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Influencing of Clay and Binder Content on Compression Strength of Soft Soil Stabilized by Geopolymer Based Fly Ash

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Abstract

Soil stabilization with binder now is a common method for treating weak soil. In this study, soft soil was mixed with geopolymer based fly ash binder to improve strength and to be environmentally friendly. Clay soil was mixed with sand to change the clay content by 24.8%, 20.4%, 14.3%, 10.2%, 6.1% and combined with fly ash geopolymer binders at the rates of 5%, 10%, 15%, 20%. Geopolymer based fly ash binder include activated alkaline solution (AAS) Na_2SiO_3/NaOH = 2, AAS/fly ash = 0.5. Compressive strength of soil specimens stabilized by geopolymer depends on several factors such as clay content, and geopolymer binders. The results show that clay and geopolymer binder content play an important role in the development and formation of strength of geopolymer-soil.

Keywords: soil stabilization, geopolymer, compressive strength, clay.

INTRODUCTION

Soil stabilization is a change of one or more properties of the soil to ensure stability during the construction works and service life. There are two basic methods for soil stabilization: mechanical and chemical methods. The mechanical method based on reducing the porosity, increasing the particle size in the soil. Also, chemical methods based on chemical reactions between soil and binders [2], [3]. Many countries around the world have used chemical methods to improve the soil with organic and inorganic binders in the construction of roads, airports, dams...with significant economic - technical efficiency. The main purpose of soil stabilization by binder is to improve adhesion of soil particles prior to change effects of clay on soil properties such as improving permeability, compressive strength and reduce erosion [4]. Certainly, in the soil, clay particles play a very important role in the formation of mechanical properties, specially permeability and compressibility. They bond coarse particles in the soil together. On the other hand, clay is a component that often changes its properties by moisture. Thereby it has a great effect on the strength and durability of soil. The additives or chemical binder to mechanical properties of soil is to fundamentally change water stability of clay [5].

The term "geopolymer" (geopolymer binder) was first introduced to the world in 1978 by French researcher, Joseph Davidovits. Geopolymer is a type of binder obtained by combining inorganic materials rich of alumosilica (Si-Al) such as metakaoline, fly ash, husk ash, blast furnace slag with chemical compounds called “activated alkaline solution” such as NaOH (or KOH) and Na_2SiO_3 (or K_2SiO_3) [6], [7]. The reaction is inorganic polymerization process (also called mineral polymerization). The structure of this geopolymer is "poly-sialate" Si-Al-O. Polysialate chain and ring structure consist of three-dimensional tetrahedrons structures of $(SiO_4)^{4-}$ and $(AlO_4)^{5-}$ by sharing oxygen atoms to replace aluminate (aluminum oxide) with difference degree in all directions. Cations may be any alkaline to neutralize the negative ion of $(AlO_4)^{5-}$ to form monomers in the polysialate network [1]:

$$M_n\{-(SiO_2)_z\text{-}AlO_2\}n.wH_2O$$

Where:

"M" is a cation or alkaline element (positive ion);

"n" is the degree of polymerization;

"-" indicates the presence of a bond;

"z" is the replacement degree for aluminate (1,2,3 or higher, up to 32).

Different dgree of aluminate replacement will produce different geopolymer molecular structures. The Si: Al ratio in the polysialate structure determines the properties of the geopolymer binder. The chemical reaction that forms the geopolymer can be summarize the following steps [1], [7]:

Dissolve the Si and Al molecules in the alumosilica material by the hydroxide ions in the activated alkaline solution;

Repositioning ions in solution to form monomers; Combining the monomers through the polymerization reaction to form the geopolymer structure.

Geopolymers can expose good mechanical properties such as low permeability, high compressive strength, high durability can be achieved if combined at certain conditions [7].

EXPERIMENTAL STUDY

Sample preparation material

- **Soil**

Soil has unconfined compressive strength of 0.04MPa, unit weight 16.68kg/m^3, moisture 55.2%. The soil was milled before conduct study. The percent finer and chemical composition are presented in Table 1 and Table 2, respectively.

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Table 1. Sieve analysis of soil

Sieve analysis (%)										
Gravel			Sand					Silt		Clay
20.0-10.0	10.0-5.0	5.0-2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05-0.01	0.01-0.005	<0.005
		0.2	0.6	0.6	2.4	8.9	17.5	17.4	28.9	24.8

Table 2. Chemical composition of soil

SiO_2	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	SO_4^{2-}-	Cl^-	TiO_2	MnO	Nd_2O_5	*LOI
59.9	16.47	0.91	12.87	5.06	1.51	0.25	0.2	1.34	0.16	0.98	0.35

**LOI: Loss on ignition*

- **Sand**

Sand is mixed with soil to reduce proportion of clay in the soil. The sand has been cleaned and dried prior to use with size particle distribution showed in Fig 1.

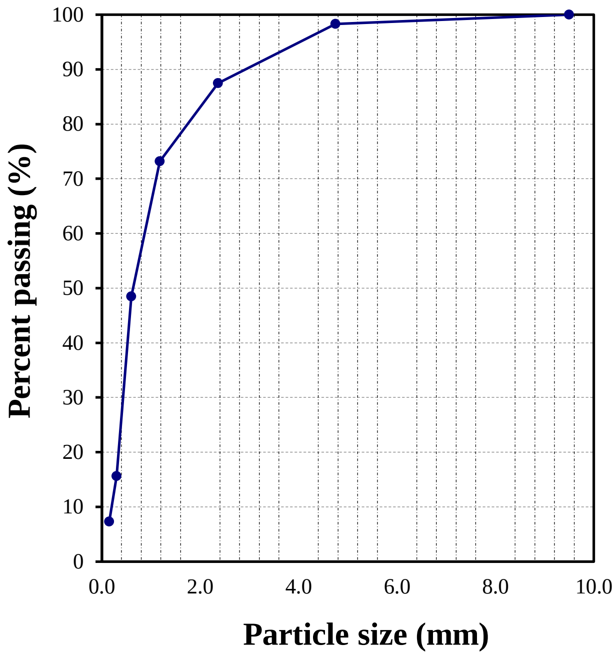

Figure 1. Size particle distribution of sand

- **Fly ash**

Fly ash in the study is product of a thermoelectric plant treated by wind-blown process. It has an 8.98% loss on ignition, less than 10% CaO content classified F according to ASTM C618-03. The chemical composition and size particle are presented in Table 3 and Table 4, respectively.

Table 3. Chemical composition of fly ash used in the study (% by volume)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	SO_3
51.74	24.53	5.59	0.81	1.95	4.42	0.11	0.76	0.31

Table 4. Size particle distribution of fly ash

Particle size (μm)	0.15	0.075	45	20	101	5
Passing (%)	98.1	81.8	68.6	51.67	33.06	16.77

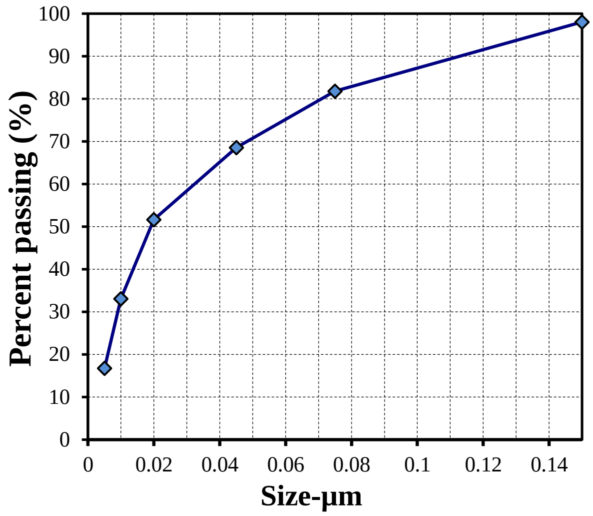

Figure 2. Size particle distribution of fly ash

- **Activated alkaline solution**

The alkaline solution was a mixture of NaOH solution with Na_2SiO_3 solution. NaOH solution 12 M was prepared from white crystalline NaOH, purity 98.5%. The chemical properties of NaOH and Na_2SiO_3 are shown in Table 5

Table 5. Chemical composition of NaOH and Na_2SiO_3

Solid NaOH	%NaOH	%NaCl	$\%Na_2CO_3$	Solution Na_2SiO_3	$\%Na_2O$	$\%SiO_2$	$\%H_2O$
	98.7	0.03	0.5		11.5÷12.2	27.5÷29.5	58.3÷61

RESEARCH RESULTS

The specimens having 40 mm diameter and 80 mm height, statically compacted at 1 mm/min velocity. They were cured at 60ºC through 24h. The unconfined compressive strength (UCS) test of stabilized soil specimens was conducted at the age of 28 days. All of geopolymer-soil mixture were tested at 0.5 mm/min velocity until failure.

Effect of geopolymer binders on sample strength

To investigate and evaluate the effect of geopolymer based fly ash binder on compressive strength of stabilized soil, variable geopolymer percentages of 5%, 10%, 15% and 20%, against every fixed clay content. Fig 2, Fig 3, Fig 4, Fig 5, Fig 6 show influencing of geopolymer content on compressive strength with different clay content of 24.8%, 20.4%, 14.3%, 10.2%, and 6.1%, respectively. As can be seen from the figures, the treated soil achieved a significant additional strength gain with the increase in geopolymer binder percentage with all clay content. For example, at clay content of 14.3%, the strength increase about 0.46, 0.65, 0.95, 1.01 MPa by replacing 20% geopolymer binder respectively. The percentage of geopolymer binders of 20 %, the stabilized soil specimens attain the highest compressive strength whereas the lowest strength get at binder of 5%. Geopolymer binder may be bonds particle soil like other aggregate to form strength. It may explained why increasing binder makes strength improving.

Effect of clay content on the strength of the sample

Fig 6 shows influencing of clay content on compressive strength. With all amount of geopolymer content, the compressive strength decreases as the clay content increases. When the clay content dropped at 6.1%, the sample compressive strength reached the highest value. On the contrary, as the clay content reached 24.8%, the sample compressive strength obtained the lowest value. It can be seen that at 6.1% clay content, the difference of compressive strength with each of geopolymer perentage is very significant, nearly 1 MPa comparing result of 5% with 20% geopolymer. Meanwhile, at 24.8%, it slightly change, about 0.31 MPa as comparing that. It is notice that clay content is important factor to effect on compressive strength. Soil has high proportion of clay which certainly decrease coarse particle component so that the strength reduce. Another reason may be from the thin clay film covering sand or coarse particle to decrease bonding between geopolymer binder and particle soil.

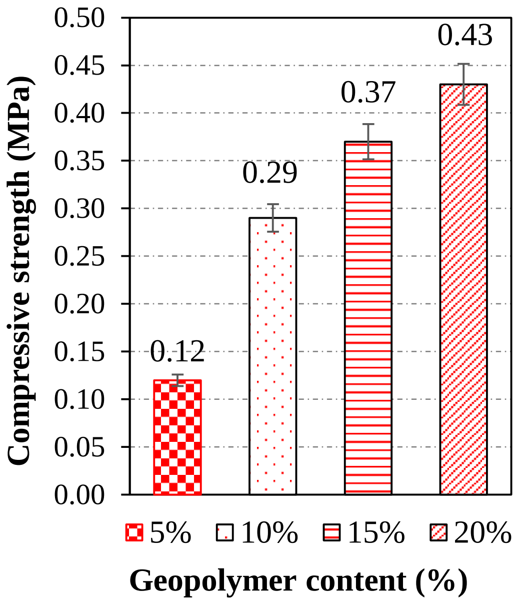

Figure 2. Effect of geopolymer content on compressive strength of specimens with 24.8% clay

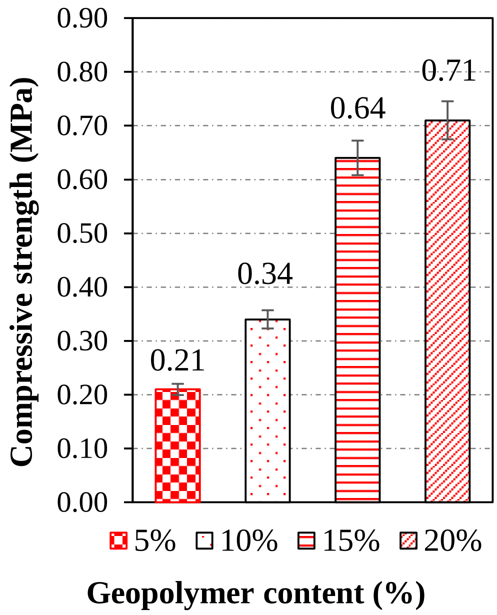

Figure 3. Effect of geopolymer content on compressive strength of specimens with 20.4% clay

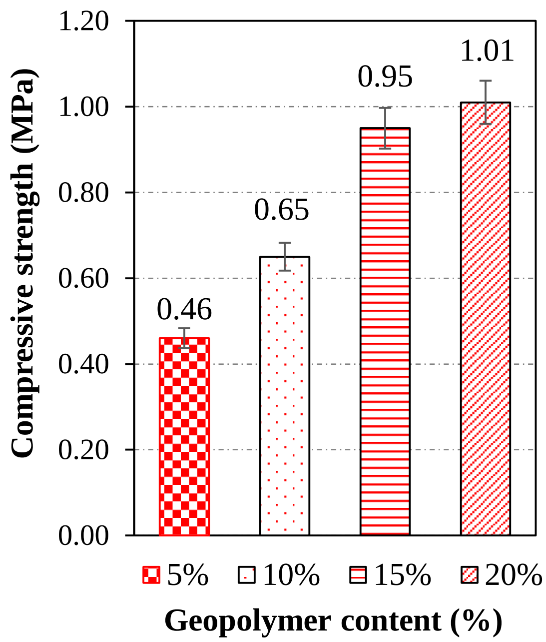

Figure 4. Effect of geopolymer content on compressive strength of specimens with 14.3% clay

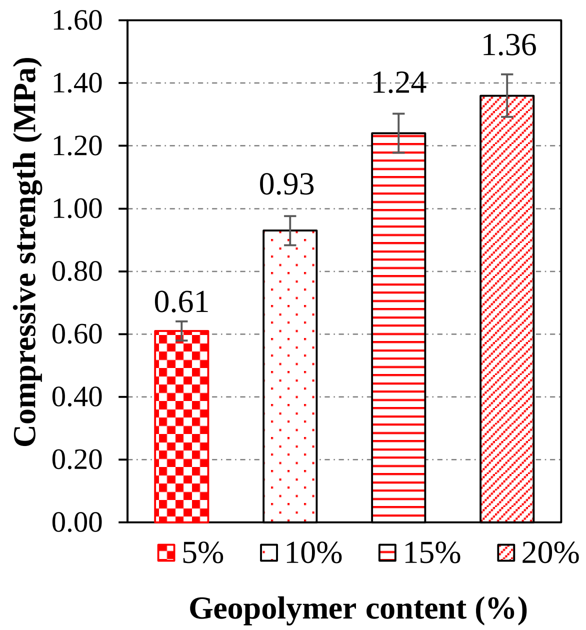

Figure 5. Effect of geopolymer content on compressive strength of specimens with 10.2% clay.

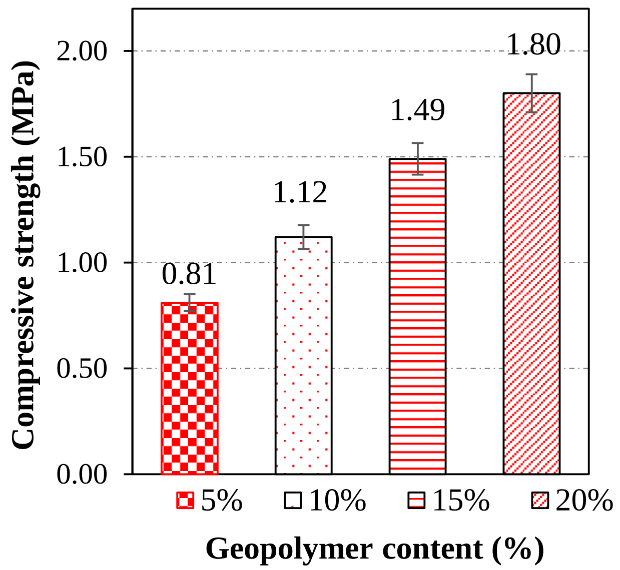

Figure 6. Effect of geopolymer content on compressive strength of specimens with 6.1 % clay

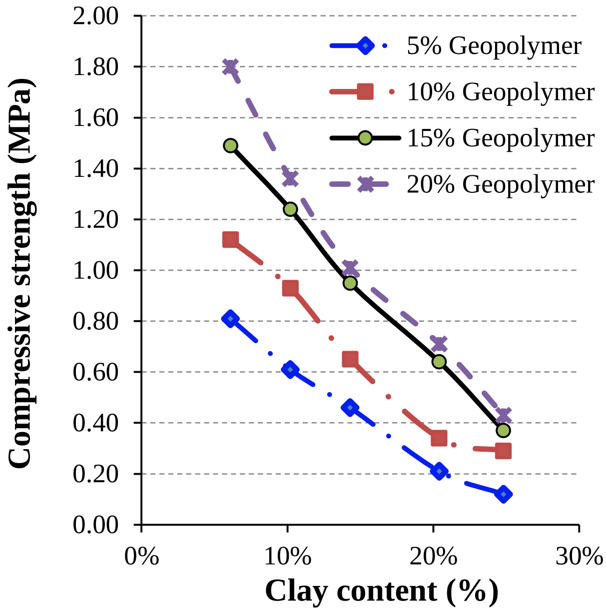

Figure 7. Effect of clay content on compressive strength of specimens

CONCLUSIONS AND RECOMMENDATIONS

- Clay and geopilymer content plays an important role in forming the strength of geopolymer-soil. The compressive strength of geopolymer-soil is proportional to the geopolymer content but inversely proportional to the clay content.
- The compressive strength is highest with clay content of 6.1% and the geopolymer of 20%, and the lowest with 24.8% clay and 5% geopolymer.
- As using geopolymer based fly ash to stabilize soft soil should pay attention to the natural clay content in the soil to select geopolymer binder so that the soil reaches the highest compressive strength.

- Further researches are necessary to understand the reaction and formation of geopolymer-soil strength.

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