Strength Improvement of Soft Ariake Creek Clay Through Solidification by PFBC Coal Ash-based Geopolymer

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ABSTRACT

This research has used the Pressurized Fluidized Bed Combustor (PFBC) coal ash as the prime material of geopolymer to solidify the soft Ariake creek clay. The objective of the research is to study the effect PFBC coal ash-based geopolymer for strength improvement of soft Ariake creek clay through the relationship between the unconfined compressive strength (q_u) and both the curing period (t) and the mixture ratio (δ). The results of the research give conclusions that mixture ratio provides a significant effect to the strength improvement of treated soil ($p<0.01$) compared to curing period ($p>0.05$), where the highest strength is achieved at ratio of 40 % among designated mixture ratio as the typical strength of very stiff soil (200-400 kPa).

Keywords : PFBC, geopolymer, Ariake creek clay

Introduction

As known, soft soil is classified as a problematic soil due to its low shear strength and excessive settlement. The un-drained shear strength of soft soil results in a low and short term-bearing capacity.To improve the strength of soft soil, many techniques are available including solidification by geopolymer. The solidification method by geopolymer to improve the strength of soft soil had been investigated previously by Sinolungan*et al* (2008) and Nishida *et al* (2008) by using fly ash as the prime material of geopolymer. However there are several materials available that usable as prime material such as coal ash, slag and rice husk ash. This research has used the Pressurized Fluidized Bed Combustor (PFBC) coal ash as the prime material of geopolymer to solidify the soft Ariake creek clay. The objective of the research is to study the effect PFBC coal ash-based geopolymer for strength improvement of soft Ariake creek clay through the relationship between the unconfined compressive 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 and alkaline activator. Ariake creek clay, excavated from a deteriorated creek in Higashiyoka in Saga prefecture, was used as the soil sample. Coal ash,a byproduct from the process of burning solid fuels by pressurized fluidized bed combustor and supplied from Kanda power station in Fukuoka prefecture, was used as the prime material. Sodium metasilicate in powder was used as alkaline activator. 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. Geopolymer was introduced as additional material to the soil according to the following: (i) addition of 10 % of geopolymer (δ = 10 %); (ii) addition of 20 % of geopolymer (δ = 20 %); (iii) addition of 40 % of geopolymer (δ = 40 %). The amount alkaline activator was 1/15 of the amount of coal ash by weight. The geopolymer was prepared by mixing the prime material and the activator. The water content of Ariake creek clay was adjusted to its obtained liquid limit prior to addition of geopolymer. Themixed ofsoil-geopolymer was compacted in a cylindrical PVC mold (4 mm x 10 mm), and was kept in humid conditions for 3 days, 7 days, 14 days, 28 days and 56 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.

Result and Discussion

The soil properties experiments give result that the Ariake creek clay has a high natural water content which is 96.5 % and a high liquid limit which is 106.2 % as well. This soil is mostly being composed by silt. The result of the unconfined compressive strength of mixed soil-geopolymer is read more in the Table 3. When geopolymer was added to Ariake creek clay, it exhibits that the strength development varying due to the applied mixture ratio. At ratio of 10 %, the strength had developed insignificantly during curing time until it reached the highest strength at 56 days of curing period. At ratio of 20 %, the strength increased higher than those of 10 % but still it developed insignificantly during curing period. The strength achievement at mixture ratio of 10 % belongs to the typical strength of very soft soil (< 25 kPa), whereas for ratio of 20 % the strength belongs to the typical strength of medium soil (50-100 kPa). The highest strength is achieved at ratio of 40 % among the designated mixture ratio where the strength belongs to the typical strength of very stiff soil (200-400 kPa). Furthermore, during the curing period the unconfined compressive strength increased with no significant difference. However, regardless to the kind of mixture ratio, all treated specimens gained their strength within the first three days of curing and no significant increase in the next days of curing. This indicates that the effect of PFBC coal ash-based geopolymer to the soft Ariake creek clay took place within the three days of curing, and noticeably stable when increasing the curing period.

Table 1. Chemical composition of PFBC coal ash

Component	% by Weight	
	Kanda Power Sta. (PFBC Coal Ash)	Mutsuura (JIS Standard)
SiO_2	38.76	63.31
CaO	19.45	3.76
Al_2O_3	24.25	22.84
Fe_2O_3	1.62	3.67
SO_3	6.62	0.50
K_2O	0.05	1.00
MgO	0.54	0.79
TiO_2	0.74	0.76
MnO_2	0.03	0.12
V_2O_5	-	0.11
ZnO	0.29	0.30
Cl	0.13	0.03
Others	7.52	2.81

Table 2. Physical and chemical properties of Ariake creek clay

Properties	Value
Natural Water Content, w (%)	96,5
Density of Soil Particles, ρ_s (g/cm^3)	2,54
Particle Size Distribution (%) :	
coarse sand (0.85 mm - 2 mm)	-
medium sand (0.25 mm - 0.85 mm)	-
fine sand (0.075 mm - 0.25 mm)	2,9
silt (5 μm - 0.075 mm)	46,1
clay (2 μm - 5 μm)	14,5
colloid (< 2 μm)	36,5
Atterberg Limits :	
liquid limit, w_L (%)	106,2
plastic limit, w_P (%)	53,1
plasticity index, I_P	53,1
Ignition Loss, L_i (%)	11,7
pH	4,2
Electric Conductivity, χ (mS/cm)	1,6
Cation Exchange Capacity, CEC (cmol/kg)	33,6

Table 3. Result of experiment

Geopolymer (%)	w (%)	q_u (kPa) at curing period (days)				
		3	7	14	28	56
10	96	12	13	13	16	19
20	88	64	67	72	88	100
40	76	218	210	224	270	301

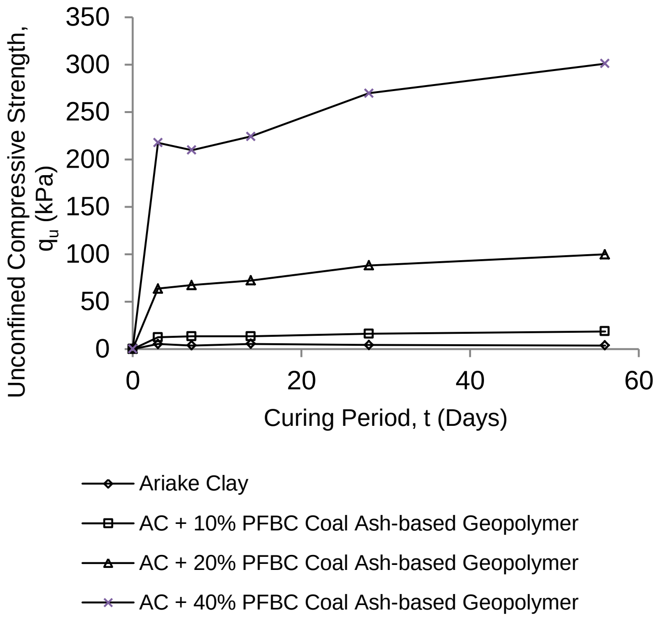

Fig. 1. Relationship between q_u and t

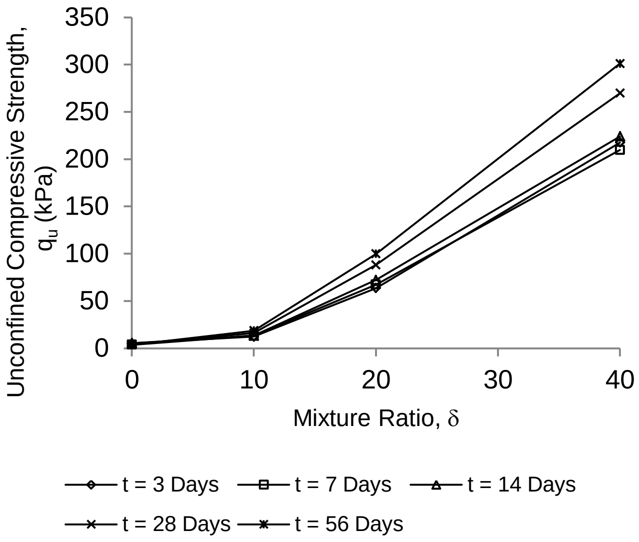

Fig. 2. Relationship between q_u and δ

The *F*-test gives result that the mixture ratio provides a significant effect ($p<0.01$) to the unconfined compressive strength of the treated soft Ariake creek clay by PFBC coal ash-based geopolymer, whereas the curing period provides a non-significant effect ($p>0.05$) to the unconfined compressive strength of the treated soft Ariake creek clay by PFBC coal ash-based geopolymer. Moreover, with the statistical analysis, the equations to determine the unconfined compressive strength of the treated soft Ariake creek clay by PFBC coal ash-based geopolymer along with their correlation coefficient to describe their relationship based on the results of experiments were established as well.

Table 4.*F*-test values for mixture ratio and curing period

Subject	Source of variation	*F* test value	*p*	Remarks
Unconfined Compressive Strength (q_u)	Mixture ratio (δ)	199.29	<0.01	**
	Curing period (t)	3.06	>0.05	ns

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

Subject	Equation	r
Unconfined Compressive Strength (q_u) and mixture ratio (δ)	$q_u = -68.40 + 7.75\delta$	0.998
Unconfined Compressive Strength (q_u) and curing period (t)		
at δ = 10 %	$q_u = 12.17 + 0.12t$	0.987
at δ = 20 %	$q_u = 63.21 + 0.70t$	0.978
at δ = 40 %	$q_u = 206.07 + 1.78t$	0.969

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