5ER-O17: ผลของความเข้มข้นของโซเดียมไฮดรอกไซด์ต่อคุณสมบัติของจีโอโพลิเมอร์มอร์ต้าร์เสริมเส้นใยบะซอลต์

Effect of Sodium Hydroxide Concentration on Properties of Basalt Fiber Reinforced Geopolymer Mortar

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บทคัดย่อ

งานวิจัยนี้ว่าด้วยการเพิ่มความเข้มข้นของสารละลายโซเดียมไฮดรอกไซด์เพื่อศึกษาคุณสมบัติของตัวอย่างจีโอโพลิเมอร์มอร์ต้าร์เสริมเส้นใยบะซอลต์ ส่วนเชื่อมประสานของจีโอโพลิเมอร์จัดเตรียมขึ้นจากปูนซีเมนต์ปอร์ตแลนด์ธรรมดา โซเดียมไฮดรอกไซด์และโซเดียมซิลิเกต ทุกส่วนผสมใช้อัตราส่วนน้ำต่อซีเมนต์และอัตราส่วนเส้นใยต่อซีเมนต์ (โดยน้ำหนัก) เท่ากับ 0.6 และ 1.0 ตามลำดับ สารละลายโซเดียมไฮดรอกไซด์ที่ความเข้มข้น 8 12 และ 16 โมลาร์ถูกใช้เป็นด่างเร่งปฏิกิริยา นอกจากนี้ผลของการใช้อัตราส่วนน้ำหนักระหว่างโซเดียมไฮดรอกไซด์และโซเดียมซิลิเกตด้วยค่าที่ต่างกันได้รับการพิจารณาร่วมด้วย ข้อมูลที่ทำการตรวจวัดประกอบด้วยความข้นเหลว ระยะเวลาก่อตัว กำลังรับแรงอัดประลัย และความหนาแน่นรวมของตัวอย่างทดสอบ จากผลทดสอบพบว่าการเพิ่มความเข้มข้นของสารละลายโซเดียมไฮดรอกไซด์ส่งผลให้ความข้นเหลวและระยะเวลาก่อตัวของตัวอย่างทดสอบลดลง กำลังอัดประลัยของตัวอย่างทดสอบที่อายุ 28 วันมีค่าเพิ่มขึ้นจากการเพิ่มอัตราส่วนน้ำหนักระหว่างโซเดียมไฮดรอกไซด์และโซเดียมซิลิเกต อย่างไรก็ตาม ผลทดสอบบ่งชี้ว่าความเข้มข้นของสารละลายโซเดียมไฮดรอกไซด์ไม่ก่อให้เกิดความแตกต่างที่ชัดเจนของความหนาแน่นรวมของตัวอย่างทดสอบ

คำสำคัญ: เส้นใยบะซอลต์ จีโอโพลิเมอร์ ความเข้มข้นของโซเดียมไฮดรอกไซด์

Abstract

This research deals with increasing concentration of sodium hydroxide solution to investigate various properties of a basalt fiber reinforced geopolymer mortar specimen. The geopolymer binder was produced using ordinary Portland cement, sodium hydroxide, and sodium silicate. For all mixtures, the water-to-cement ratio and the fiber-to-cement ratio (by weight) were kept constant at 0.6 and 1.0, respectively. Sodium hydroxide solution was introduced as an alkaline activator at a molar concentration of 8, 12, and 16. Additionally, the effect of different weight ratio between sodium hydroxide and sodium silicate had been evaluated. The measured data consisted of consistency, setting time, compressive strength, and bulk density of the tested specimens. The results showed that the increase of sodium hydroxide solution caused a reduction in consistency and setting times of specimen. The 28-day compressive strength of specimen increased as the weight ratio between sodium hydroxide and sodium silicate increased. However, there had no detrimental effect for the bulk modulus of the specimens with different sodium hydroxide solution concentration.

Keywords: Basalt fiber, Geopolymer, Sodium Hydroxide Concentration

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Introduction

The production of Portland cement continuously contributes to large amount of global CO_2 emission (Parveen et al., 2018; Rahmiati et al., 2015; Scrivener and Kirkpatrick, 2008; Turner and Collins, 2013). This is the crucial reason for developing low-energy materials to reduce environmental problems and CO_2 emissions and make the most of by-products, resulting in a new development approach. One example is developing geopolymer materials, a new alternative binder to replace concrete, using powdery materials containing high silica (Si) and Alumina (Al) to react with strong bases. It is often a large by-product of industrial manufacturing processes. The development of a geopolymer is one attempt to reduce energy consumption to reduce the use of ordinary Portland cement (OPC) and clinker, and it also brings out a large amount of waste material. A development of geopolymer began using the chemical reaction of Si-Al-containing elements in a mature alkaline state through a polycondensation process (Davidovits, 1994). Geopolymers is different to conventional concrete since the formation of calcium-based system, known as calcium silicate hydrate system, will not produce. An amorphous microstructure formed by aluminum-silicon compound. The non-crystalline structure of hardened geopolymer concrete is stabilized to resist various environmental conditions and loading due to serviceability. According to the present research on geopolymer research, by-products of various industries have been introduced, and the use of reinforced fibers in concrete has become increasingly popular. In this research, basalt fiber (BF) was selected to be used in the development of geopolymer mortar.

The use of fiber reinforcement has great potential to enhance various properties of geopolymer mortars. The literature has been focused on different type of fibers, e.g. basalt (Punurai et al., 2018; Saloni et al., 2020), glass (Al-Majidi et al., 2017; Alomayri, 2017; Bhutta et al., 2018; Goncalves and Bindiganavile, 2018), steel (Faris et al., 2016; Farhan et al., 2018; Ma et al., 2019b; Onuaguluchi et al., 2017), and synthetic materials (Behfarnia and Rostami, 2017; Nguyen et al., 2018a; Nguyen et al., 2018b; Noushini et al., 2018). Basalt fiber is selected as the reinforcing particle of geopolymer mortars tested in this research. The reason of this choice is due to an improvement of strength and setting time of mortars. The total porosity, drying shrinkage, and critical pore size were also reduced (Punurai et al., 2018; Saloni et al., 2020). Some basalt fiber geopolymer materials have been studied from previous research, but few studies have been done. Therefore, in this research, further studies are being carried out to develop geopolymer materials by replacing basalt fibers for further improvement by adjusting the sodium hydroxide (NH) to sodium silicate ratio (NS) ratio. This research focuses on various properties, such as consistency, setting time, compressive strength, and bulk density of geopolymer mortars. To be useful research information for those who are interested in developing new materials to replace old materials and to use in the development of building materials for the construction industry.

This research presents an experimental study to evaluate the significance of increasing both sodium hydroxide (NH) concentration and NH to sodium silicate (NS) ratio to a basalt fiber reinforced geopolymer mortar specimen. The properties of fresh pastes and hardened mortars are examined. Experimentations to determine durability and microstructural properties are beyond the scope of this work.

Experimental Program

The chemical compositions of OPC and BF are presented in Table 1. The cement and fiber used in this research were identical to those in the literature (Soeurt and Chalee, 2017; Punurai et al., 2018). OPC, used for all mixtures, conformed to the requirements of Portland cement standard (ASTM, 2020). Natural river sand, which have a specific gravity of 2.5, was utilized as fine aggregate. BF used was classified as alkaline basalt, since silicon dioxide content is less than 42%. The combination of NH and NS solutions were used for the alkaline activation of geopolymer mortar.

Table 1 Chemical analysis of OPC and BF.

Compound (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	LOI
OPC	20.10	5.20	3.15	60.24	1.13	0.11	0.43	2.42	2.03
BF	32.80	13.20	0.81	31.30	6.39	0.46	0.42	0.67	0.45

The total mass of OPC and fine aggregate, applied to each mixture, was 650 and 650 kg/m^3, respectively. Free water to OPC ratio was kept at 0.6. The basalt fiber content used was 100% by weight to minimize the porosity of geopolymer mortar as suggested in the literature (Punurai et al., 2018). The constituent activators in the geopolymer mortars are summarized in Table 1. NH, that is offered in solid pellet form and conformed to the requirements of NH standard (TIS, 2006), was solved in distilled water. NH solutions were prepared separately, at concentrations of 8, 12, and 16 mol, and mixed with aqueous NS solution. The specimens were designated according to the NH / NS ratio by weight and NH concentration. The NH / NS ratio was set to 1, 1.5, and 2 for the S1, S2, and S3, respectively. The amount of NH solutions (in kg/m^3) for each mixture did not keep constant because the total quantity of NH and NS solutions was set as 390 kg/m^3 to control the level of alkaline solution in geopolymer pastes. Effects of variation of NS solutions with constant NH solutions on properties of geopolymer concrete are recommended for further evaluation.

Table 2 Mixture proportion of geopolymer mortars.

Specimen	S1-8M	S1-12M	S1-16M	S2-8M	S2-12M	S2-16M	S3-8M	S3-12M	S3-16M
NH (mol)	8	8	8	12	12	12	16	16	16
NH (kg/m^3)	195	234	260	195	234	260	195	234	260
NS (kg/m^3)	195	156	130	195	156	130	195	156	130

Generally, mixing water with strong bases is considered as exothermic reaction, which may generate significant amount of heat. To prevent a vigorous exothermic reaction, NH in aqueous solution was rested for 24 hours before mixing with NS solution. The alkaline solution, obtained from a combination of NH in aqueous solution and NS solution, was then mixed with other components. OPC, BF, fine aggregate, and alkaline solution were blended under a dry condition for 5 minutes. The well-blended mixture was obtained as demonstrated in Figure 1(a). The basalt fiber reinforced geopolymer pastes were casted, shown in Figure 1(b), using acrylic prism mold with a size of 50×50×50 mm. After 24 hours, the hardened mixtures were demolded and further cured with plastic sheeting for 7 or 28 days. The curing process of mortars are captured in Figure 1(c).

(a) Homogeneous fresh mixture (b) Specimens casting (c) Curing process

Figure 1 Specimen preparation.

Fresh mortar mixture was then examined for its consistency using flow table test as seen in figure 2(a). The procedure was based on the standard testing (ASTM, 2015), which is widely applied in the previous studies (Huseien et al., 2018; Lu & Poon, 2018; Pangdaeng et al., 2014). The Vicat apparatus according to the specification (ASTM, 2019), as depicted in Figure 2(b), was applied to measure a penetration resistance in terms of initial and final setting time of mortars. The compressive strength of specimens was determined by the test shown in Figure 2(c), as per the standard (ASTM, 2005), at 7 and 28 days using 50×50×50 mm cubes.

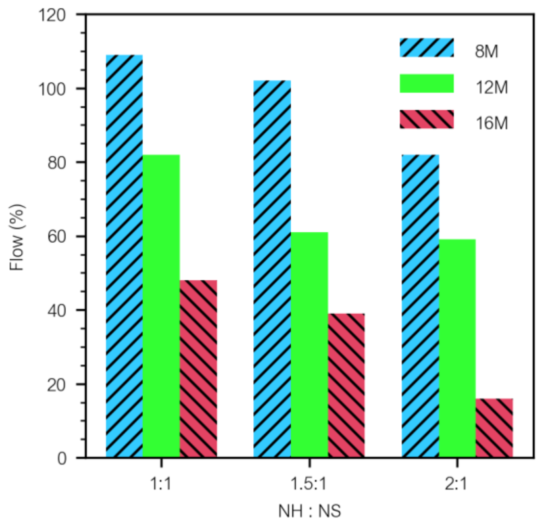
A constant loading rate of 0.5 MPa per second was applied to the specimens until crushing failure occurred. A failure load value divided by a cross-sectional area of specimen is evaluated as the compressive strengths of geopolymer mortars.

Results and Discussions

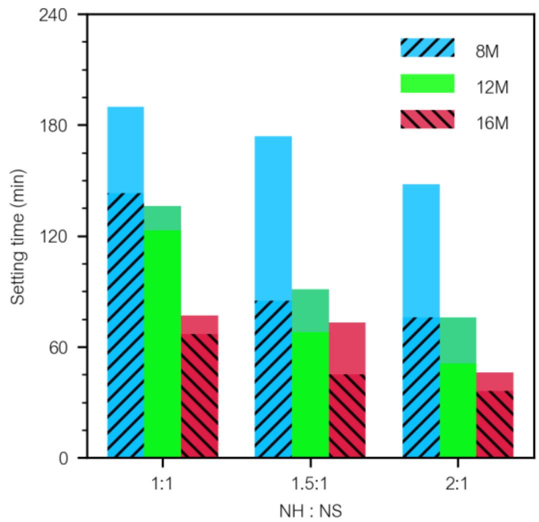
The experiment yielded a number of results associated with various properties in both fresh and hardened state of the specimens. The flow percentage, as reported in Figure 3(a), was pursued to achieve the rheological property of geopolymer mortars. A similar trend could be identified for all mixture that the flowability decreased with increasing NH concentration. Rates of change of flow percentage increased as the increasing amount of NH concentration, except for the case with NH / NS ratio of 1.5. These identical trends could be also obtained while determining the rate of change by setting NH / NS ratio as a control parameter. Even though the case with NH / NS ratio of 1.5 had made remarkable rate of change of flow percentage, the results also suggested that increasing NH / NS ratio will reduce flowability of fresh mixture of the geopolymer pastes.

(a) Standard flow test (b) Penetration resistance test (c) Uniaxial compressive test

Figure 2 Geopolymer mortar testing.



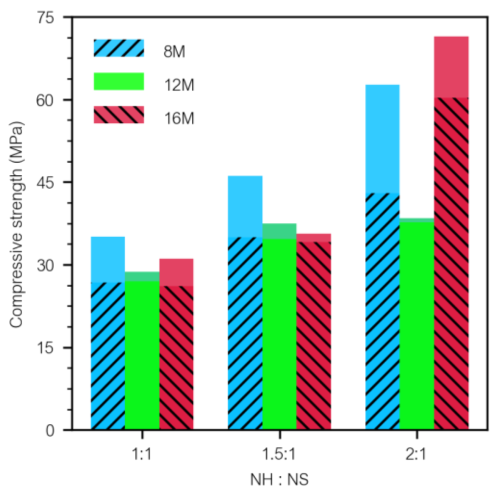
(a) Consistency



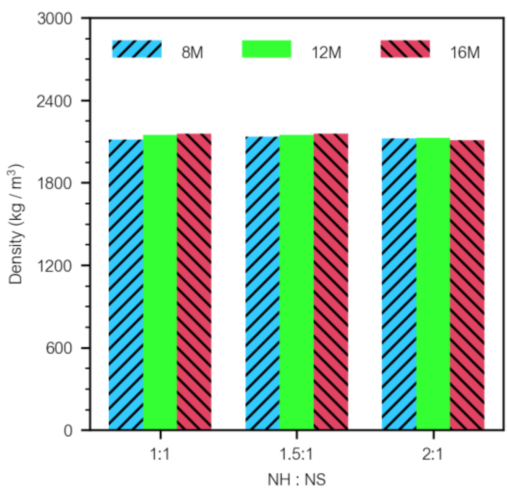
(b) Setting time

Figure 3 Effect of solution concentration on workability of geopolymer pastes.

The results of setting times were shown in Figure 3(b). The hatched bars and the non-hatched bars indicate the initial setting time and the final setting time of geopolymer mortars, respectively. The samples which were increasing the NH / NS ratio from containing different concentration of NH. It is shown that the NH / NS ratio can cause urgent of setting times. Higher concentration of NH leads to longer setting times. The reasons are similar to those described for flowability finding. According to the results plotted in Figure 4(a), the hatched bars and the non-hatched bars represent the compressive strength of mortar at 7 days and 28 days, respectively. The 28-day compressive strength of samples containing high concentration of NH are not slightly different of the lower but It is obvious that higher proportion of NH / NS causes increase in compressive strength,



(a) Compressive strength



(b) Bulk density

Figure 4 Effect of solution concentration on physical properties of mortar specimens.

The bulk density of sample, depicted in Figure 4(b), which study the concentration of NH that may not always be able to effect of density, because of mixture proportion of geopolymer mortars were measured and equal in weight ratio. However, a limited number of geopolymer mortar specimens could lead to a lower generalization of the current results. Further research should be extended to determine the optimal amount of NH concentration, which can effectively improve both strength and workability, for basalt fiber reinforced geopolymer mortars.

Conclusions

This research experimentally investigated the geopolymer mortar specimens to evaluate the effect of NH Concentration on consistency, setting time, compressive strength, and bulk density of the tested specimens. Based on the test results, the following conclusions are drawn:

- The decrease in flowability was more pronounced with the increase in NH concentration. Furthermore, the flow percentage of the pastes was also reduced as the NH / NS ratio improved.
- Increasing the NH / NS ratio from containing different concentration of NH and NH / NS ratio can cause urgent of setting times
- It is obvious that higher proportion of NH / NS ratio causes increase in compressive strength.
- The concentration of NH that may not always be able to effect of density.

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