

Correlation of the Na_2SiO_3 to NaOH Ratios and Solid to Liquid Ratios to the Kedah's Soil Strength

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Abstract. Geopolymer was used for the soil stabilization of Kedah's soil at different ratios of solid to liquid and Na_2SiO_3 to NaOH in order to achieve the desired compressive strength. The geopolymerization process which produces an aluminosilicate gel was occurred due to the mixing of Kedah's soil and fly ash with Na_2SiO_3 and NaOH . Soil stabilization by geopolymer was synthesized by the activation of fly ash and Kedah's soil with Na_2SiO_3 and NaOH at different ratios of solid to liquid (1.5, 2.0, 2.5 and 3.0) and Na_2SiO_3 to NaOH (0.5, 1.0, 1.5, 2.0, 2.5 and 3.0) at a specific constant concentration of NaOH solution of 6M. The compressive strength up to 5.12 MPa was obtained at 3.0 of solid to liquid ratio and 2.5 of Na_2SiO_3 to NaOH ratio in 7 days curing at room temperature.

1 Introduction

One of the first steps in the design of civil engineering is the investigation of soil conditions on the site of the proposed structure. Engineering properties important not only as a basis for the project but also as a construction material for many structures, including roads embankments, earth dams, and other types of grading projects. Soil is a collection of solid parts and is not bound with each other (including possibly organic material) between the cavities of the material filled with air and water [1]. In the field of civil engineering, soil defined as all material in the earth's crust which is not consolidated and consider that the rock is an aggregate of minerals which are connected by a wide range of great strength, while the soil is the natural particle that can be destroyed with a low strength. In other words, soil is loose material outside layers of rock, which is comprised of a group of mineral grains of various sizes and shapes as well as the content of organic matter, water

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and air. In the civil construction frequently encountered problems in soft soil type, among others are the low bearing capacity and settlement is high if subjected to load. Because of the soft soil has low permeability, the time required for consolidation is longer. Soil consolidation is the process where the bulk soil volume is reduced under loading due to flow of pore water. Then slowly the pressure is transferred to the effective stress soil, so soil has increased in terms of soil strength and bearing capacity. Thus, if the construction is to be built on soft soil, the construction process should be done after soil has been consolidated completely. This is to avoid large settlements on the building and obtain the soil bearing capacity that is good enough. Therefore, we need a method of soil improvement to overcome this problem.

Soil stabilization can be done either only stabilization of the ground surface or material in the soil [2]. Nowadays chemical stabilization with cementitious materials has been broadly practiced and implemented to improve the physical characteristics of the problematic soil [3]. Developing of geopolymer technology by Davidovits [4, 5] offers an attractive solution for soil stabilization regarding the emission of carbon dioxide to the atmosphere that produced by Ordinary Portland Cement (OPC) in conventional method [6, 7]. Soil stabilization by using geopolymer have been popularly applied in construction field such as fly ash [8] rice husk ash [9], lime [10] and metakaolin [11]. Dali Bondar et. al. [12] stated that highest compressive strength can be achieved when the molarity of the solution is between 5 and 7.5 M. The ratios of fly ash to alkaline activator and Na_2SiO_3 to NaOH can be influenced the compressive strength of geopolymer. A study conducted by D. Hardjito [13] showed that the use of a Na_2SiO_3 to NaOH ratio of 0.4 resulted in lower compressive strength, whereas a ratio of 2.5 gave the highest compressive strength. In addition to obtain the best compressive strength, the researchers used a ratio of sodium silicate to NaOH in the range of 0.4 to 2.5 and a ratio of fly ash to alkaline activator in the range of 2.5 to 3.3 [14].

Thus, the combination is relevant for precast products used for practical purposes. The purpose of this study was to identify the mix design proportions that can produce optimum compressive strength of geopolymer soil stabilization.

2 Experimental Method

2.1 Raw Material

Materials used in this study include soil, fly ash, sodium hydroxide and sodium silicate.

2.1.1 Soil

Laboratory tests were performed on the reddish colour clayey soil with high amounts of oxides as residual laterite soil recovered in Kedah, Malaysia [15]. This soil is found commonly in tropical regions [16] and it can be considered as representative of typical soils from the north of Malaysia. After being submitted to characterisation analysis, this laterite soil classified as MH according BS classification [17] and the properties described in Table 1 [18]. It was oven dried and sieved down by using 300 μm sieve before being thoroughly mixed. Additional characterisation included X-Ray Fluorescence (XRF) to determine chemical composition of this soil (Table 2).

Table 1. Physical properties of Kedah's soil.

Properties	Percentage (%)
Sand	11
Silt	52
Clay	37
Specific gravity	2.63
Optimum Moisture Content	35
Maximum Dry Density	1.3
Liquid Limit	77
Plastic Limit	42
Plasticity Index	35

Table 2. Chemical composition of Kedah's soil.

Chemical composition (oxides)	Percentage (%)
SiO ₂	66.50
Al ₂ O ₃	21.50
Fe ₂ O ₃	8.24

2.1.2 Fly ash

The fly ash that used in this study had low calcium content (class F) that obtained from the Manjung Power Station in Lumut, Perak. Its characterisation (Table 3) was carried by X-Ray Fluorescence (XRF) [18].

Table 3. Chemical composition of fly ash.

Chemical composition	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	SO ₃
Percentage (%)	52.11	23.59	7.39	0.88	2.61	0.78	0.42	0.80	1.31	0.49

2.1.3 NaOH

NaOH can be used to make geopolymer material as the liquid medium mixture. It was obtained from the Formosa Plastic Corporation, Taiwan. The specification of NaOH is shown as Table 4.

Table 4. Specification of Sodium Hydroxide.

Items	Specifications
Physical Form	Pellets
Colour	White
NaOH Content	More than 99%
Water Solubility	100%
Molecular Weight	40 g/mol

2.1.4 Na_2SiO_3

Na_2SiO_3 is also used as ingredients for making material where obtained from the South Pacific Chemicals Industries Sdn. Bhd. (SPCI), Malaysia. The specification of Sodium Silicate is tabulated in Table 5.

Table 5. The specification of Sodium Silicate liquid.

Items	Specifications
Water (H ₂ O)	60.5%
Silica	30.1%
Sodium Oxide	9.4%
SiO ₂ /Na ₂ O Ratio	3.2
Molecular Weight	122.06 g/mol
Viscosity at 20°C	0.40 Pa·s
Specific gravity at 20°C	1.40 g/cm ³

2.2 Sample Preparation

Geopolymer material mixture is manufactured by trial and error which is expected to obtain the optimum compressive strength value of the geopolymer material. It is by regulating the solid and liquid materials. The geopolymerization process for soil stabilization was synthesized by the activation of fly ash and soil with alkaline solution at solid to liquid ratios of 1.5, 2.0, 2.5, and 3.0 and $Na_2SiO_3/NaOH$ solution of 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0. Then the mix design proportion of the entire manufacturing of geopolymer material is determined by the following ratios in Table 6.

Then geopolymer soil stabilization was produced by mixing the materials. First of all, sodium hydroxide must be dissolved early in distilled water based composition that has been planned for the concentration was kept constant at 6M. Then sodium silicate put into a sodium hydroxide solution which had been dissolved in distilled water and the solution is allowed to stand for 24 hours. After that, the solution is mixed with fly ash and soil and it has been stirred evenly so it gets homogeneous mixture and good workability.

2.3 Moulding, Curing and Unconfined Compressive Strength (UCS) Testing

Material that has been cast into a cylindrical mould in three layers was left to stand for 24 hours before being extruded from the mould. After extruded from the mould, the samples are wrapped and left for curing at room temperature in 7 days before the compressive strength test needs to be run. A low testing speed (0.25mm/min) was used to mitigate any influence of this parameter on the test result.

Table 6. Mix design details.

Solid/Liquid	Na ₂ SiO ₃ /NaOH	Solid		Liquid	
		Fly Ash (g)	Soil (g)	NaOH + H ₂ O (g)	Na ₂ SiO ₃ (g)
1.5	0.5	157.5	892.5	466.67	233.33
1.5	1.0	157.5	892.5	350.00	350.00
1.5	1.5	157.5	892.5	280.00	420.00
1.5	2.0	157.5	892.5	233.33	466.67
1.5	2.5	157.5	892.5	200.00	500.00
1.5	3.0	157.5	892.5	175.00	525.00
2.0	0.5	157.5	892.5	350.00	175.00
2.0	1.0	157.5	892.5	262.50	262.50
2.0	1.5	157.5	892.5	210.00	315.00
2.0	2.0	157.5	892.5	175.00	350.00
2.0	2.5	157.5	892.5	150.00	375.00
2.0	3.0	157.5	892.5	131.25	393.75
2.5	0.5	157.5	892.5	280.00	140.0
2.5	1.0	157.5	892.5	210.00	210.00
2.5	1.5	157.5	892.5	168.00	252.00
2.5	2.0	157.5	892.5	140.00	280.00
2.5	2.5	157.5	892.5	120.00	300.00
2.5	3.0	157.5	892.5	105.00	315.00
3.0	0.5	157.5	892.5	233.33	116.67
3.0	1.0	157.5	892.5	175.00	175.00
3.0	1.5	157.5	892.5	140.00	210.00
3.0	2.0	157.5	892.5	116.67	233.33
3.0	2.5	157.5	892.5	100.00	250.00
3.0	3.0	157.5	892.5	87.50	262.50

3 Results and Discussion

The compressive strength for geopolymer soil stabilization at different ratios of solid to liquid and Na₂SiO₃ to NaOH is shown as Figure 1. The optimum ratio of Na₂SiO₃ to NaOH (2.5) contributed to a maximum compressive strength for all ratio of solid to liquid which 1.5, 2.0, 2.5 and 3.0 are obtained 0.34 MPa, 1.23 MPa, 2.83 MPa, and 5.12 MPa, respectively. Based on the figure below, the pattern of the graphs was steep rise for each group of bar graph. The value of compressive strength tended to decrease after ratio of Na₂SiO₃ to NaOH of 2.5 for all ratios of solid to liquid.

Among the ratios of solid to liquid, the maximum compressive strength (5.12MPa) was obtained by the ratio of solid to liquid at 3.0. This shows that the increasing the ratio of solid to liquid resulted in an increase the compressive strength of geopolymer soil stabilization. Geopolymer gels increase could influence the increasing of compressive strength with the curing age and fill the pores in geopolymer samples, thus leading to the formation of a denser structure. The solid to liquid ratios, by mass should be approximately 3 to produce fly ash-based geopolymers to allow for geopolymerization process and alkaline activator solution formed a thick gel instantaneously upon mixing with source material [19]. In this case the activator solution is also very influential in the polymerization process and it's also one of the factors that determine the compressive strength. However,

when the ratio was increased to 3.5, the compressive strength of soil stabilization cannot be done due to low workability and non-homogeneous geopolymer mixture.

The optimum compressive strength was obtained at ratio of Na_2SiO_3 to NaOH at 2.5 for every solid to liquid ratios as shown in result. As a reason, the compressive strength of geopolymer soil stabilization seems more affected on Na_2SiO_3 to NaOH ratio compared to solid to liquid ratio. This study showed that the ratio of solid to liquid and the ratio of Na_2SiO_3 to NaOH were influenced the compressive strength of geopolymer soil stabilization.

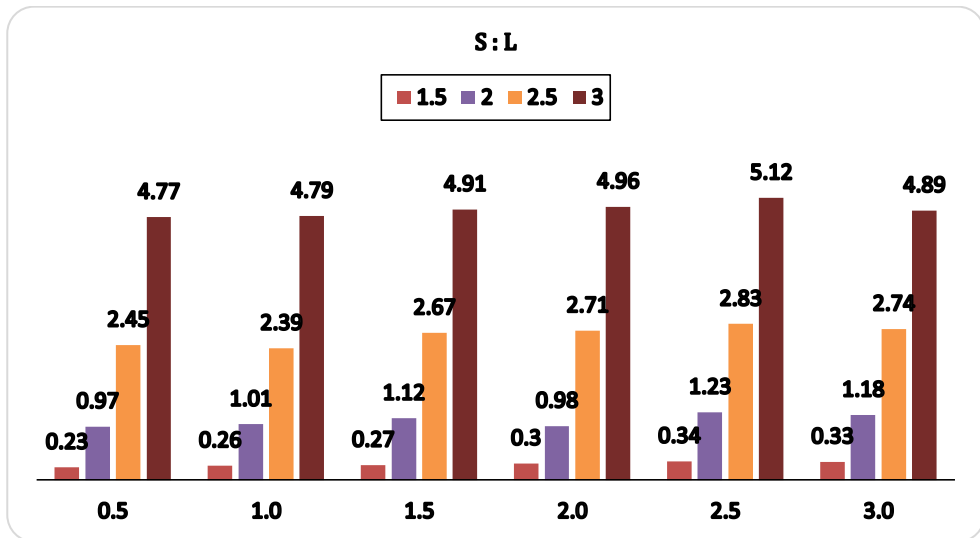


Fig. 1. The compressive strength for geopolymer soil stabilization at a different ratios of solid to liquid and Na_2SiO_3 to NaOH.

4. Conclusion

From the analysis of compressive strength results of fly ash based geopolymer soil stabilizer, the compressive strength was optimized at 2.5 of Na_2SiO_3 to NaOH ratio and 3.0 of solid to liquid ratio with 5.12 MPa. The compressive strength of Kedah's soil was increased as the increases of solid to liquid ratios. This might due to the fine size of fly ash particle which it can play a role like an OPC and the dominant of SiO_2 and Al_2O_3 in terms of chemical composition. So that the fly ash is suitable for use as a raw material to produce geopolymer material and feasible to be applied as a stabilizer in the soil. The amount of waste can be reduced and resulting in green and environmentally friendly when using fly ash in the production of soil stabilizer.

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