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PERFORMANCE OF GEOPOLYMER BRICKS WITH VARIOUS NaOH CONCENTRATIONS AS ACTIVATOR

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ABSTRACT

This study investigated the performance of geopolymer bricks that were produced using fly ash, chippings and sodium hydroxide (NaOH) solution. Brick mixtures were designed with solution-to-binder ratio of 0.35. The NaOH solutions of 5, 8, 10 and 12 M were used as alkaline activators. The effect of NaOH concentration on properties of geopolymer bricks, including compressive strength, ultrasonic pulse velocity, thermal conductivity, and electrical resistance was investigated. In addition, the scanning electron microscope (SEM) was also used to observe the microstructure of geopolymer bricks. Test results indicated that the compressive strength, ultrasonic pulse velocity, thermal conductivity, and electrical resistance of geopolymer bricks increased with increasing NaOH concentration. Furthermore, SEM micrographs showed a higher hydrate rate of fly ash in brick samples with higher NaOH concentration. All brick samples investigated in this study exhibited a good quality with compressive strength of above 10 MPa, ultrasonic pulse velocity of above 2500 m/s, and electrical resistance of above 2 kΩ-cm.

Keywords: geopolymer brick, sodium hydroxide, fly ash, compressive strength, ultrasonic pulse velocity, thermal conductivity, electrical resistance, SEM observation.

INTRODUCTION

Approximately 22 billion units of the building bricks are produced in Vietnam annually [1]. In which, fired-clay bricks referred to as conventional bricks still occupy a large proportion among all types of brick. However, the production of conventional brick causes environmental problems and natural resource depletion. To overcome these concerns, unburn bricks are enhancing to produce instead of fired-clay bricks, especially the incorporation of industrial wastes in unfired bricks. Besides, around 16.4 million tons of fly ash and bottom ash from coal power plants were released annually and such quantity keeps increasing day by day in Vietnam. Additionally, in Thailand, Malaysia, and India, the released fly ash and bottom ash were 4.0, 8.5 and 173 million tons, respectively [2-4]. In which, fly ash content was a majority with about 80% in total. Even a part of fly ash is reused in the production of construction materials such as cement, concrete, and bricks, a large remain quantity of it is still discharged in the landfill. That is also a cause of environmental pollution.

Geopolymer is an alternative method to recycle fly ash into pozzolanic products under alkali activation. Based on this method, fly ash can be fully used to replace cement, and it plays a role as the cementitious material. This method was applied to make pastes [5-8], mortars [7, 9, 10], paving block [11], and self-compacting concrete [12]. As a results, the compressive strength of those fly ash-based products was comparable to the corresponding cement-based products. For example, the compressive strength of paste, mortar, paving block, and self-compacting concrete could be reached 56.0, 59.3, 28.0, and 51.5 MPa, respectively.

Furthermore, the geopolymer method has been also applied for the production of unfired building bricks. With the use of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solutions as activator, unfired building bricks made from fly ash, rice husk ash, unground rice husk ash, and sand had unit weight of 1.55-2.0 T/m^3, compressive strength of 20.1-33 MPa, flexural strength of 5.4-6.9 MPa, and water absorption of 8.8-18% [13-15]. It is noticed that those bricks were produced under forming pressure of around 35 MPa. With the use of only sodium hydroxide as an activator and under forming pressure of 0.5 MPa, Ngo *et al.* [1] have produced bricks with a unit weight of 1.37-2.22 T/m^3, a compressive strength of 1.5-29 MPa, and water absorption of 3.7-31.9%. Chen et al. [16] has been studied the use of ground bottom ash under the activation of sodium silicate, sodium hydroxide, potassium hydroxide, and lithium hydroxide solutions to produce geopolymer bricks. Test results indicated that the geopolymer bricks had a compressive strength ranged from 4.7 MPa to 24.4 MPa.

In Vietnam, unburnt bricks are mostly produced from cement and chippings - a by-product in the process of crushing stones. In this study, the fly ash was used to fully replace cement, and sodium hydroxide solution was used as an alkaline activator. The effect of various NaOH concentrations on properties of geopolymer bricks was investigated.

MATERIALS AND EXPERIMENTAL PROGRAMS

Materials

Fly ash (FA) sourced from Nghi Son coal power plant in Thanh Hoa - Vietnam was used as a binder material that activated by NaOH solution at different concentration (5, 8, 10, and 12 M). Density and loss on ignition (LOI) values of fly ash are shown in Table-1, showing the main components of SiO_2 and Al_2O_3. Similar to chemical analysis, the X-ray diffraction (XRD) patterns of fly ash indicate that main components of fly ash are also SiO_2 and Al_2O_3 under stable crystals of mullite and quartz (Figure-1). Figure-2 shows the scanning electron

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micrograph (SEM) of fly ash. As can be seen, fly ash particles were clearly observed in a spherical shape with different sizes. Besides, some particles in irregular shapes were detected, which may be unburnt impurities causing the high loss on ignition of fly ash.

Chippings with a density of 2.69 T/m^3 was sourced from the stone crushing factory. Table-2 shows the sieve analysis of chippings with a maximum size of 5 mm, and a fineness modulus of 3.39.

Table-1. Chemical composition of fly ash.

Composition (wt.%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Others	Loss on ignition (%)
Fly ash	51.5	20.2	7.07	1.99	1.23	2.16	15.9

Table-2. Sieve analysis and fineness modulus of chippings.

Sieve size (mm)	5.0	2.5	1.25	0.63	0.315	0.14	FM*
Percentage of passing (%)	99.6	49.3	42.6	31.3	22.2	15.3	3.39

*FM = Fineness modulus

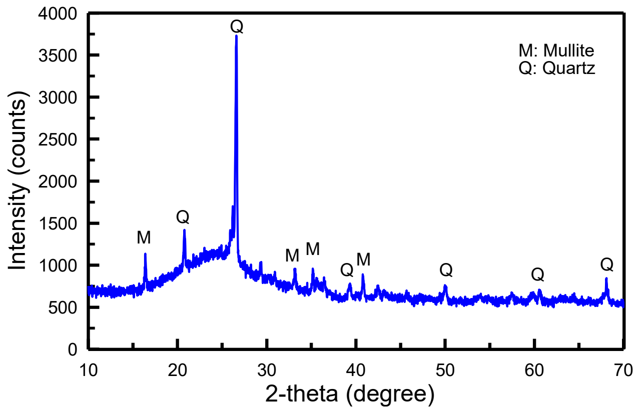

Figure-1. XRD patterns of fly ash.

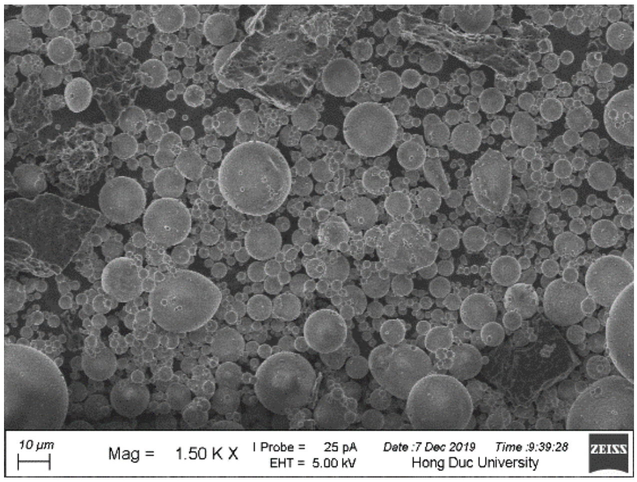

Figure-2. SEM images of fly ash.

Brick mixtures

Mixture proportions for the preparation of brick samples are shown in Table-3. Brick mixtures were designed with sodium hydroxide solution-to-binder ratio (S/B) of 0.35. In Table-3, GB denotes geopolymer bricks, whereas 5M, 8M, 10M, and 12M denote concentrations of NaOH solution. The performance of geopolymer bricks with different concentrations of sodium hydroxide solution was evaluated.

Table-3. Mixture proportions for the preparation of brick samples.

<table>
<tr><th rowspan="2">Mixture</th><th rowspan="2">NaOH concentration (M)</th><th rowspan="2">S/B*</th><th colspan="3">Ingredient proportions (kg/m^3)</th></tr>
<tr><th>FA</th><th>Chippings</th><th>NaOH solution</th></tr>
<tr><td>GB-5M</td><td>5</td><td rowspan="4">0.35</td><td rowspan="4">457</td><td>1762</td><td rowspan="4">160</td></tr>
<tr><td>GB-8M</td><td>8</td><td>1784</td></tr>
<tr><td>GB-10M</td><td>10</td><td>1797</td></tr>
<tr><td>GB-12M</td><td>12</td><td>1809</td></tr>
</table>

* Note: S/B = solution-to-binder ratio

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Samples preparation and test programs

Fly ash was firstly mixed with NaOH solution for 3 minutes. Chippings were then added to the paste and kept mixing until a homogeneous mixture was obtained. The brick samples were casted in a steel mold with dimensions of 160×85×40 mm under a low forming pressure of around 0.5 MPa. The compressive strength of geopolymer bricks was tested in accordance with TCVN 6477 [17]. Other properties of geopolymer bricks such as ultrasonic pulse velocity (UPV), thermal conductivity, and electrical resistance, were also measured. The SEM images of brick samples was used to investigate the microstructure of those bricks. The compressive strength and UPV tests were conducted at 3, 7, 14, and 28 days, while other tests were conducted at 28 days. The reported value was the average value of three measurements. It is worth noting that the compressive strength values of all brick mixtures in this study were multiplied with the shape factor of 0.7 as stipulated by TCVN 6477 [17].

RESULTS AND DISCUSSIONS

Compressive strength

Figure-3 shows the compressive strength development of geopolymer birck samples with different concentrations of NaOH solution. The strength of bricks increased with increasing concentration of the activator solution. This result is similar trend to experimental results from previous studies [5, 18]. Under high alkaline concentration, the dissolution rate of Si and Al ions was high, and the formation of aluminosilicate was encouraged, resulting in high compressive strength. The 28-days compressive strength of brick samples increased from 12.3 to 28.2 MPa when NaOH concentration increased from 5 M to 12 M, respectively. Even with the use of NaOH solution of 5 M, the brick samples still had a 28-days compressive strength of above 10 MPa, this value is a high strength for building bricks. When NaOH solution of 12 M was used, the compressive strength of geopolymer bricks increased to over 25 MPa. This strength value is comparable to normal concrete strength and this is really high for building bricks. The classification of bricks based on compressive strength complying with TCVN 6477 [17] is presented in Table-4. It is noticed that, almost bricks used in practice had a compressive strength of 5 MPa or 7.5 MPa, referred to grade M5.0 or M7.5, respectively.

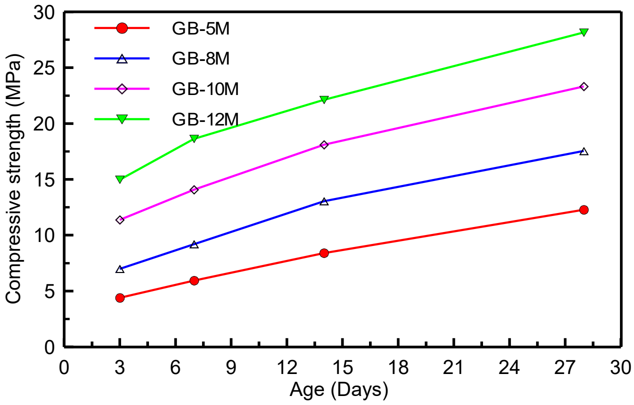

Figure-3. Compressive strength development of geopolymer bricks with various NaOH concentrations.

Table-4. Classification of bricks based on compressive strength [17].

Grade	Compressive strength (MPa)	Grade	Compressive strength (MPa)
M3.5	3.5	M10	10
M5.0	5.0	M12.5	12.5
M7.5	7.5	M15	15

Ultrasonic pulse velocity

Ultrasonic pulse velocity (UPV) is often used to evaluate the relative quality of concrete [19] and bricks [1, 20]. Figure-4 shows the UPV values of brick samples with various concentrations of NaOH solution. At 28-days age, the UPV values of brick samples ranged from 2690 m/s to 5000 m/s corresponding to NaOH concentrations changed from 5 M to 12 M. It means that the UPV values increased with increasing NaOH concentration. As stated by previous studies, the quality of brick is classified as good if the UPV value was higher than 1700 m/s [20, 21]. All bricks investigated in this study were good quality because their UPV values were all above 2500 m/s. Furthermore, Bogas *et al*. [22] has indicated that the UPV value is associated with the compressive strength. Therefore, brick samples with high NaOH concentration resulted in high UPV values. It is attributable to the formation of aluminosilicate, leading to improving compressive strength and UPV values of geopolymer brick samples.

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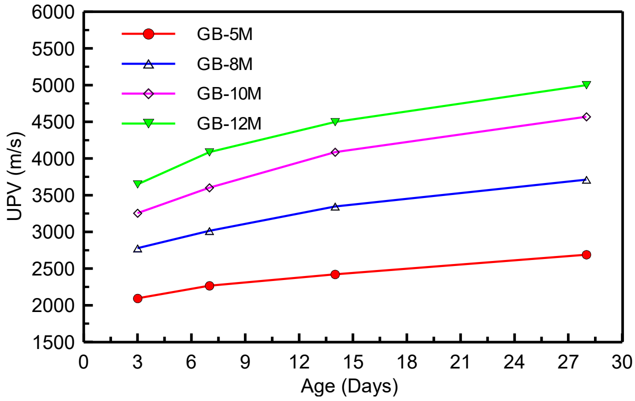

Figure-4. Utrasonic pulse velocity of geopolymer bricks with various NaOH concentrations.

Thermal conductivity

Figure-5 shows the effect of NaOH concentration on the thermal conductivity (TC) of brick samples. The thermal conductivity of brick samples ranged from 1.52 to 1.78 W/m.K. As an increasing NaOH concentration, the thermal conductivity of brick samples increased. This is because the thermal conductivity is related to moisture content [23] and density [24] of samples, thus it also related to other properties of samples such as compressive strength and ultrasonic pulse velocity. With higher NaOH concentration, the density of the brick sample is increased and the inside structure of a brick sample is more uniform due to the formation of aluminosiliate. This results in higher compressive strength, higher ultrasonic pulse velocity, and higher thermal conductivity.

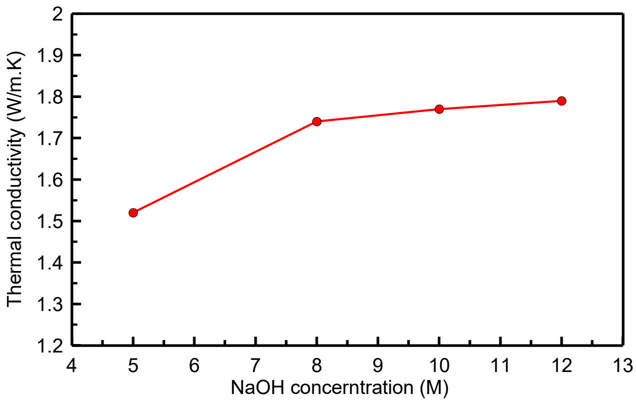

Figure-5. Effect of NaOH concentration on thermal conductivity of geopolymer bricks.

Electrical resistance

The properties of brick samples related to chemical attack resistance are evaluated through electrical resistance test. The 28-days electrical resistance values of all brick samples are shown in Figure-6. The electrical resistance of brick samples ranged from 2.0 kΩ-cm to 19.4 kΩ-cm. As an increasing NaOH concentration, the electrical resistance of brick samples increased. It is attributable to the formation of aluminosilicate, making the inside structure of bricks denser. Therefore, the electrical resistance of bricks increased as well as compressive strength values. For concrete samples, Morris *et al.* [25] have stated that the sample had a low chemical attack resistance if the electrical resistance value was lower than 10 kΩ-cm. However, the required quality of bricks is not as high as concrete. For instance, the normal compressive strength value of concrete is often over 20 MPa, while that value of brick is often from 5 MPa to 7.5 MPa. Based on other properties of brick samples investigated above, the electrical resistance value of 2 kΩ-cm was suggested as acceptable for bricks. The brick samples with electrical resistance of higher than 10 kΩ-cm (GB-10M and GB-12M) shows good resistance to chemical attack.

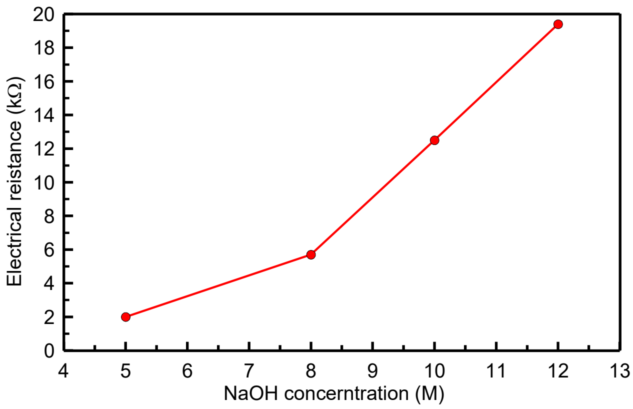

Figure-6. Effect of NaOH concentration on electrical resistance of geopolymer bricks.

SEM observation

Figure-7 shows the close observation of brick's microstructure under an electronic microscope scanner. Many free fly ash particles were still observed in the images of brick samples with NaOH concentration of 5 M and 8 M. For samples with NaOH concentration of 10 M and 12 M, the free fly ash particles were fewer, and the hydrated products were seen as large textures, resulting in increasing quality of bricks as aforementioned. This finding is similar to results from previous studies [5, 18, 26]. In which, Fraay *et al*. [26] have pointed out that a high alkaline solution encourages the reaction of fly ash.

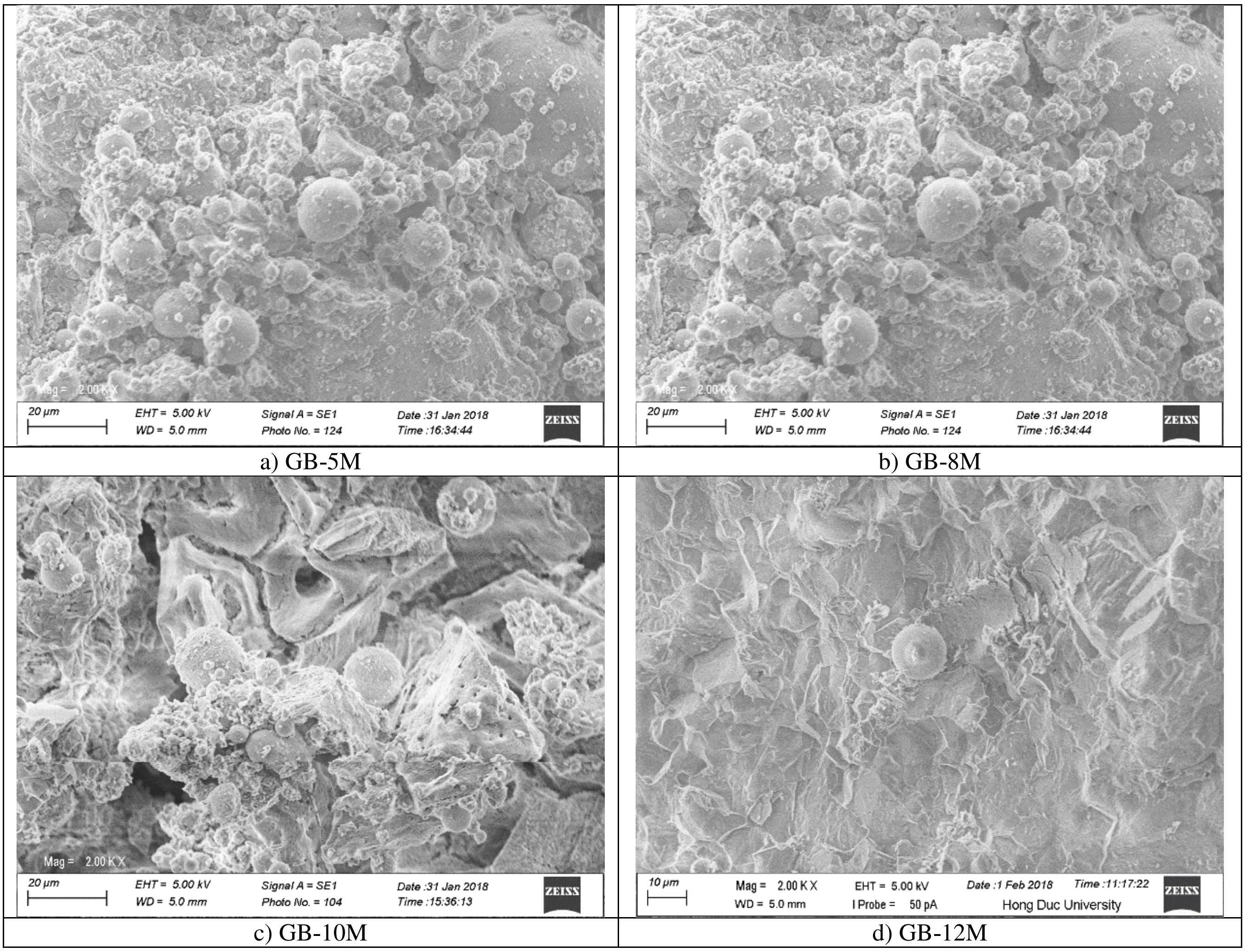

Figure-7. SEM micrographs of geopolymer brick samples with various NaOH concentrations.

CONCLUSIONS

The geopolymer bricks were produced in this study using fly ash, chippings, and NaOH solution. The effect of different NaOH concentrations on properties of bricks was investigated. The brief conclusions can be drawn as follows:

a) As increasing NaOH concentration resulted in increasing compressive strength, ultrasonic pulse velocity, electrical resistance, and thermal conductivity of geopolymer bricks.

b) The SEM images demonstrated that the high concentration of the alkaline solution enhanced the pozzolanic reaction of fly ash, which is closely related to the quality of geopolymer brick.

c) All brick samples produced in this study showed excellent performance with compressive strength of above 10 MPa, ultrasonic pulse velocity of above 2500 m/s, and electrical resistance of above 2 kΩ-cm.

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