MATEC Web of Conferences **97**, 01012 (2017)
ETIC 2016
DOI: 10.1051/matecconf/20179701012

Effect of Alkaline Activator to Fly Ash Ratio for Geopolymer Stabilized Soil

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Abstract. Geopolymer technology have been developed and explored especially in the construction material field. However, lack of research related to geopolymer stabilized soil. In this research, the utilization of geopolymer has been investigated to stabilize the soil including the factors that affecting the geopolymerization process. Unconfined compressive test (UCT) used as indicator to the strength development and hence evaluating the performance of geopolymer stabilized soil. This paper focusing on the effect of fly ash/alkaline activator ratio, Na_2SiO_3/NaOH ratio and curing time on geopolymer stabilized soil. A various mix design at different fly ash/alkaline activator ratio, Na_2SiO_3/NaOH ratio were prepared and cured for 7 and 28 days. Molarity and the percentage of geopolymer to soil were fixed at 10 molar and 8 percent respectively. Then, the UCT tests were carried out on 38mm diameter x 76mm height specimens. The highest strength obtained at the fly ash/alkaline activator ratio 2.5 and Na_2SiO_3/NaOH ratio 2.0 at 28 days curing time.

1 Introduction

Infrastructures such as road, highways, slope, and embankment are built on top of the soil. In fact some of them are built by cutting and trimming the soil (i.e; slope and embankment). Thus, the strong and stable soil is an important part of the infrastructure construction. However, in many construction cases, to find the soil that naturally high strength and high durability is very difficult and the soil need to be treated. Since a decade, the treatment technologies and methods are well developed by researchers and some of them are well implemented to stabilize the soil before the constructions begin. One of the recent material technology (since 1970's) is geopolymer. This material developed by Davidovits [1] and gives a number of benefits to the construction material field especially for the building structures. Since then, extensive research on geopolymer material are conducted to understand the behaviour, properties and strength at various conditions.

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Looking at the advantages of this material, the research on suitability of this material for soil stabilization is presented.

In general, geopolymer produced from the reaction between raw material (i.e; fly ash) and alkaline activator. The termed 'geopolymers' comes when the inorganic polymeric material synthesized in a manner similar to thermosetting organic polymers. For this reason, these materials names geopolymer [2]. Scientifically, geopolymer is the reaction of a solid aluminosilicate with a highly concentrated aqueous alkali hydroxide or silicate solution to produces a synthetic alkali aluminosilicate material [3]. Fly ash (residue from coal combustion) is used finely divided residue resulting from combustion of coal and has been used as cement replacement for the recent years [4]. Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solutions is commonly used to make an alkaline activator [5,6].

A lot of factors contribute to the strength development of geopolymer stabilize soil such as types of soils, types of raw materials, solid to liquid ratio, sodium hydroxide to sodium silicate ratio, temperature, and curing time [2], [7-11]. The influence of solid to liquid ratio and sodium hydroxide to sodium silicate ratio are highlighted in this paper. Some researchers stated that optimum compressive strength can be achieved at solid to liquid ratio in between 2.0 and 3.0 [12, 13]. However, the ratio can be varies depend on its application. It should be noted that, the compressive strength is optimum at the ideal solid to liquid ratio. For geopolymer, some researchers discovered that a geopolymer strength up to 70 MPa could be achieved when the mixture is formulated at ratio 2.0 [12]. Different curing time also give an impact to the strength of geopolymer. Geopolymerisation process highly influence by curing time. Researchers reported the strength increased as the curing time increased [11-14].

The objective of this paper is to present the effect of various fly ash to alkaline activator ratio, Na_2SiO_3/NaOH Ratio and curing time on the compressive strength of geopolymer. The result obtained will be used as a design mix for soil stabilization.

2 Experimental setup

2.1 Material selection

Fly ash is an industrial by product resulting from coal combustion. This raw material collected from Tenaga Nasional Berhad (TNB) Manjung Power Station, Telok Rubiah, Lumut, Perak, Malaysia. The compositions of this fly ash are suitable for geopolymerization process. The activator used in this study is combination between sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH). NaOH was prepared by mixing sodium hydroxide pellets (97–99 % purity) with distilled water at 10M concentration. Untreated soil used collected from Kampung Padang Durian, Pendang, Kedah, Malaysia. After classification test the soil fall under coarse grain sand.

2.2 Sample preparation

Series of sample at various fly ash/alkaline activator ratio and Na_2SiO_3/NaOH ratio were prepared, then curing for 7 and 28 days at room temperature. The percentage of geopolymer to soil was fixed at 8 percent (8%). The uniaxial compressive test (UCT) used to determine the shear strength of each sample. Details mix design tabulated in Table 1.

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Table 1. Mix design geopolymer stabilize soil.

Sample	**Fly-Ash / Activator ratio**	**Na_2SO_3 / NaOH ratio**
1-1	2.0	2.0
1-2	2.0	2.5
1-3	2.0	3.0
2-1	2.5	2.0
2-2	2.5	2.5
2-3	2.5	3.0
3-1	3.0	2.0
3-2	3.0	2.5
3-3	3.0	3.0

First, soil and fly ash were dry mixed together to allow the fly ash distributed uniformly. Meanwhile Na_2SO_3 were mix together with NaOH at design ratio to form alkaline activator (AA) and rest for 30 minutes for complete reaction. After that, the AA is poured into fly-ash and soil and mixed together until the AA mixed evenly. Then, the 38mm diameters x 76 mm height sample were prepared. The process continued at different design mix. The sample then test under UCT to obtain the maximum shear strength.

3 Results and discussion

3.1 Soil classification

Particle size distribution (PSD) test used to classify type of soil for this study. A set of sieve varies from 2 mm to 0.063 mm opening sorting according to British Standard (BS). Soil sample was sieving for 10 minutes to allow the soil particle distribute accordingly. The particle distribution curve is presented in Figure 1. From figure 1, soil use for this study are classify as Coarse Sand (CS).

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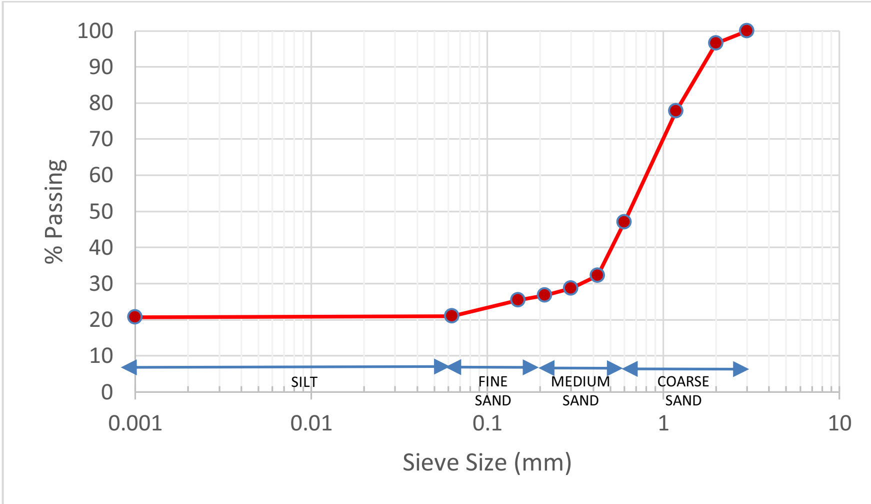

Fig. 1. Particle size distribution curve.

3.2 Chemical composition of fly ash

X-ray fluorescence (XRF) test was used to determine chemical composition of fly ash. The main chemical composition of fly ash is silica oxide SiO_2, followed by Fe_2O_3, CaO, and Al_2O_3. The XRF result is tabulate in Table 2 below.

Table 2. Chemical composition of fly ash using XRF.

Chemical	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MnO	CuO	K_2O	P_2O_5	SO_3	SrO
wt.%	38.8	14.7	19.48	1.02	18.1	0.16	0.041	1.79	0.054	1.50	0.11

Percentage of calcium oxide (CaO) is 18.1% and the summation of SiO_2, Al_2O_3, and Fe_2O_3 is 72.98%. Referring to fly ash standard classification in ASTM C618, this fly ash classified as Class F.

3.3 Standard compaction test

Standard compaction test is used to determine the optimum moisture content (OMC) and maximum dry density (MDD) of soil. OMC and MDD results are used to prepare the specimen for uniaxial compressive test (UCT). Compaction curve from the test is shown in Figure 2. From the curve, the OMC and MDD are 14.7 % and 1.78 Mg/m^3 respectively.

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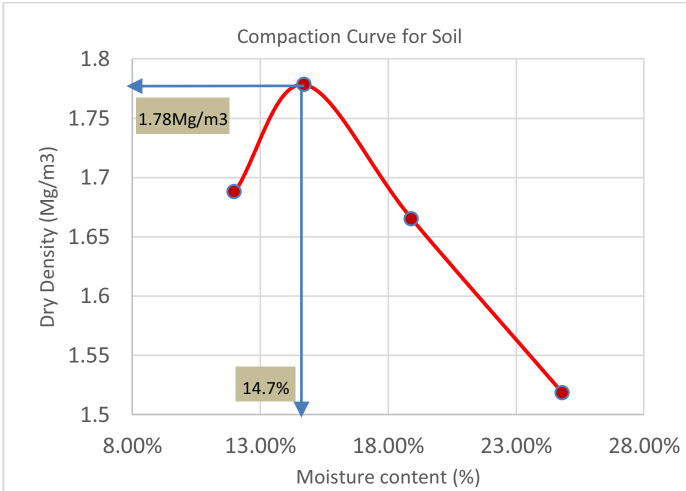

Fig. 2. Compaction curve.

3.4 Uniaxial compressive strength test

All samples were test under uniaxial compressive test (UCT) to determine the shear strength for each sample. UCT test used to indicate the best mix design for fly ash-geopolymer stabilize soil. The result then plot in Figure 3 and Figure 4. From both figures, the highest shear strength obtained at sodium silicate (Na_2SiO_3) to sodium hydroxide (NaOH) ratio of 2.0 and a fly ash to activator ratio of 2.5. There are significant increase of shear strength at various solid to liquid ratio and activator ratio. At 7 days curing time, the different between the highest strength (0.395MPa) and the lower strength (0.215MPa) is about 46% increment whereby at 28 days curing the different between the highest strength (0.645MPa) and the lower strength (0.337MPa) is about 48% increment.

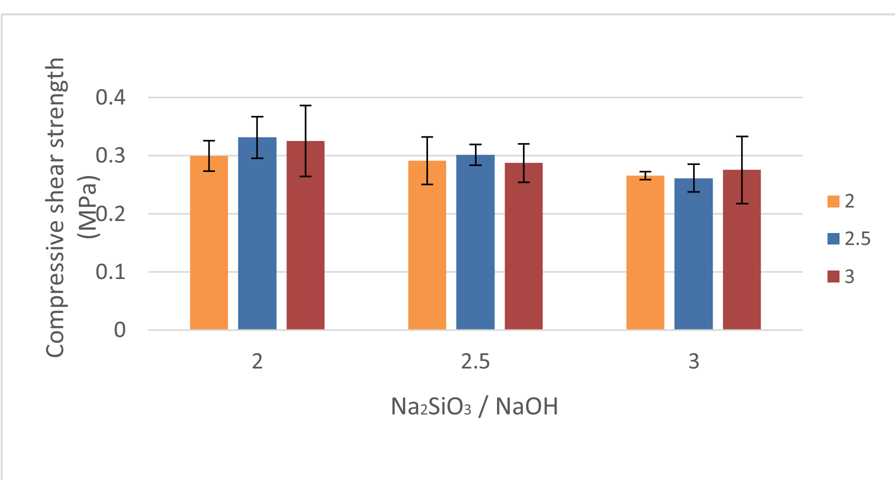

Fig. 3. Compressive strength of various proportions of activators at 7 days curing.

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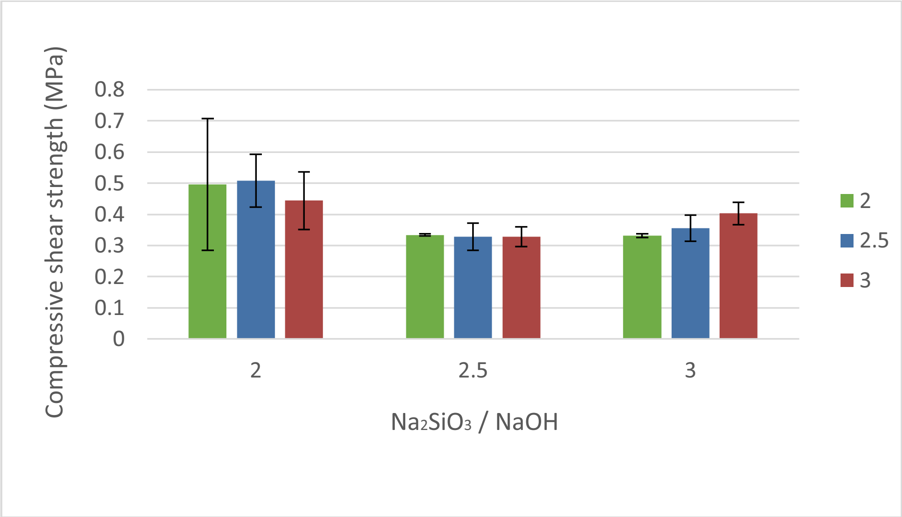

Fig. 4. Compressive strength of various proportions of activators at 28 days curing.

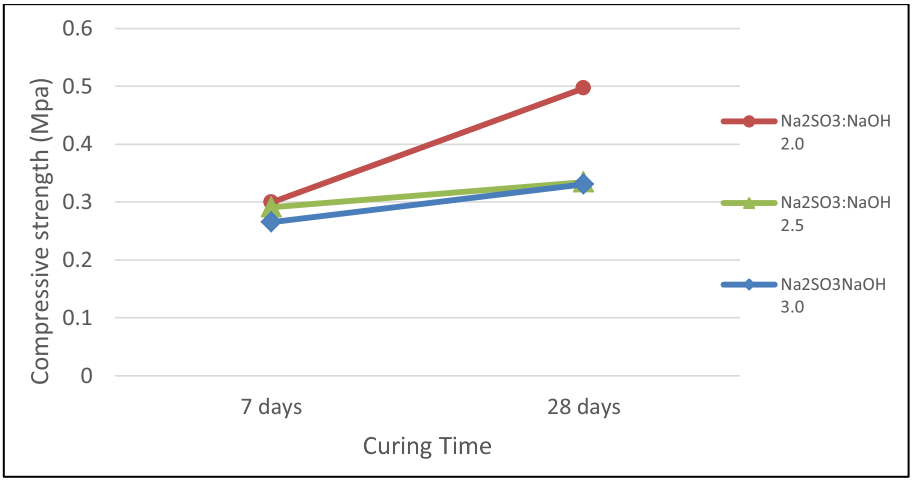

Fig. 5. Effect of Na_2SO_3 / NaOH ratio at different curing time.

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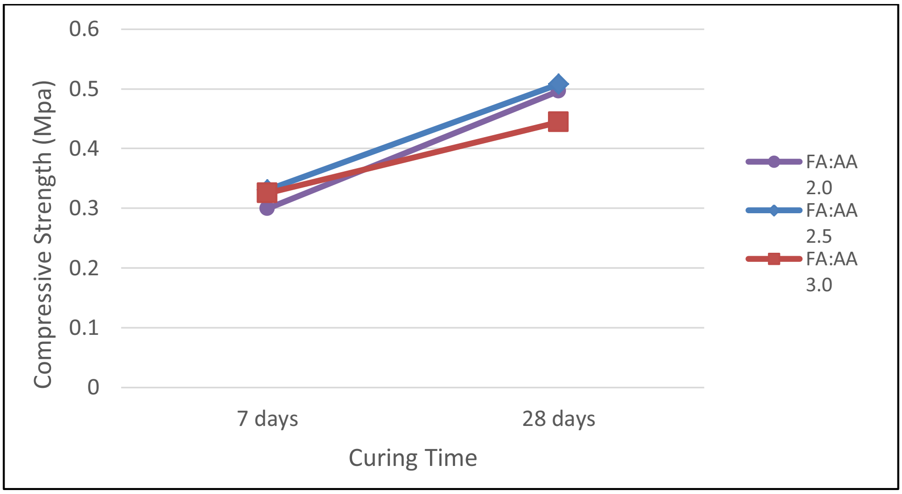

Fig. 6. Effect of FA / AA ratio at different curing time.

Figure 5 and Figure 6 shows the effect of Na_2SiO_3 / NaOH ratio and effect of FA / AA ratio at different curing time respectively. From both figures, there is significant strength increment from day 7 to day 28 of curing time. The different ratio of Na_2SiO_3 / NaOH gives a significant impact compare to the different ratio of FA / AA. At the ratio Na_2SiO_3 / NaOH of 2.0, there are 54% increment from day 7 to day 28 of curing. This is showing that geopolymerization process occurs during the curing time. This result shows the curing time plays an important role for strength development in geopolymer stabilized soil.

4 Conclusions

The aim of this paper is to present the effect of fly ash/alkaline activator ratio, Na_2SiO_3/NaOH ratio and curing time for geopolymer stabilized soil. From the experimental results, the following conclusions have been made:
1) The highest strength determine at the ratio of fly ash/alkaline activator and Na_2SiO_3/NaOH 2.5 and 2.0 respectively.
2) Curing time plays an important role where the highest strength determines at 28 days curing.

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