Solidification of Sand for Strength Improvement

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ABSTRACT

Several investigations have used geopolymer to increase the strength of soft clay. This research has used the Electric Arc Furnace (EAF) slag, a byproduct from the process of producing steel, as the prime material of geopolymer and activator to make the geopolymer paste to solidified the sand. Two types of treatment were used which were distinguished by the type activator. Its objective is to study the effect of EAF slag-based geopolymer of solidified sand through the relationship between the strength (q_u) and both the curing period (t) and the mixture ratio (δ). The results of the research give conclusions that the mixture ratio provides a significant effect to the strength of improvement solidified sand ($p<0,01$ and $p<0,05$) than the curing period($p>0,05$). The highest strength is obtained at the ratio of 50 % among designated mixture ratio, which also delivers the strength of hard soil (over 400 kPa).

Keywords : solidification, sand, geopolymer, EAF slag

Introduction

The solidification method by geopolymer to improve the strength of soft soil had been investigated previously by Nishida *et al* (2008), Sinolungan *et* al (2008) and Zhao *et* al (2010) using fly ash as the prime material. However there are several materials that consumable as prime material, such as coal ash, slag and rice hush ask. Other previous investigations by the author have used the Pressurized Fluidized Bed Combustor (PFBC) coal ash and the Electric Arc Furnace (EAF) slag as the prime materials of the geopolymer in the process of solidication of soft clay to improve its strength. This research has the same purpose which is to study the effect of the EAF slag-based geopolymer for the strength improvement of solidified sand through the relationship between the strength (q_u) and both the curing period (t) and the mixture ratio (δ).

Materials and Method

The materials used in the research consist of soil, prime material of geopolymer and alkaline activator. The soil is the commercial decomposed granite soil, called the commercial Masado soil. It is the type of non-plastic soil. The physical and chemical properties of the soil is read more in the Table 1. The EAF slag, the solid waste generated during the metallurgical process of extraction and refined, is obtained from a local stainless company. It is the EAF type F slag. The chemical composition of EAF Slag is read more in the Table 2. The research involved experimental works in the laboratory. For the soil properties experiment, it referred to the Japanese Industrial Standard (JIS) and the Japanese Geotechnical Society (JGS) standard procedures. The geopolymer was introduced as the mixture component to the soil according to the proportion : i) 25 % of geopolymer – 75 % of soil (δ = 25 %); ii) 50 % of geopolymer – 50 % of soil (δ = 50 %); iii) 75 % of geopolymer – 25 % of soil (δ = 75 %). As for the alkaline activator, two types of treatment were prepared. The first treatment has used the mixture of commercial sodium silicate no. 3 (Na_2SiO_3) and tap water. The second treatment has used the mixture of commercial sodium silicate no. 3 and 18 M of sodium hydroxide (NaOH). To determine the composition of each component to make the geopolymer paste, the formula below is used :

$$W_{gp} = x + y + 0.2y \quad (1)$$

x is defined as slag. y + 0.2y are defined as the activator, consists of sodium silicate no. 3 and tap water / sodium hydroxide, where y = sodium silicate no. 3 and 0.2y = tap water / sodium hydroxide. The ratio of activator to slag was designated to be equal 0.7. Thus :

$$\frac{y+0.2y}{x} = 0.7 \quad (2)$$

From (2), x is obtained :

$$x = 1.7143y \quad (3)$$

Substitute x in (1), y is obtained :

$$y = \frac{W_{gp}}{2.9143} \quad (4)$$

where W_{gp} is the weight of the geopolymer paste to be prepared according to the proportion. The mixed of soil-geopolymer was compacted in a cylindrical PVC mold (4 mm x 10 mm), and was kept in humid conditions for 7 days, 14 days, and 28 days prior to testing to observe the development of strength. The unconfined compression test device was functioned to determine the unconfined compressive strength of the specimens. In the analysis of the result, statistical analysis is used to assist in drawing a conclusion according to the objective of the research.

Table 1. Physical and Chemical Properties of Soil

Properties	Value
Natural Water Content, w (%)	19
Density of Soil Particles, ρ_s (g/cm^3)	2,61
Particle Size Distribution (%) :	
coarse sand (0.85 mm - 2 mm)	32,4
medium sand (0.25 mm - 0.85 mm)	50,0
fine sand (0.075 mm - 0.25 mm)	17,5
silt (5 μm - 0.075 mm)	0,1
clay (2 μm - 5 μm)	-
colloid (< 2 μm)	-
Atterberg Limits :	
liquid limit, w_L (%)	-
plastic limit, w_P (%)	-
plasticity index, I_P	NP
Ignition Loss, L_i (%)	2,1
pH	7,4
Electric Conductivity, χ (mS/cm)	0,018
Cation Exchange Capacity, CEC (cmol/kg)	10,9

Table 2. Chemical Composition of EAF slag

Component	Composition
Cu	< 0.01 %
Zn	< 0.01 %
Pb	2 mg/kg
Hg	< 1 mg/kg
CaO	48.16 %
SiO_2	26.73 %
Al_2O_3	5.32 %
MgO	5.47 %
Na_2O	0.02 %
K_2O	0.02 %
Fe_2O_3	1.01 %
P_2O_5	0.01 %
TiO_2	1.54 %
SO_3	0.43 %
Cd	< 1 mg/kg
Cr_2O_3	2 %
Cl	< 0.01 %
CN	< 1 mg/kg
Water Content	20.2 %
Ignition Loss	5.0 %

Table 3. Chemical Composition of Sodium Silicate (JIS K 1408-1966)

Classification / Item	Sodium Silicate No. 1	Sodium Silicate No. 3
Appearance	Colorless or light color liquid like starch syrup	
SiO_2 (%)	35 – 38	28 – 30
Na_2O (%)	17 – 19	9 – 10
Fe (%)	0.03 max	0.02 max
Water-insoluble matter (%)	0.2 max	0.2 max

Table 4. Condition of Experiment

Mixture Proportion		Weight (g)				
Soil	Geopolymer	Soil	Geopolymer			
(%)	(%)		Slag	Sodium Silicate No. 3	Tap Water	Sodium Hydroxide 18 M
1st Treatment						
75	25	1125	220.60	128.68	25.74	-
50	50	750	441.18	257.35	51.47	-
25	75	375	661.76	386.03	77.21	-
0	100	-	882.35	514.71	102.94	-
2nd Treatment						
75	25	1125	220.60	128.68	-	25.74
50	50	750	441.18	257.35	-	51.47
25	75	375	661.76	386.03	-	77.21
0	100	-	882.35	514.71	-	102.94

Result and Discussion

The soil properties experiments give result that the commercial Masado soil consists of medium sand fraction (50 %), coarse sand fraction (32,4 %), fine sand fraction (17,5 %) and silt (0,1 %), and categorized as non-plastic (NP) soil. It has 19 % of natural water content. The result of the unconfined compressive strength of mixed soil-geopolymer is read more in the Table 5. When geopolymer was mixed with the soil by either first treatment or second treatment, it solidified the soil and changed its consistency from non-plastic to hard. Although the highest strength is given by ratio of 50 %, other designated ratios has given the strength of hard soil (over 400 kPa) as well. From the statistical analysis, the mixture ratio gives a significant effect to the unconfined compressive strength at ratio of 50 %. It means this ratio yields to the highest compressive strength of commercial Masado soil mixing with EAF slag-based geopolymer. The curing period gives a non-significant effect to the unconfined compressive strength, which means at any curing period the strength develops insignificantly. Upon all designated mixture ratios, the strength of specimens increased gradually until the peak was reached at a very small strain, followed by gradually decreasing of strength over small strain increments. Although the peak strength of each ratio is significantly different, but the strain of those is considered same which is very small strain. It implies a typical behavior of dense specimen, where the existence of geopolymer has increased stiffness, peak strength and brittleness. Furthermore, during curing period the unconfined compressive strength increases with no significant difference. However, irrespective to the mixture ratio, all treated specimens gained their strength within seven days of curing and increased insignificantly in the next days of curing. This indicates that the effect of EAF slag-based geopolymer to commercial Masado soil took place within seven days of curing, and is considered stable when increasing the curing period.

Table 5a. Result of The Experiments
1st Treatment

Mixture Ratio (%)	q_u (kPa) at curing period (days)		
	7	14	28
25	525	869	810
50	3907	6716	5026
75	1288	1972	1686
100	5403	6845	8426

Table 5b. Result of The Experiments
2nd Treatment

Mixture Ratio (%)	q_u (kPa) at curing period (days)		
	7	14	28
25	922	959	826
50	1634	2410	3479
75	815	1342	2293
100	592	719	1224

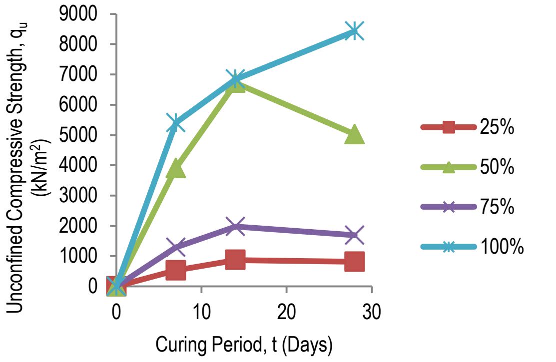

Fig. 1a. Relationship between q_u and t (1st treatment)

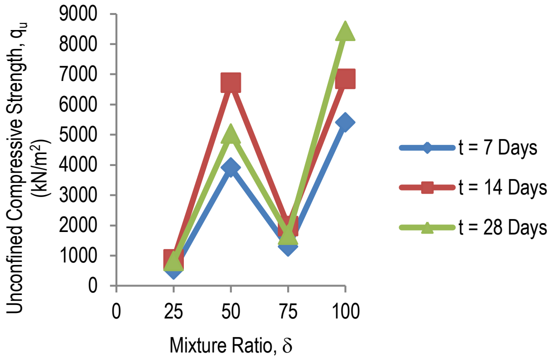

Fig. 1b. Relationship between q_u and δ (1st treatment)

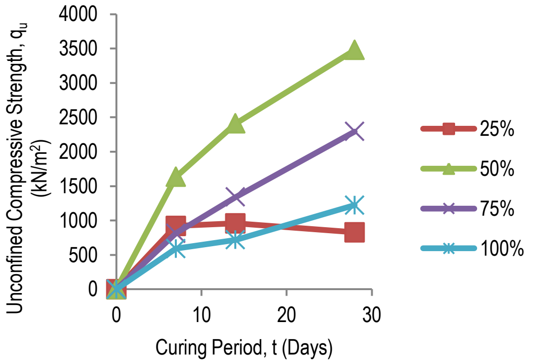

Fig. 2a. Relationship between q_u and t (2nd treatment)

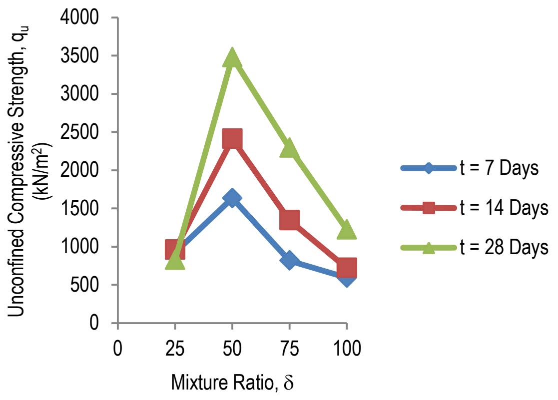

Fig. 2b. Relationship between q_u and δ (2nd treatment)

The *F*-test of both treatment give result that the mixture ratio provides a significant effect (*p<0.01 and p<0,05*) to the unconfined compressive strength of the treated commercial Masado soil by EAF slag-based geopolymer, whereas the curing period provides a non-significant effect (*p>0.05*) to the unconfined compressive strength of the treated commercial Masado soil by EAF slag-based geopolymer. Moreover, with the statistical analysis, the equations to determine the unconfined compressive strength of the treated commercial Masado soil by EAF slag-based geopolymer along with their correlation coefficient to describe their relationship based on the results of experiments were established as well.

Table 6a. *F*-test values for mixture ratio and curing period (1st treatment)

Subject	Source of variation	*F* test value	*p*	Remarks
Unconfined Compressive Strength (q_u)	Mixture ratio (δ)	36,42	<0.01	**
	Curing period (t)	2,66	>0.05	ns

Table 6b. *F*-test values for mixture ratio and curing period (2nd treatment)

Subject	Source of variation	*F* test value	*p*	Remarks
Unconfined Compressive Strength (q_u)	Mixture ratio (δ)	7,24	<0.05	*
	Curing period (t)	3,20	>0.05	ns

Table 5a. Linear equations among mixture ratio, curing period and unconfined compressive strength, and their correlation coefficient (*r*) (1st treatment)

Subject	Equation	r
Unconfined Compressive Strength (q_u) and mixture ratio (δ)	$q_u = -3.2196\delta^2+7.75\delta-4631.2$	1,000
Unconfined Compressive Strength (q_u) and curing period (t)		
at δ = 25 %	$q_u = 554.58 + 11.04t$	0.642
at δ = 50 %	$q_u = 4751.84 + 28.43$	0.215
at δ = 75 %	$q_u = 1430.80 + 13.34t$	0.415

Table 5b. Linear equations among mixture ratio, curing period and unconfined compressive strength, and their correlation coefficient (*r*) (2nd treatment)

Subject	Equation	r
Unconfined Compressive Strength (q_u) and mixture ratio (δ)	$q_u = -0.7012\delta^2+73.994\delta-23.113$	1,000
Unconfined Compressive Strength (q_u) and curing period (t)		
at δ = 25 %	$q_u = 988.08 – 5,23t$	-0,820
at δ = 50 %	$q_u = 1099,20 + 86,25t$	0.995
at δ = 75 %	$q_u = 339,64 + 70,03t$	1,000

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