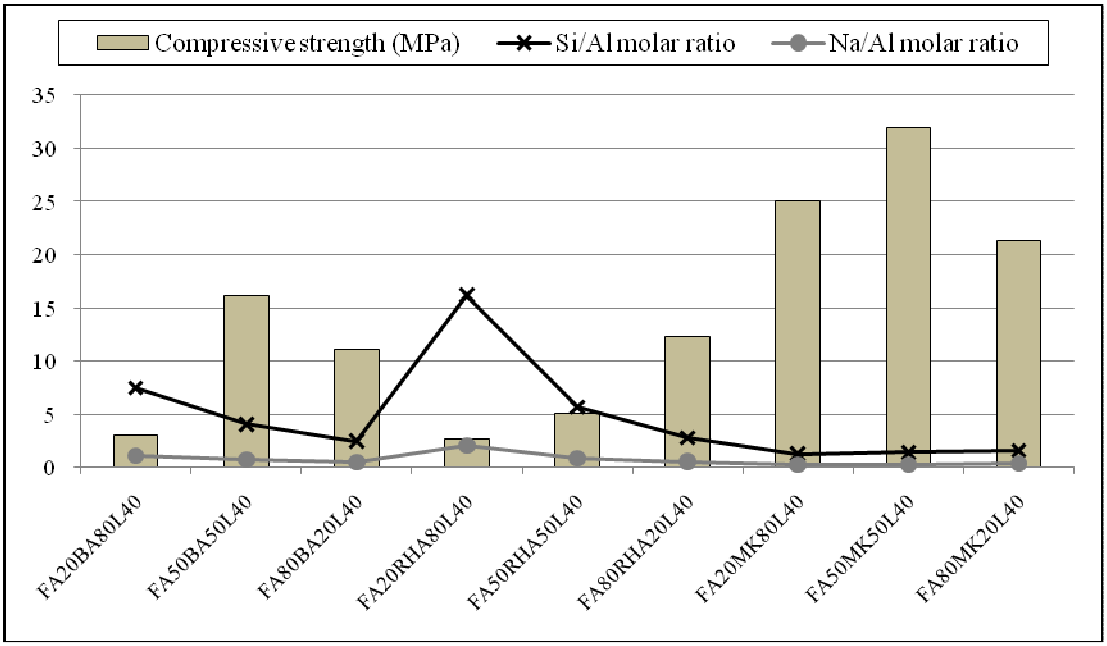

Fig. 3 Compressive strength vs. quantity of pozzolanic materials

The results of compressive strength of geopolymer specimens were shown in Fig. 3 at 40% alkali liquid and FA: other pozzolans (e.g. BA, RHA and MK) as 20:80, 50:50 and 80:20. The 50% FA-50% MK performed the maximum compressive strength (31.89 MPa) whereas the 20%FA-80%RHA performed the minimum (2.63 MPa). It was clearly found that the compressive strength of samples of BA and RHA mixed with FA, in Fig. 3, were much higher than those of only BA and RHA, in Fig. 2. For samples of MK mixed with FA and those of only MK, the compressive strength of them was similar because both materials have similar chemical compositions. It was interesting to consider the Si/Al molar ratio and Na/Al molar ratio with the compressive strength. In Fig. 3, the higher than 20 MPa compressive strength performed with the Si/Al molar ratio the value between 1 and 2 and Na/Al molar ratio less than 1.

3.3. Water absorption, density and porosity

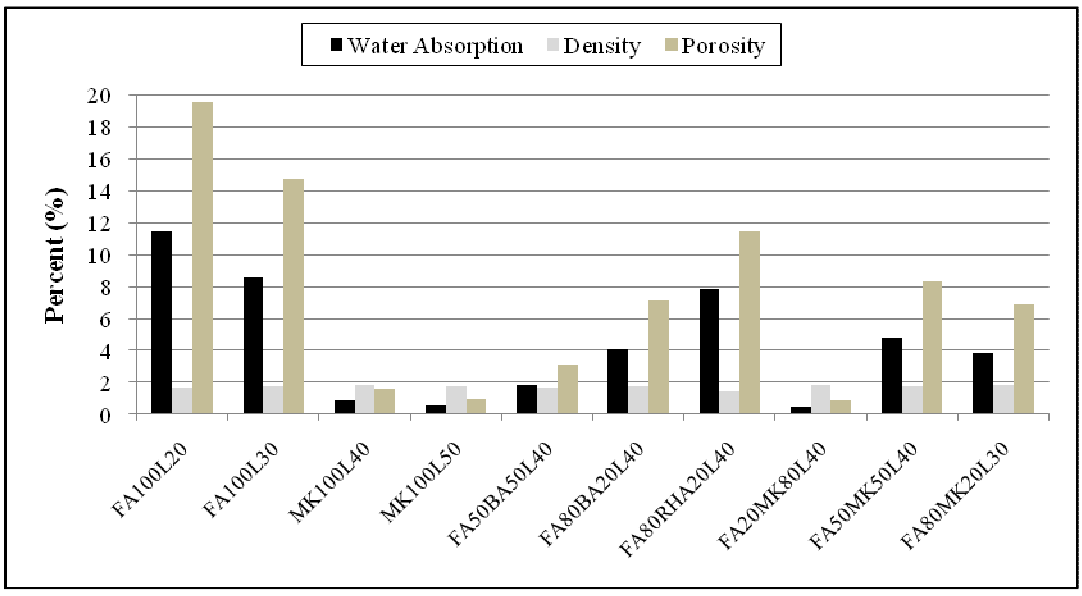

Fig.4 Water absorption, density and porosity

From Fig. 4, the maximum water absorption (11.43%) and porosity (19.52) were earned from FA100L20. The minimum water absorption (0.46%) and porosity (0.83) were received from FA20MK80L40. The water absorption of specimens was present in the same trend as the porosity. Each specimen has the comparable density. There were some specimens such as the 100% BA and 100% RHA not stable in water. The MK geopolymers present obviously low water absorption and porosity while FA geopolymers did oppositely. If these physical properties were compared with compressive strength, it was found that the lower water absorption and porosity, the higher compressive strength.

Conclusion

1. The compressive strength of geopolymers increased with the percentage of alkali liquid.
2. The Si/Al molar ratio of the value between 1 and 2 and Na/Al molar ratio of less than 1 were appropriate to produce geopolymers.
3. FA increased the amount of Al_2O_3 when mixed with BA and RHA and caused the Si/Al molar ratio to decrease.
4. The maximum compressive strength was gained from FA50MK50L40 specimens.
5. The minimum water absorption and porosity were received from FA20MK80L40 specimens.

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